



HØGSKOLEN  
I STAVANGER

# Dimensioning of Product Support

Issues, Challenges, and Opportunities

Doctoral Thesis by

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Submitted in partial fulfillment of the  
requirements for the degree of  
DOKTOR INGENIØR  
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# Abstract

The research study examines issues related to dimensioning of product support strategies for advanced industrial products on the basis of a case study conducted in a manufacturing company that produces automated production line systems. The focus is mainly on investigating engineering factors/parameters that influence product support.

Product support can be defined as any form of assistance that companies offer their customers to gain maximum value from manufactured products. In general, it creates additional value/profit for the product owner as well as for the manufacturer. It can be broadly classified into two, namely, services to support product and services to support customers. Services to support the product are mainly dependent on the product's designed-in characteristics, operational environment, as well as on owner's operational, maintenance, and support strategies. Services to support the customer are influenced by customer characteristics related to operational and maintenance skills and capabilities. Dimensioning of product support is influenced by the product's designed-in characteristics – especially those characteristics related to RAMS (Reliability, Availability, Maintainability and Supportability).

Within the scope of the case study, various approaches and methods to integrate RAMS in combination with LCC (Life Cycle Costs) in design work processes to arrive at the most cost effective product support strategy for industrial systems and components is examined. Often a considerable amount of information and data about product failures/weaknesses and product RAMS characteristics is available in various databases. Unfortunately, these information sources/databases are not usually integrated with work processes in design, and thus these cannot be used for dimensioning of product support effectively. An approach for integrating RAMS information into design processes is suggested.

Furthermore, various aspects of product support strategies for functional products where the customer buys only the performance, not the physical product is studied and analyzed. In the conventional product scenario, the manufacturer benefits from

selling support services, whilst this profit generating process becomes a cost and liability in the functional product scenario. Based on this study it is concluded that the product support strategy for functional products will differ considerably compared to that for the conventional product.

Moreover, it is shown that the service delivery strategy of the manufacturer or service provider must be in line with the service reception strategy of users/customers. The study also provides a critical view on the role of the negotiation process in the development of cost effective and competitive service delivery strategies. In addition, there exists a need to involve personnel who are involved in the support services as well as in manufacturing, assembly, and quality assurance, etc. processes in the design process to arrive at the best strategy for product support.

The scope of the thesis is limited to studying the relationship between a manufacturer of advanced industrial products and customers using those products in production lines. Furthermore, this thesis is limited to investigating engineering aspects of support services. Implications of the research open up research areas related to product support strategies, functional products, as well as to development of methods for integrating RAMS information in design work processes.

**Keywords:** Product Support, Maintenance and Service, Functional Product, Support to Product, Support to Customer, Service Delivery Strategy, Service Reception Strategy, LCC, LCP, Work Processes in Design, RAMS, RAMS Information, Service Negotiation

# Preface and Acknowledgements

This thesis is submitted in partial fulfillment of the requirements for the degree of Doktor Ingeniør (Dr. Ing.) at the Stavanger University College, Norway. The research was carried out at the Stavanger University College, Stavanger, Norway, in the period from August 1999 to June 2003. The compulsory courses attended have been given at Stavanger University College. The work was funded by a grant from the City of Stavanger and Stavanger University College.

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# Some Definitions

*Availability:* The ability of an item to be in a state to perform a required function under given conditions at a given instant of time or a given time interval, assuming that the required external resources are provided. (This ability depends on the combined aspects of the reliability, the maintainability and the maintenance supportability. Required external resources, other than maintenance resources, do not affect the availability of an item.)

*Conventional Product:* A Conventional product can be defined as a product where the customer buys, operates, maintains, and disposes of product. The manufacturer designs, manufactures, and supports the product according to requirements and/or agreement.

*Functional Products:* Functional products can be defined as products where the customer buys the performance of the product, not the product. The customer needs to have a license for the technology. The product is owned by the manufacturer or third party supplier. The product owner is responsible for operation, maintenance, support and disposal of product at end of life. (In this thesis the term *functional product* is also referred to as *delivery of performance*. Furthermore, in this thesis only the scenario where the manufacturer delivers the performance to a industrial customer is considered.)

*Maintainability:* The ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources. (Maintainability is also used as a measure of maintainability performance.)

*Maintenance:* It is defined as a combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, as state in which it can perform the required function. Services like lubrication, cleaning, oil and filter change, and calibration, adjustments, etc. are included in the maintenance concept.

*Maintenance support:* Resources, services and management necessary to carry out maintenance. (Support may include, for example; personnel, test equipment, workrooms, spare parts, documentation.)

*Maintenance supportability:* The ability of a maintenance organization of having the right maintenance support at the necessary place to perform the required maintenance activity at a given instant of time or during a given time interval

*Product support:* Product support can be defined as any form of assistance that companies offer to customers to help them gain maximum value from the manufactured products. It is commonly referred to as after-sales service, customer support, technical support, or simply as service.

*Reliability:* The ability of an item to perform a required function under given conditions for a given time interval. (The term ‘reliability’ is also used as a measure of reliability performance and is often defined as a probability.)

*Service Concept:* Product support and service delivery strategy from the manufacturers and suppliers form the basis for the service concept of any product.

*Service Delivery Strategy (SDS):* A generic plan for achieving the service delivery goals. This defines what is to be achieved in terms of services, what is to be delivered, how to deliver them based on considerations of product characteristics, operating environment, operational requirements, customer characteristics and preferences, geographical location, etc. The plan should as well define how to measure the service delivery performance. The plan should have a general section for all customers and a specific section for customers with special needs.

*Service Reception Strategy (SRS):* A generic plan for achieving the service reception goals. The SRS is developed by customers/ service receiver and defines how to receive the services provided by service supplier so as to maximize the value added. The plan should as well define how to measure the service reception performance. The plan should have a general section for all suppliers and a specific section for products with special needs.

*Services to Support the Customers:* Services to support the customers can be defined as services intended to support the client’s actions in relation to the product. They include services such as advanced training, performance analysis, operations and maintenance strategy development, etc. This kind of service is governed by customer’s and manufacturer’s knowledge, expertise, as well as their wants, needs, and preferences.

*Services to Support the Products:* Services to support the products can be defined as services needed to ensure a product's functional performance. These services are governed by the product's functional weaknesses. It includes support services such as maintenance, repairs, spare parts, expert advice, diagnostics, etc.



# Part I



# 1 Introduction and Background

During the last few decades, the industrial markets have become bigger and more global leading to increased international trade and competition. One of the results is that the industry faces shorter time between product inception and delivery, causing increased demands on production plant availability and performance. Moreover, as more products performing the same function are available, customers demand more value for reduced prices. As a result, many industries increase their focus on core activities and on reducing costs. To compete, the performance of production processes need to be streamlined with respect to output quality, uptime, efficiency, as well as cost effectiveness.

As technological innovations have been introduced in existing as well as in new products, they have become increasingly advanced and complex. Even though the quality and reliability of many product components and sub-systems have improved and become less prone to failure, the increased complexity has resulted in increased demands with respect to skills and capabilities of operations and maintenance personnel. Additionally, an advanced product/system may be composed of various combinations of mechanical, electrical, electronics, and maybe hydraulic or pneumatic parts and sub systems. Such products/systems are often monitored and controlled by advanced sensors and software as well. This can result in more complicated and time-consuming failure diagnosis, as well as investigation of possible causes for reduced performance. Modularization technology therefore is often used to reduce downtime and production losses.

In the earliest life cycle stages, support may be needed to assist customers to define and clarify product specifications since many customers require customized products. In the exploitation phase, support is needed to operate the product correctly and within design constraint, as well as for diagnostics and prognostics. Support may also be needed to optimize operational, maintenance, as well as support strategies. In the end-of-life phase, support may be needed to recycle or dispose, to remove or replace, to reengineer or sell, etc.

The above trends create a motivation for forcing manufacturers of advanced products to integrate RAMS in the design processes deliver products with recommended preventive maintenance and support strategies. This means that

manufacturers of industrial equipment need to make design processes more effective and efficient with respect to both productivity and cost.

However, the outlined development above also creates new opportunities for manufacturers as well. As products become more advanced and complex, many manufacturers find themselves supplying more services related to product exploitation, maintenance, modifications, upgrade, and so on. For many manufacturers the support services provide a source of long-term revenue. Furthermore, the services are important to achieve customer satisfaction, loyalty, and customer retention (see also Grönroos, 2000).

Product support can be defined as any form of assistance that companies offer customers to gain maximum value from the product. Therefore, product support is closely related to maintenance and operations, as well as customer's logistical inventory system. Product support creates additional values for customers and manufacturers/service providers alike.

Furthermore, production line process owners are adopting outsourcing as a business approach to focus on core activities. As a result, a new trend is emerging where 'total functions' are outsourced. After all, the customer is interested in benefits the industrial product provides, improved functional performance, and ability to generate profit compared to function alternatives available in the market. By outsourcing the total function to the manufacturer, the responsibility for function operations, maintenance performance, as well as support, falls on the manufacturer. Choosing the manufacturer as a partner based on 'function performance' is advantageous given that the manufacturer should know how to utilize, operate, maintain, etc., the product optimally since they design and make it. Additionally, the manufacturer could use knowledge and experience gained in the exploitation phase to improve existing and next generation product models, to create new products, as well as to improve product and service delivery processes.

The starting point for this thesis was to develop a methodology for deciding the maintenance needs of the system through risk analysis for different phases of its life span. However, as the thesis progressed we found an opportunity to do a case study in a company producing advanced and complex industrial products. The company was starting started to see new demands related to operations and maintenance in the market. They were therefore interested in improving the products with respect to RAMS and product support through improvement in design processes and service delivery strategies.

Next sections addresses state of the art, research questions, research scope and objectives as well as limitations of the study.



## 1.1 State of the art

High availability is dependent on reliability, maintainability, and supportability. Even though many products have become much more reliable, they still occasionally fail to perform satisfactorily. Therefore, as products become more advanced and complex, it often becomes more difficult to diagnose, repair and/or restore failures. Furthermore, preventive maintenance is often needed to assure high reliability. Services to support products therefore are often influenced by a product's RAMS characteristics. Many of these characteristics can only be improved through design. In the following, the state of the art in product support and RAMS will be surveyed.

To meet the challenges associated with RAMS and product support in engineering design with respect to product complexity and the use of advanced technology, many design related concepts and tools have been developed. There exist a large volume of literature dealing with basic knowledge on reliability, maintainability, and availability (see for example Aven (1992), Barlow et al (1981), Blischke and Murthy (2000), Blanchard et al (1995), Blanks (1992), Dhillon, (1999a), Ebeling, (1997), Knezevic, (1997), Kumar, (1990), Leitch, (1995), Villemeur, (1991a), Villemeur, (1991b) for details on statistical methods for reliability and maintainability). Advanced reliability models often require advanced knowledge of statistics, which is not always engineer's greatest strength. Furthermore, many of the reliability models are based on assumptions not always easy to fit with the problem in consideration. Analysis methods/tools like FMECA (Failure Modes Effect and Criticality Analysis), ETA (Event Tree Analysis), CCA (Cause Consequence Analysis), and so on, were developed a long time ago but mainly focus on HSE (Health, Safety and Environment).

It is well known that maintenance requirements are often not considered before late in the design phase even though the biggest impact on maintenance costs and total ownership cost would come from considering operational and maintenance requirements as early as possible (see Dhillon, 1998, and Blanchard and Fabrycky, 1998, for discussion). In some cases the cost impact of a design defect rectification increases tenfold for each life cycle phase it is postponed (Dhillon, 1999a). The results from such analysis can be used for LCC assessments, planning and recommending preventive maintenance strategies as well as testing, installation and commissioning, and decommissioning/ removal/ disposal.

Many of these methods are used in large-scale projects and/or in projects where reliability and safety is important. They are however equally usable for design with respect to maintenance and life cycle costs. The problem is often that the tools are not integrated into design processes. Many engineers use the methodology implicitly by attempting to design out known weaknesses, or to reduce the effect of weaknesses. However, many companies are not using the tools systematically to document

weaknesses as well as improvements. This means that they do not have formal procedures for using them in various design phases. One reason for this is that many of the tools depend on statistical data and information not readily available to the design engineer. Moreover, information may exist in various qualitative but not quantitative formats.

Furthermore, even though many have focused on how to reduce operations and maintenance costs (for example by improving design through increased focus on reliability and maintainability and through application of the tools and concepts), little has been published on how to integrate the application of these tools/ methods/ models into the work processes that create and make the products. The notable exceptions are Blanchard and co-workers (see for example Blanchard et al, 1995, Blanchard and Fabrycky, 1998, Blanchard, 1998, Fabrycky and Blanchard, 1991), Dhillon (see e.g. Dhillon, 1998, Dhillon, 1999a, Dhillon, 1999b), Moss (1985), and Thompson (1999). These authors focus on the application of tools and methods in design analysis and synthesis. Design influences repair and maintenance, training and upgradability, as well as performance effectiveness/ efficiency, and cost aspects.

In the area of supportability, research has been performed with focus on logistics and ILS (integrated logistics support). Furthermore, in the area of logistics there has been much done in the area of production involving, among other things, the concept of JIT (just in time). Blanchard and Fabrycki (1998) give an excellent review of literature.

Customer support (product support and after-sales service is used as synonyms for customer support) appears to be important for industries where the equipment is complex, where it fails frequently or has serious failure consequences (high risk), or where cost of ownership is important. Four major components of customer support strategies are critical (Goffin, 1999):

- 1) identifying customer's support requirements,
- 2) design for supportability,
- 3) choosing/managing distribution channels, and
- 4) promoting support for competitive advantage.

Component 1 clearly relates to supporting the customer in operating and maintaining the product to 'get the best' from the product. Component 2 relates to a product's RAMS, functional, and other characteristics such as usability, documentation, etc. Component 3, relates to logistics of spare parts, availability and capabilities of maintenance personnel, outsourcing of customer support to third party supplier. Component 4, relates to marketing customer support and making sure that the customer knows its importance, as well as making sure the investments in customer support really become a competitive advantage.

In a series of publications related to product support Goffin reports that relative little research has been published on how product design influences product support (Goffin, 1998, Goffin, 1999, Goffin, 2000, Goffin and News, 2001). In a research study it was found that only 50% of the observed companies followed/used a formal product support plan with quantitative goals during design. More than two thirds of the companies started to begin planning of support in the second half of the product development process. Some consumer product manufacturers (Kodak in the photocopier market, Hewlett-Packard in the medical ultrasound market, and a manufacturer of vending machines) focus on support to gain competitive advantage. Caterpillar is famous for the services provided to support its earth moving equipment (see also Fites, 1996). Product support is a key source of revenue and a means of competitive advantage in many industries.

In a different case study, it is emphasized that product support is heavily influenced by design and therefore needs to be considered in the product development phase. In this study, Goffin and New (2001) describe a conceptual model of 'stages' in the development of a design for supportability approach during new product development. In the first stage, there is no evaluation of support requirements. In the final stage, stage five, the management promotes design for supportability. At this stage, financial reporting mechanisms are used to visualize that design for support pays off. The five companies studied are placed in the model according to which degree they evaluate support. Some best practices are identified, such as:

- 1) involvement of customer support experts in new product development,
- 2) performing comprehensive support requirements at design stage and setting suitable goals,
- 3) using data management to monitor all aspects of field support,
- 4) helping top management to recognize importance of customer support, and
- 5) using customer support to gain a competitive advantage and increase revenue.

In a number of publications Goffin and co-workers have contributed to clarifying the product support concept as well as reviewing and classifying published literature in the area. However, whilst having performed case studies involving mostly suppliers of consumer products, and some manufacturers of industrial products, they do motivate further study in the area, but do not specifically tell how this can be done.

Services may account for as much as 90% of all employment in the West (Gummesson, 2002b). Simultaneously there are more goods than ever before. This paradox is a result of that mass manufacturing systems are now so mechanized, robotized and digitalized that they need fewer workers. What they need instead is supportive services.

Often literature emphasizes *support to product*. Mathieu (2001a) clarifies the support concept by classifying industrial support as services. By providing support, a

service is delivered to the customer. Services can be divided into three categories, namely (see Mathieu, 2001a and Mathieu, 2001b for details):

- 1) services to support the product,
- 2) services to support the customer, and
- 3) service as an independent product.

Services to support the product relates to the traditional after-sales service such as spare part provision, expert assistance to resolve problems, etc. This kind of support is explicitly related to product weaknesses not possible to design out, either of cost or technical related constraints. The recipient of the services is the product.

Services to support the customer are services that enhance the client's actions in relation to the product. Such services demand intimate knowledge of the customer's operations and how the service will support the core business activities. This kind of service focuses on assisting the customer to take maximum advantage of the product purchased. It includes services such as advanced training of operations and maintenance personnel, evaluation of operations and maintenance strategies. Mathieu, (2001a), emphasizes that "...the mission is not just to make the product work, but to help the client maximize all the different processes, actions and strategies that are associated with the supplier's product". The recipients of the services in this case are people/persons.

In the third category, the manufacturer uses organizational knowledge, gained from manufacturing and supporting the product as well as customers, to offer services independent of the physical product. For example, Fiat offers information technology services (Mathieu, 2001b).

Our literature survey shows that relatively little has been done to analyze the importance of service to customers on product performance. It is reported that the strength of the relationship with the customers is closely linked to the ability to develop services to support the customers. Support to the product is a common and traditional service, whilst support to customer presents some promising opportunities (Mathieu, 2001a).

Van Baaren and Smit (1998) report on the development of a model based on a systems engineering approach for incorporating RAMS and LCC aspects in design. The model is developed based on several case studies in the aerospace, chemical process, and automotive industries. Their emphasis is on the design and development process of large-scale, complex, and technical systems such as one-of-a-kind chemical process plants, small to medium series aircraft, and mass production automotive industry.

## 1.2 Research Questions

Physical products and related work processes must be seen in a holistic perspective to create the necessary synergies to benefit process participants as well as end-customers. The product and the work processes are interrelated and complementary activities, and are not exclusive. Similarly, customers should not be seen as passive recipients of products and services, but rather as reactive, proactive, and interactive partners in a performance and profit enhancement process. In the development and exploitation of advanced complex industrial products, the manufacturer and the customer enter a long-term relationship with the goal of taking advantage of each other's strengths to increase competitiveness and to better manage the value stream. Additionally, the development in communication and information technology has opened up new avenues for collecting data, information, and knowledge. The technology has also created new possibilities for information distribution and to communicate across distances in a much more effective and efficient way than ever thought possible.

However, even though the communication and information sharing process have become faster and more reliable, the literature survey shows that little is done with respect to integrating approaches for reducing life cycle costs during the design phases. It also shows that the concept of product support has many dimensions that open up new opportunities for manufacturing companies, and that product support is closely related to product design characteristics as well as to information flow and communication. It is established that product support need to be analyzed in the design stage, but there is little evidence that manufacturing companies actually are taking steps to improve the design process with respect to product support and to take advantage of the opportunities available.

The literature review in addition to our own industrial experience and discussions with personnel in the industry raises many interesting research questions. On the basis of the stated interests from the company participating in the case study and limitations with respect to available time, financing, and resources, as well as our own priorities, we selected to focus the research on the following questions addressing discrepancies between practice and theory:

- How does product support strategies affect business practices in the manufacturing sector?
- What factors, knowledge, and information affect dimensioning of product support?
- What is the most appropriate life cycle phase for dealing with the product support problem?
- Are there differences between services to support the product and services to support the customer? How do these services relate to the product and the

design process? What possibilities exist for the manufacturer and customer to benefit from the two types of services?

### 1.3 Research Scope and Objectives

Based on the principal research questions, the scope of this thesis was to study the support issues related to advanced industrial products used in production lines with high demands on performance, output quality, and availability. Moreover, it is mainly focusing on studying engineering factors such as RAMS in design and manufacturing processes.

The main objective of this research study is: to map, study, and analyze factors/ parameters/ issues influencing product support strategy for industrial products and to explore measures to control them.

Sub-objectives includes:

- Study and analysis of factors influencing maintenance and product support concepts.
- Investigation of issues related to RAMS integration in design processes.
- Examination of product support practices in the industry to provide services to support products and to support customer actions related to the products.

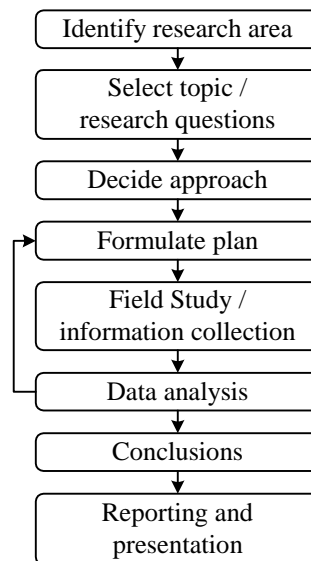
### 1.4 Limitations of the Study

During this study we only considered the relationship between the manufacturers and their customers. Influences of end-customers (customers of the products produced in the production lines) or sub-suppliers (suppliers of components and sub-systems used in the products) are not considered. Various scenarios where operations, maintenance, and/or support are outsourced to a third party are only briefly discussed. Issues related to various outsourcing strategies, outsourcing contracts, and logistics operations/ management are not taken up for investigation.

The thesis does not take into account organizational aspects of processes. With respect to delivery of spare parts, only some factors are discussed. Optimization of logistics support is not considered. Furthermore, JIT (Just in Time), TQM (Total Quality Management), TPM (Total Productive Maintenance), QFD (Quality Function Deployment), and other concepts and methodologies focused on quality and continuous improvement efforts, were not included within the scope of this thesis.

## 2 Research Approach and Method

Generally speaking, the research process is formed by the sequence of: identifying the research area, select the topic of interest, decide approach, formulate plan, collect information, analyze data, and present findings (Gill and Johnson, 2002). The overview of the overall plan for the research process in this thesis is described in Figure 1. The research study was exploratory in nature, and was based on empirical evidence from a case study and literature. Since the research presented was inductive in nature, the planning, information collection, and analysis sequences were iterative until findings became relatively more conclusive.



*Figure 1: Research Process*

The research reported in this thesis is based on research questions developed on the basis of research problems defined with help of literature survey and perceived product support needs by the industry. Throughout the thesis, we intend to examine issues and factors influencing product support strategy for industrial products and to contribute to the existing knowledge in the field. See Gill and Johnson (2002) and Gummesson (2000) for further discussions for such research approach.

Since we wanted to study a topic involving industrial practices, it was appropriate to adopt a case study research approach to achieve the focused research objectives and to answer the research questions. According to Yin (1994): “A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident”. Since we believed that the contextual situations might have a significant influence of the phenomenon under investigation we selected the case study research approach. As such, a case study is different from an experiment where one attempts to divorce (or control) the phenomenon from its context to focus only on a few variables. Since phenomenon and context not always are distinguishable, Yin (1994) also emphasizes that: “The case study inquiry copes with technically distinctive situations in which there will be many more variables of interest than data points, and as one result relies on multiple sources of evidence, with data needing to converge in a triangulating fashion, and as another result benefits from the prior development of theoretical propositions to guide data collection and analysis.” Furthermore, case studies can be a mix of both qualitative and quantitative evidence from multiple sources, they constitute an all-encompassing and comprehensive research strategy.

Since I planned to participate in an organizational process in change, and beside being an observer partially would act as a change agent, the participatory action research case study technique seemed especially suitable as a research approach. Gummesson (2000) asserts: “Action research is the most demanding and far-reaching method of doing case study research”.

In the following the participatory action research methodology will be discussed briefly. Thereafter the company and their products, the work performed and why it was performed, will be briefly presented. Finally, the case study data and information collection and sampling, as well as results verification methods will be briefly discussed.

## 2.1 Participatory Action Research Method

The case study methodology used in this thesis can be characterized as Participatory Action Research (see e.g. Eden and Huxham, 1996, Gill and Johnson,



2002, Gummesson, 2000, Westbrooke, 1995). The action research methodology formally developed in social science during the 20<sup>th</sup> century, goes back to the late 19<sup>th</sup> century (Masters, 1995). Action Research involves testing out ideas in practice as a means of improvement and increasing knowledge. It often progresses in a spiral of steps of planning, action, and evaluation of the results of the action. Based on an overview of the current practice and knowledge as well as ideas, one starts with the planning of critical actions necessary to improve current practice. Then the group implements the action and observes the response. Finally, one reflects upon and evaluates the results of the action. Based on this evaluation new actions are planned and observed (Hatten et al, 1997).

In participatory action research, the researcher participates in the processes under investigation, through collaboration and interaction with people involved in the process. Thus, the researcher is not an independent observer. Participatory research is a means to testing out ideas in practice in collaboration with clients to improve the client's work processes. This indicates that the researcher works as an observer as well as a change agent actively involved in processes in change (See Gummesson, 2000, for further reference). The term *research* implies that new knowledge should be generated. The term *action* means that the research assists in solving a problem for the client. The focus is on changing practice to make it more consistent with the goals. Hence, one should gather evidence about the extent to which practice is consistent or inconsistent with the goals. In this study, the object studied was a social system that exists in the form of an organizational system and its employees who also are subjects that have feelings, thoughts, etc. As such, it is difficult to separate subject and object, and therefore "we have to take into account a continuously on-going interaction between subject and object which together form a field of unity" (Ottoson, 1996).

Furthermore, the general research approach in this thesis (aside from that in the case study) can be characterized as interactive research as described by Gummesson (2002a). "*The elements of interactive research represents various interactions, such as between the researcher and the object of study and its actors; between the researcher's consciousness and qualities of his or her inner self; between substantive data and general concepts; between the parts and the whole; between words, numbers, non-verbal/body language and tacit language; and between data collection, analysis, interpretations and conclusions treated as concurrent, non-linear and dynamic elements of scholarly inquiry*". He further adds interactions between researcher and audiences and between the researcher and the computer.

The concepts and ideas presented in this thesis are a result of a learning and understanding process based on discussions and interactions between the researcher, advisors, colleagues, and employees in the company, as well as with other researchers at conferences and seminars.

The case study was performed in a company that manufactures industrial production systems for production/ assembly lines.

## 2.2 Research Object: The Company Studied

The company investigated is part of a large (175,000 employees) industrial group of companies with regional offices worldwide. At the time of the study the manufacturing company had about 250 employees. They produce various types of customized integrated production systems. The systems incorporate mechanical parts and subsystems, are powered by electrical motors, and are controlled by advanced software solutions, electronics and various sensors. The systems are designed for a 50,000 hours service life.

The goal of the company is to be a preferred supplier to their three most important customers, to be global, market dominant, and a leading supplier of this kind of systems. This means that the customer focus is of utmost importance. The focus should be on the customer needs, wants, and preferences, and the products and services delivered should reflect these issues. Thus, the customer focus must be to deliver products and services that make the customers satisfied with respect to technical solution, price, LCC, service, user interface, training, etc.

The systems are typically used in production lines where function capability, uptime, capacity, and quality are of utmost importance. The need for maintenance is most often impossible to design out of such systems due to costs and technological constraints. Operation and maintenance of such systems demand advanced skills (and hence advanced training) both in respect to being able to utilize and exploit built-in capabilities, to diagnose impending failures, and/or repair/restore actual failures, as well as create performance prognosis. Furthermore, often the systems require original spare parts and expert assistance from the manufacturer.

Normally, the customers purchase a system to fit into their own production line from the group's closest regional office. The regional office purchases the systems from the manufacturer and integrates it into the customer's production system. Both during the product acquisition and exploitation phase, the customer mainly interacts and communicates with the regional office. However, if they are not able to resolve the problems, the customer communicates with the manufacturer directly. Figure 2 shows a simplified model of typical interaction, coordination and communication interfaces. The primary and secondary interaction and communication are shown with continuous and broken lines respectively. During the product exploitation phase the customers interface with the regional office, but frequently they also need to interface directly with the manufacturer to solve complicated and complex problems.

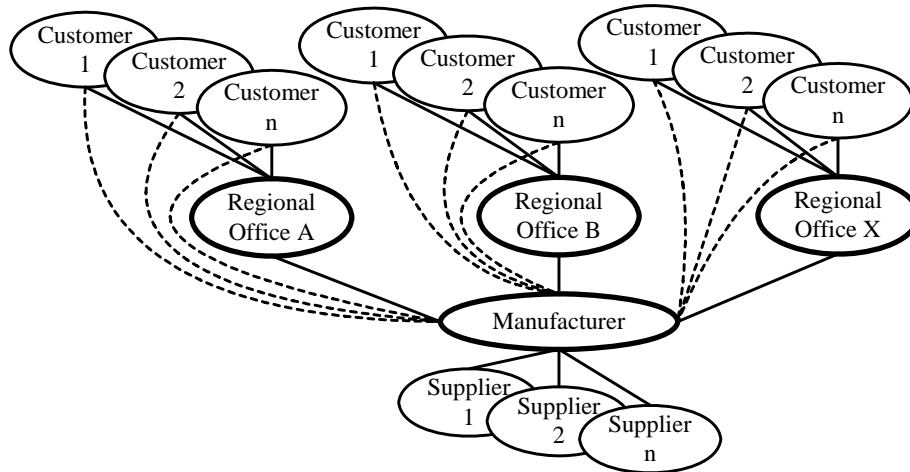


Figure 2: Communication and interface between manufacturer, regional offices, suppliers, and customers

The company has observed an increase trend in product support needs. It is not clear if this is caused by more products being sold, increased product complexity, reduced product reliability compared to earlier, or by changed or more intensive product use. Since the customers also increasingly face shorter lead-times in delivery of their own products, increased speed of product changes and production line output, process restructuring, etc., they (the customers) may also need to be more flexible and prepared to meet market requirements at short notice. This may reflect on the manufacturer in shorter lead-times and increased needs for support. The company makes money on product support, but for the customer it is a cost. The product will be more attractive if these costs are as low as possible, or, in other words, the product is designed for minimal required support and optimal support delivery.

### 2.3 Case Study: Background and Introduction

The core of the thesis work is based on a case study and is the basis for Papers II, III, IV, and V. The case study was conceptualized during a seminar on maintenance engineering, arranged by the Center for Maintenance and Asset Management, Stavanger University College, in February 2000. A representative of the company gave a presentation on how they approached the problem of implementing RAMS tools and methods in their design process. Since this coincided well with the research goal of this thesis, they invited me to study and facilitate the implementation process. At that time I had already started to get a good grip on the state of the art in the

research area, and therefore could provide valuable support for improving their design and manufacturing processes.

The main goal and purpose of the study was to identify areas where the company should focus for improvements with respect to products and work processes involved in product design, development, delivery, and support. One of the goals was to evaluate information sources and to identify information needs not covered in the databases. Furthermore, we wanted to evaluate how RAMS and risk analysis can be integrated in work processes. The study also aimed to motivate and provoke a discussion within the company about the design process and related problem areas, and to make the involved employees aware of the issues and complexities involved.

The study was completed in two phases, namely a preliminary and main study. In the preliminary study, we aimed to become acquainted with the employees, to understand the work processes involved in design and manufacturing, and to identify factors and areas that affect the design process and product service life performance. In the main project phase, we selected some of the areas and work processes found in the preliminary study for further detailed study. The preliminary study lasted for four months, where three months were spent in the company. The main study lasted for nine months, where six months were spent in the company collecting information and participating in their work processes.

As we would be entering partly uncharted territory as well as dealing with people in dynamic work processes, we decided to advance with caution and to be flexible with respect to project goals and to adjust them if necessary depending on findings. We realized that to improve the product with respect to RAMS, all the work processes involved in delivering and supporting the product would be influenced. The process of implementing a 'design for RAMS approach' in a complex design and manufacturing setting became a project of studying continuous changing processes. The subject of research became a study of processes in transformation. Therefore, each stage of research was discussed and negotiated in a collaborative relationship involving the researcher, advisors, and participants from the company. Based on the discussions we mutually agreed on what the next stage of the research should be.

## 2.4 Data Collection, Sampling, and Analysis

To ensure reliability and confirmation of findings, it is recommended to collect data and information using several sources and methodologies. The use of focus groups, documentation, archival records, interviews, direct observations, and participant observations are some of the possible techniques (see Cooper and Schindler, 2001, Gummesson, 2000, and Yin, 1994, and for further discussion). In this study evidence was collected by the use of informal interviews, focus group

surveys in the form of questionnaires, data and information collection and analysis, discussions with employees and external specialists, and by participation in projects and meetings. In the preliminary case study, the focus was on collection of qualitative information and data (e.g. questions regarding degree of integration of failure statistics, degree of focus on customer needs, etc.). In the main study, the questionnaire contained both qualitative and quantitative questions (e.g. number of databases are used, number of employees using them, etc.). To get a holistic view of the company we selected employees from most departments and departmental groups to participate in the surveys. Many of them were department managers, group managers, or specialists within the groups. We attempted to involve the employees performing the work as well as the employees managing the work processes. This, it was hoped, would provide insight as well as holistic understanding of the issues involved. By involving senior management, we further expected to get more focus and support.

In the preliminary study, 22 employees were invited to participate in the employee survey. However, only five employees answered. Nine employees participated in a meeting discussing the project topics. The response rate was affected by various internal conditions and even by issues personal to the employees. This was partly expected as the company had just started to introduce RAMS technology in design. Detailed interviews in the form of guided discussions were held with specialists. In the main project phase, 51 employees participated in the study and 47 answers were received. In-depth interviews were conducted with 17 of them. Some of the employees preferred not to be interviewed. They instead submitted written answers to the questions in the interview guide. Both surveys included employees from all departments. Before creating either surveys, time was spent to study literature and theory to frame and form the survey. The second survey included both a combined quantitative and qualitative section distributed among many employees, and a qualitative part performed in an interview setting.

I also participated in designing a training course for the employees intended to teach, motivate, and train them with respect to design for maintenance philosophy, RAMS issues, tools, and methods (see Papers I, II, and IV). In this RAMS training course I participated with theoretical presentations and in discussions with the employees. Additionally, I participated in various discussions with the RAMS coordinator related to development of a RAMS strategy, related to RAMS tools information infrastructure, and related to services to support the products as well as to support their customers.

SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis methodology was applied in both the preliminary and main study to organize and categorize information obtained from personnel. Simple descriptive statistical data analysis and ranking was performed on the quantitative data collected. Furthermore, the qualitative

information obtained from interviews, surveys, discussions and documents, were analyzed, examined, recombined, and described to address the to the research topic and research questions, to build explanations, and to reveal patterns and gaps between theory and industrial practices. See also Yin (1994), Gill and Johnson, 2002, Gummesson (2000) for discussions on case study research.

## 2.5 Verification of Results

The manufacturing company studied operates in a dynamic market where the ability to adapt and adjust to changes in market demands is becoming increasingly important. Flexible processes are an advantage in a dynamic market. The internal processes are fitted to the product delivered, as well as to the market demand. The organizations managing the work processes therefore are different from one company to another.

When making observations on how to improve products and processes in a company, many of the observations are responded to and implemented quickly (if they make sense and relate to something concrete). Furthermore, when observing the company and their work processes through questionnaires, interviews, training participation, and discussions, the observer influences the subjects observed because questions are asked, and focus is put on special issues and problems. A study like this is therefore not objective but is rather subjective, as by performing observations of something you can affect the performance (I am here thinking about Heisenberg's principle of uncertainty, see Bjørkum, 1998, for details). A rock will not fall differently whether there is a theory explaining the fall or not. However, in general, theories with reference to human behavior may contribute to our understanding of behavior, but it may also influence the behavior. It was observed that the company employees' attitudes and understanding of the subject under investigation changed during the case study and that they got more involved and motivated to contribute to improve products and work processes.

Collecting and analyzing data from several sources confirmed and increased the reliability of the findings (for further discussions see Cooper and Schindler, 2001, Gill and Johnson, 2002, and Yin, 1994). Furthermore, the findings from phase one of the study were documented in form of a report where six new 'areas' were identified for further study. These were incorporated in the phase two of the study, together with some other topics. A report for the second phase was used as a basis for a workshop to which many of the participants were invited. The results were presented and discussed. In both case study phases, a Reference Group was constituted of the researcher, two professors, and three senior employees from the company to provide guidance and to check the validity of results. They further verified the accuracy of the evidence and that the results made sense. In both phases, we adjusted and rescheduled

activities to make sure the project was focused enough to deliver better and relevant results. Most of the work are published and accepted for publication indicating industrial relevance and scientific contribution.





## 3 Discussion of Results and Conclusions

In this section, the six papers forming the main contribution of this thesis will be linked together in an attempt to create a holistic view of the work performed. Together, the six papers examine the basic concepts, issues, challenges, and opportunities associated with dimensioning of support for industrial products, and contribute to bridging theoretical knowledge and practice. Issues related to dimensioning of product support during design and operation is studied with special reference to maintenance and support needs of the product, as well as the needs, wants, and preferences of the manufacturer and the owner.

In this thesis the focus is equally on the services needed to support industrial systems/ products/ machines/ equipment used in manufacturing sector as well as on services to support the users and maintainers of such systems. Moreover, the thesis examines how product support strategies are influenced by a product's designed-in operational characteristics, as well as characteristics related to customers/users, manufacturer, operational environment, operators and maintenance skills, and so on. The goal is to reduce operational and maintenance costs, and to increase profit generated by the products through improving product characteristics in design as well as through improving the product support delivery strategies during exploitation. In short, the thesis partly constitutes a framework for dimensioning product support strategies based on its RAMS characteristics. The research work also discusses development of product support for functional products (the new trend) for meeting market trends of purchasing performance instead of product. The thesis identifies issues, challenges, and opportunities related to dimensioning of product support for industrial products so that optimal product support strategy can be developed.

### 3.1 Maintenance and Product Support: Basic Concepts

High reliability does not mean that a product is maintenance free, but rather that the product is more reliable because maintenance is performed according to needs and specifications. If a very reliable product fails unpredictably, corrective maintenance will be needed. Since the failures are seldom, the owner may have neither the capabilities and resources necessary to diagnose and repair the failure, nor the expertise in spare part/inventory management or planning. In addition, spare parts may not be available. The consequence may be a costly repair process where the manufacturer often has to be involved. If all products became close to maintenance-free, the capabilities of handling product failures within the company would reduce over time. This could result in more severe failure consequences (increased downtime and repair costs) than if the organization is used to handling the events. Even though high reliability reduces the probability of failure, the risk may remain the same since risk is a combination of likelihood and consequences of failure.

In general, due to cost and technological considerations, it is almost impossible to design a system that is maintenance-free. In fact, maintenance requirements come into consideration mainly due to lack of proper designed reliability and quality for the tasks or functions to be performed. Thus, the role of maintenance and product support can be perceived as the process that compensates for deficiencies in design, both in terms of product reliability and in terms of quality of the output generated by the product (Markeset and Kumar, 2001). These shortcomings in design are compensated through appropriate maintenance and product support programs (Figure 3).

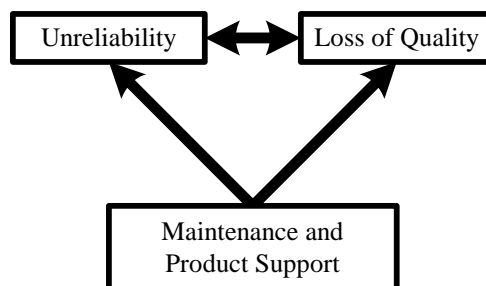


Figure 3: The compensating role of maintenance and product support

Apart from unreliability and poor quality, other factors such as human errors, statutory requirements, accidents, etc. also influence the design and development of product support and maintenance concept. The goal of maintenance and support is to

reduce business risk, and to satisfy the customers of the maintenance process (see Figure 4).

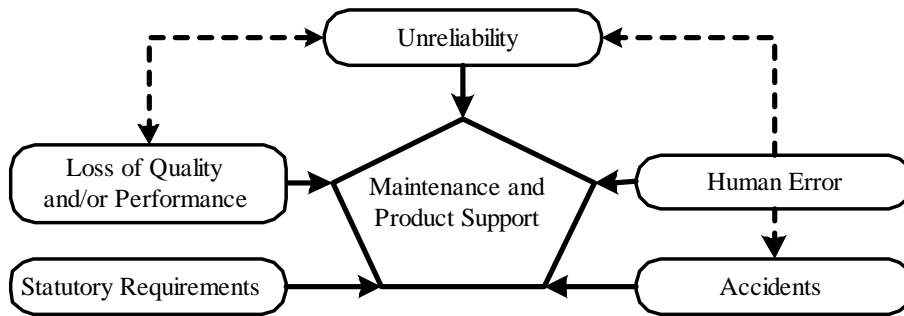


Figure 4: Factors influencing the need for maintenance and product support (Markeset and Kumar, 2001)

Most physical products can be classified into three categories according to maintenance and support needs. The first category forms products that are almost maintenance-free such as refrigerators, microwave ovens, television apparatus, etc. The second category forms products that require more frequent attention, repairs, maintenance, and support. Typical examples include products such as automobiles, buses, railway, etc. The third category is that of complex and safety intensive machines/heavy duty systems that need maintenance and support constantly. Typical examples are airplanes, mining equipment, etc. (see Figure 5).

### 3.1.1 Services

To specify what constitutes a service or a product can be difficult. The word product is used about both tangible assets (e.g. car, wrench, drill, aircraft, etc.) and intangible assets (e.g. idea, speech, performance, etc.). The word service is used about situations such as serving coffee, delivering mail, transporting passengers, changing oil on a car, providing hotel accommodations, banking, public administration, etc. A service therefore can be defined as a set of benefits or activities exchanged (sold) between two parties. Zeithaml and Bitner (2000) assert that services are deeds, processes, and performances. Deeds are activities the provider can perform to solve a problem for a customer. Process refers to a identified approach to perform the deeds, whilst performance relates to the effectiveness and efficiency of the process.

Services often follow physical products and are considered add-ons (Grønroos, 2000). To many economists, the concept of a product is used for both goods and services. However, under the popular usage, 'product' often means goods only (Juran and Blanton, 1999). Common to both concepts is that they are the result of an effort.

One can, for example, say that a product is the output of a process (work process or technical process). In this thesis, the word ‘product’ is used about physical technical assets, which are designed according to some specifications to fulfill various functions, and which are traded between two parties, most often companies. Services are all the actions/activities which follow from the contact between the parties involved in producing and supporting the product and the customers.

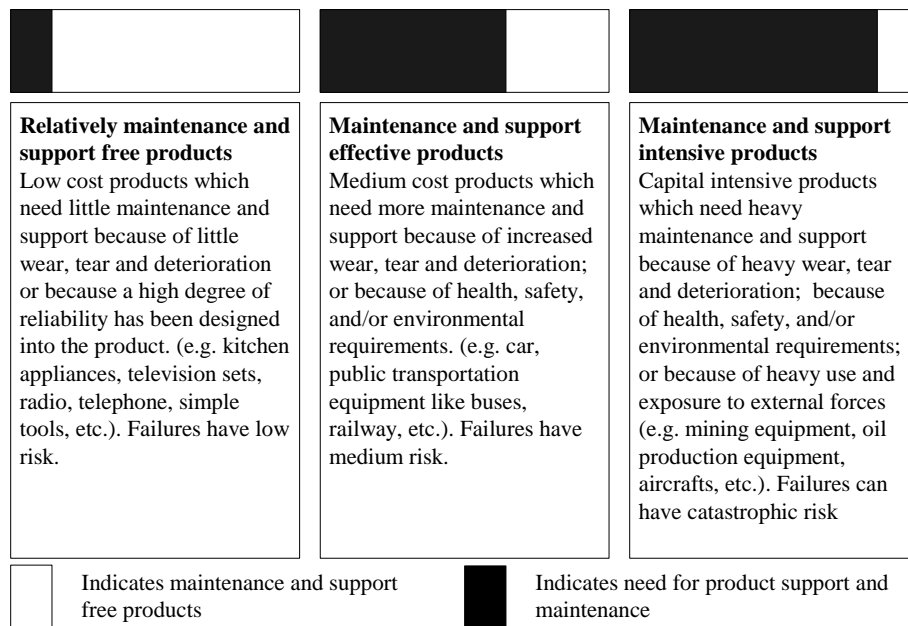


Figure 5: Product classification based on maintenance need (Markeset and Kumar, 2001)

### 3.1.2 Product Support and Service

Customers are foremost interested in the product performance, both in respect to its profitability and output. Kasper and Lemmink (1989) studied the perceptions between industrial customers and service managers in evaluation of after sales service quality and state that "...product and service strategies should be matched properly because the industrial customer will evaluate the quality of the physical product as well as the quality of the attached services".

Many manufacturers now realize that a surprisingly large part of their turnover comes from repair, maintenance and modernization/modification services. Consequently, customer relationship management and service quality have become increasingly important for their long-term survival. Products and/or services are

judged by the users according to some criteria or attributes (which may vary among customers both with respect to type of criteria and strength). Concrete product attributes have consequences and benefits for the customers affecting their sense of how the basic needs or values are served (see also Paper IV). A judgment about product performance can be measured by measuring customer satisfaction of how the product characteristics or attributes fulfill the customer needs and requirement. The company developing products and services needs to understand what consequences and benefits the attributes have on customer needs and values. The ultimate goal of the product or the service is to cover or fulfill the customer goals and values. These goals therefore need to be designed into the product or service.

Services related to the product are delivered to the customer throughout the service life, as discussed in Paper IV. Typical forms of support include installation, commissioning, training, maintenance and repair services, documentation, spare parts supply, product upgrading and modifications, software, and warranty schemes (Blanchard, 1998, Goffin, 1999, Wilson et al. 1999). In the past support used to be thought of merely as maintenance (including repair and services like lubrication, oil change, filter change, etc.). However, the scope of product support has broadened over the past decade to include user training, telephone support, upgrades, etc. (Goffin, 2000). Figure 6 illustrates some of the basic elements of maintenance and service support that function as a basis for a service delivery strategy to support a product.

Paper IV further discusses the basic elements for formulating a product support strategy.

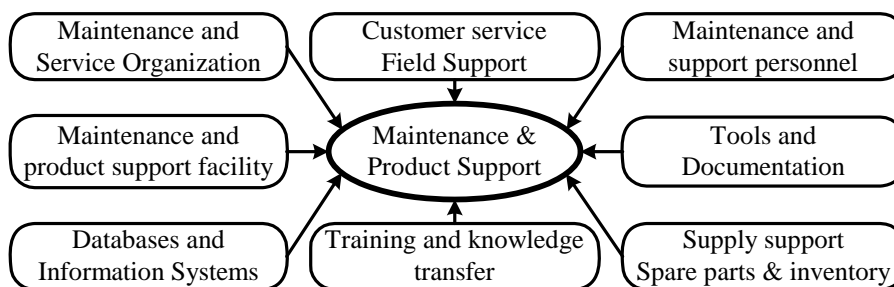


Figure 6: Some of the basic elements of maintenance and product support (Adapted from Blanchard, 2001)

### 3.1.3 Services to support product and services to support customer

A manufacturer can offer services before the product is sold, during the design and manufacturing phase, in the product utilization phase, and during the phase-out, re-use or disposal life cycle phase. In this thesis, we differentiate between services

supporting the product (product support, after sales service) and services supporting the client (customer support). Product support relates to support governed by product function weaknesses and is tied to the product. Examples are installation and commissioning tools, spare and warranty parts, documentation, expert assistance to diagnose problems, and so on. Customer support relates to support during the product life cycle to enhance the owner's utilization of the product. Examples include advanced training in operations and maintenance, development of customized operational and maintenance strategies to enable product dependability during stable and dynamic market situations, and so on. Customer support also is referred to as supplementary services, consulting services, or professional services. The need for customer support is based on customer's needs, wants, and preferences. In addition it is dependent on availability and costs. Often manufacturers offer this kind of support based on their knowledge, capability and capacity, but it can be supplied by third parties as well. See Papers IV and V for further discussion.

#### **3.1.4 Maintenance management in the operation phase**

In the product exploitation phase, the overall objective of the maintenance process is to increase the profitability of the business in a total life-cycle cost perspective without compromising safety or environment. Once a system or product is commissioned for use, the maintenance concept is more or less fully governed by the type of maintenance strategy adopted for the system. Establishing a maintenance strategy requires understanding the technical characteristics of the product, functions to be performed, and the maintenance objectives. Of course, one has to examine the types of resources (organization and level of competence) available. Figure 7 illustrates some of the factors that influence the establishment of maintenance and service strategy for the product. Factors and parameters influencing maintenance and product support strategies are discussed further in Paper IV.

From the discussion above, it is clear that product support and maintenance are strongly influenced by design. In particular, a product's RAMS characteristics influence the product's performance as well as maintenance, operational and support strategies. Consequently, it is especially important to consider the RAMS characteristics in the design and to integrate RAMS analysis and synthesis in the design process activities in a systematic manner. Furthermore, it is important to consider all the needs, wants, and preferences of the customer and to integrate them in the design specifications as well as in design and support activities.

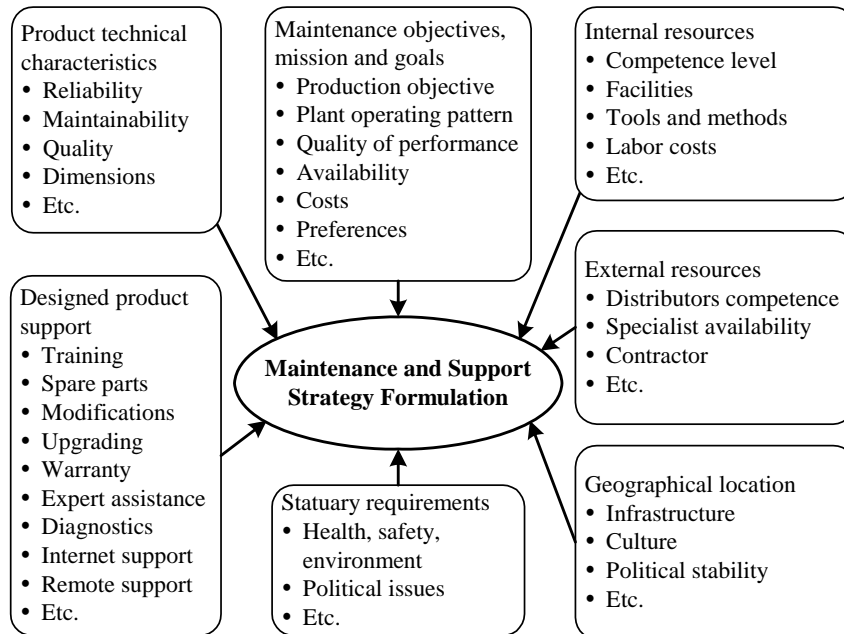


Figure 7: Some factors influencing the formulation of a maintenance and support strategy

### 3.2 Integration of RAMS in Design

During design, opportunities exist to optimize the design for the best possible lifetime effectiveness by avoiding maintenance as a whole, or to improve access to the critical parts if maintenance is unavoidable, and/or to enable improvement of the planning of asset maintenance. The cost of maintenance and its influence on the total system effectiveness is therefore too great for the manufacturing and other engineering industries to ignore. Maintenance function (process) is critical for the economic viability of many of the engineering companies. A major part of such costs can directly be attributed to the poor design of parts, components, or systems. It is argued that if due attention is paid during the design phase about the 'maintenance need' of the system, a considerable saving can be made in operation phase and even during the manufacturing stage.

Key customer satisfaction drivers are customers' perception of product quality and value (the benefits or quality relative to the costs or prices incurred) compared to their

expectation (Johnson, 1998). Profit margin and market share can be improved by focusing on:

- integrating customer needs, wants and preferences in design,
- improving product quality,
- improving utilization of employee/ customer knowledge (learning and training),
- improving design process and project management,
- reducing business and project risk,
- and by manufacturing improved products with respect to reliability and maintainability.

These activities are not only dependent on information, but also on the skill of using the information to increase the knowledge about the product, the design process, and the market/customer. By focusing on delivering high quality products with respect to LCC, reliability and maintainability, by delivering the products and services the customers require, want, prefer, and expect, and by controlling project and business risk, the company competitiveness should increase. Adding value to all stages of product life should benefit both the customer and manufacturer.

A product's life cycle phases are divided as shown in Figure 8. It is worth observing that commitment to technology, configuration, performance, as well as to life cycle cost are made in the early phases, even though the actual accrued costs come later. For new products, little information may be available at the design stage to make prediction of LCC. However, for products that are developed through an evolutionary fashion, a lot of knowledge, experience, data, etc. already exist at manufacturer, distributor's, customer's, as well as at third party (e.g. a company who performing maintenance based on outsourced contract) sites. This knowledge needs to be fed back to the product designer and used in an effective and efficient way to improve the products, as well as all work processes related to the product existence whether it is in the design or exploitation phase (See discussions in Papers I, II, III, and IV). As a product design process progresses it becomes increasingly difficult and expensive to make changes.



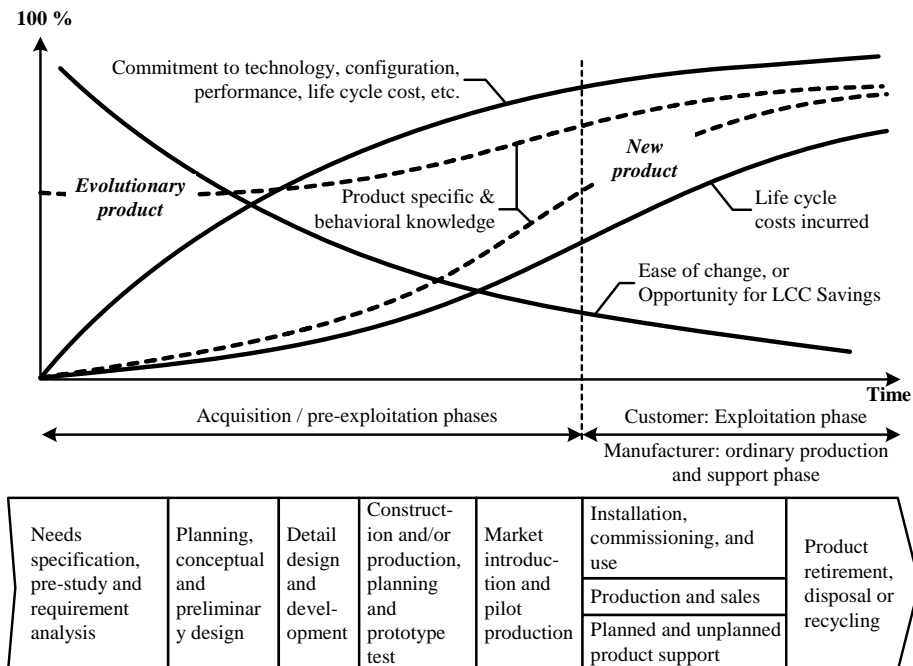


Figure 8: Commitment, Knowledge, and Costs (adapted from Blanchard and Fabrycky, 1998)

### 3.2.1 Strategies for Dimensioning Product Support

For a manufacturer, three strategies for product development can be considered while considering maintenance, namely 1) *design out maintenance*, 2) *design for maximum profit*, and 3) *design for performance* (or design for maintenance and support). Adopting Strategy 1, means that one attempts to design out the need for any kind of maintenance and support. The product is simply designed and sold. There is no wear, tear, or deterioration causing maintenance or support. The buyer uses the product until it fails and then discards or recycles it. For a product to be maintenance-free there should be no need for services like oil change, lubrication, and so on, either. If the product fails during the warranty period, the product is replaced. The design out maintenance strategy most often proves impossible due to cost or technological limitations.

Adopting Strategy 2, design for profit, means that the manufacturer designs the product so it is competitive in price, but does not attempt to reduce exploitation life

cycle costs by reducing maintenance and support needs. Instead, the manufacturer speculates in spare part sales and expensive product support. In the worst case the manufacturer designs in wear and deterioration mechanisms in parts and subsystems that will require special spare parts obtainable only from the manufacturer. The manufacturer will in this case design the product such that the need for spare parts will not be required before the warranty period is over. Operational procedures can as well be made such that more failures happen. Maintenance and service procedures can also be made demanding replacement of parts that normally do not wear or tear. The justification for replacing these parts will then be hazy or non-existent. This strategy can be regarded as dishonest. Such a strategy may work for some time, but we believe the customer would see through the behavior eventually and stop using this supplier. This would result in loss of goodwill and possible, financial liability for the manufacturer.

In the third product development strategy, the product is designed for performance. This means that the manufacturer first attempts to increase reliability as much as possible within technological and economic constraints, and thereafter tries to make the product easy to maintain and support through increasing product characteristics such as maintainability and supportability. Furthermore, product performance can be increased by providing excellent product support and customer support. The goal for both manufacturer and customer is to create long-term relationships, customer satisfaction, as well as developing competitive products.

In the design of industrial products, the performance of the product needs to be considered in a holistic and long-term sense. The basic building blocks are shown Figure 9. Moreover, in designing products for performance and maximum LCP, LCC analysis can be used both as an economic and engineering tool to assess trade-offs in design and to balance constraints.

See also discussions in Papers I, II, III, IV, V, and VI.

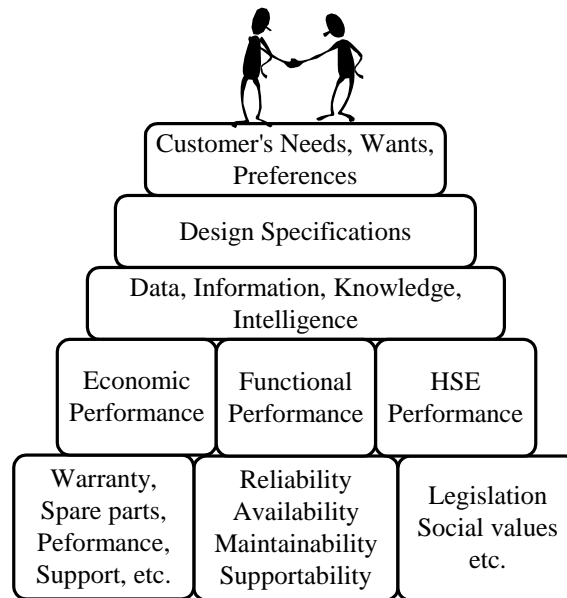


Figure 9: Design for Performance

### 3.2.2 LCC and LCP

Life Cycle Cost (LCC) analysis has been used for many years as a tool to predict the total cost of a system throughout the product's service life. Others have proposed Life Cycle Profit (LCP) as an analysis method for optimizing production system utilization and added value. Common to both these methods is that they look upon the product from a product/system owner's perspective. From the product owner's perspective, maintenance is needed to ensure satisfactory functioning of the equipment. Maintenance activities need to be planned and performed at the right time at the lowest cost to achieve the desired production level. Maintenance activities also need to be flexible so they can be adjusted to meet changed production demands (Ahlman, 1984).

In the pre-exploitation phase, the manufacturer is responsible for making sure the product is designed according to specification and to optimal LCC and LCP. However, the customer is responsible for providing the correct specifications in cooperation with the manufacturer in the specification phase. LCC and LCP are normally applied to the product in the exploitation life cycle phase and as seen from the owner's perspective. However, these concepts can also be applied as seen from the manufacturer's perspective. To achieve a win-win situation for all parties

involved, LCC and LCP need to be assessed and agreed upon in the design stage since a major part of LCC is decided at this stage.

Life Cycle Profit analysis was as far as we know first suggested by Bazovsky (1974) and further developed by Ahlman (1984). Bazovsky suggested a concept for optimizing system support policies and design or equipment purchase and lease alternatives. Minimizing the cost of support is not necessarily the optimum, but an optimum policy is assured when net profit is maximized in a profit-oriented situation. LCP can be increased by reducing the losses caused by equipment unavailability due to too low reliability, too long maintenance time needed to retain equipment in an acceptable condition or to restore it after failure, and by reducing administrative and logistic delays during maintenance. In other words, life cycle profit is influenced by a product's RAMS characteristics. LCP is, in addition, influenced by an owner's maintenance and operational strategies. As pointed out by Ahlman (1984), LCP is affected by market situation, both stable and dynamic. In a stable market (continuous, stable demand), the focus would be on minimizing LCC through optimizing RAMS, maintenance and operational effectiveness and efficiency. In a dynamic market where the market demand varies over time, the product owner will be more dependent on the equipment being reliable and providing quality output during specific periods. During these periods, the operational effectiveness and efficiency need to be optimal, and maintenance strategies need to be optimized such that the equipment is dependable during this period. Maintenance strategies need to be optimized to make sure the equipment is able to function and produce high quality output when needed. (See also Paper V)

### **3.2.3 LCC and Risk Analysis**

As mentioned, the purpose of maintenance and support is to reduce business risk. It includes all events that have the potential for a reduction in value-creation activities and can result in a loss of competitiveness. In the business risk concept, we include the loss of business opportunities that have the potential to increase the value generation. Any efforts that reduce product LCC, or increases LCP, also reduce business risk. Business risk can, for example, be reduced by improving a product's RAMS characteristics, improving the capacity and capability utilization, improving the operation and maintenance strategies, etc. It can also be reduced by improving the work processes in place to produce the business output or profit. Risk analysis should therefore be performed together with the LCC analysis, as LCC analysis is incomplete without an assessment of risk and uncertainty. (See also Paper I, IV, V, and Markeset and Kumar, 2000)

### **3.2.4 Work Processes in Design**

To be able to sustain competition, to deliver a superior product, and to continue growing, companies need to focus on making the processes as effective and efficient as possible and to focus on the value chain – to analyze the process for value added

activities and cost drivers. This means that they need to analyze the value chain and the activities involved in the design process, to identify value creating activities and assign costs, revenues, and assets to these activities. Furthermore, cost drivers that regulate each value activity need to be identified and diagnosed. Finally, a sustainable competitive advantage can be achieved, either by superior cost control or by modifying the value chain to the company's advantage (Botten and McManus, 1999). One way to increase process output is to reduce the waste of resources, capabilities, knowledge, etc., that are required in the transformation process. To optimize the values the processes create, the processes themselves must be optimized. Therefore, process activities that produce no value and waste resources must be identified and corrected. By mapping the processes, identifying the wanted and unwanted inputs, and by identifying the wanted and unwanted output, actions can be taken to improve the process and control it.

As discussed, product support and maintenance needs are heavily influenced by a product's RAMS characteristics. To design a product with respect to RAMS, the manufacturer needs to integrate them into the design process. In the company studied, a RAMS Coordinator position was created for this purpose. The RAMS Coordinator is now responsible for coordinating and organizing activities, and for making sure that the employees have the necessary training and skills to use and evaluate the product in respect to maintenance and support needs. Furthermore, as the various RAMS tools require information and data, the Coordinator also is responsible for making information sources accessible for the engineers and other involved employees. Part of the task is to find where the information can be found and then to route it to the engineers. The company developed a tool based on the FMECA methodology to be used for analysis. As the RAMS requirements are evaluated in design, the engineers responsible for the design are also given the responsibility to evaluate individual RAMS and maintenance needs related to the components, subsystems, etc. The tool is also used in project meetings to evaluate progress and status. Furthermore, a Stage Gate Model is used to control the design and manufacturing process. See Papers II, III and IV for further details.

Typical support activities and processes found in design and manufacturing processes includes:

- RAMS integration activities (RAMS coordination, activity planning, accommodation of tools/methods, RAMS philosophy training, etc.)
- Risk analysis and risk reduction activities (financial risk, technical risk, risk related to time, design risks such as specification implications)
- Quality assurance activities (quality control, quality assurance routines and integration, supplier quality assurance programs, etc.)
- Finance and administration activities (finance planning and management, economic analysis and reporting, functional management, etc.)

- Stage Gate Model for project planning and control (project tools, project review documents, procedures, routines, checklists, etc.)
- Communication activities between parties involved (E-mail, Internet, meetings, telephone conferences, etc.)
- Information systems (customer feedback, product data, ERP (enterprise resource planning) system, customer help-lines, product documentation, etc.)

Figure 10 shows sequential and parallel activities in a typical product delivery process such as that observed in the case study.

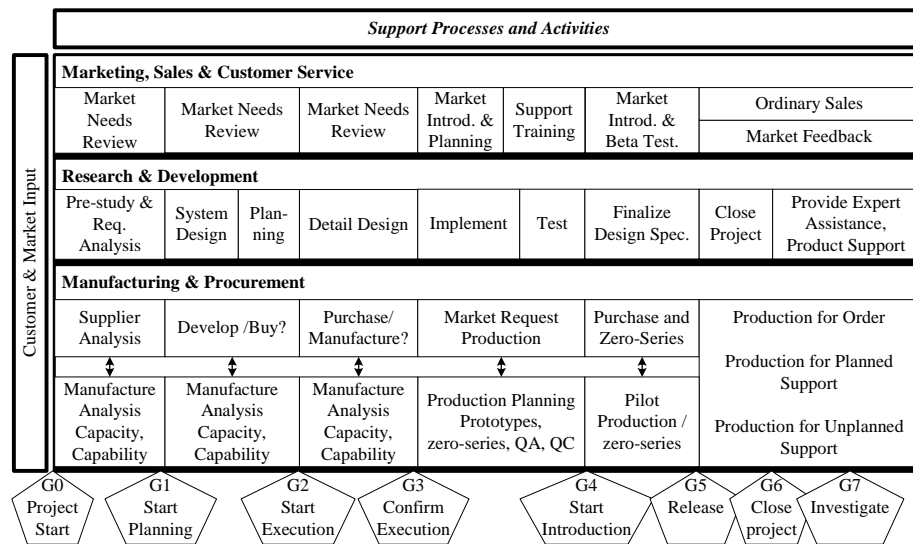


Figure 10: Typical concurrent product development process including Stage Gate process control (The symbols G0, G1, etc. refer to project “gates” as used in the “Stage Gate Model”. See Paper II for further details and references)

### 3.2.5 Motivation and Attitude Improvement

Work processes are heavily influenced by people, their motivation and attitudes. Management of risk and risk avoidance is therefore dependent on the organization’s capability to create positive attitudes and to motivate employees to perform their work according to established procedures and routines. Policies, procedures, routines, and guidelines are in place to control the work processes and to reduce risks associated with the processes.

### **3.2.6 Integration of RAMS and LCC in Design Processes**

It is very important that formal reliability and risk assessment form an integral part of the system design process where engineers from Operations and the designers decide the structure of the system, examine various alternatives and evaluate their possible impacts in terms of availability and system outage in operation phase (Baker et al., 1996). Furthermore, during the operation phase savings can be realized due to fewer breakdowns / stoppages causing major economic consequences. The idea of integrating maintenance either through '*designing out maintenance*' by enhancement of reliability or '*designing the system for easy and cost efficient maintenance*' through better RAMS characteristics at design board stage, is gaining momentum and many companies are adopting this approach to reduce the life cycle costs of their product. Manufacturing companies can gain a lot from improving the design process by integrating '*the maintenance need analysis*' at design board stage.

Analysis of failure development, processes, and mechanisms, the corresponding effects and subsequent methods to eliminate the failure, is addressed in Paper I. In addition, concepts for integration of information technology and diagnosability are addressed. Other issues, such as '*design for manufacturability*', which has an important bearing on future maintenance costs, are examined as well. Paper II discusses integration of RAMS tools and methods in a dynamic design process based on a case study of advanced industrial products. The company applies a design tool based on standard FMECA methodology in parallel with other project tools to improve both products and work processes.

### **3.2.7 Design for Customer Satisfaction and Quality**

As mentioned earlier, reliability characteristics have to be designed into the product. As in later life cycle phases, reliability can only worsen. Quality assurance and control are in place to make sure the product is designed according to specifications and no waste is produced. In each life cycle phase, there are opportunities for reducing the reliability. In the construction and/or manufacturing phase, the reliability can be reduced by not conforming to specification, in the installation and commissioning phase it can be reduced by not being installed, calibrated, or adjusted correctly. In the exploitation phase, reliability can be reduced by not operating the product or performing the maintenance correctly, or simply using the product other ways than intended or by overloading it.

If the customers are satisfied with the physical product purchased and the processes involved with acquiring and supporting the product (product specification, installation, support), they may consider buying more products from the same manufacturer/ supplier. Hence, customer satisfaction is related to both product and support quality. Customers' perception of product quality is affected by how well the product conforms to specification and fits for intended use as well as by product reliability over time (Juran and Blanton, 1999). However, quality is also related to the

level of performance of the processes producing, operating, and supporting the product throughout the service life. Since most products need some kind of maintenance and product support, customer satisfaction is also affected by product characteristics such as maintainability, supportability, and product support, and by the processes involved in providing product support. Customers are becoming sensitive to the quality of not only services provided but also how they are delivered.

### 3.2.8 RAMS Information Integration in Design Processes

The manufacturer is interested in learning as much as possible from existing products in use and to apply that knowledge to improve their products, as well as both product and customer support. An effective communication process between the manufacturer and customer may benefit the customer as well through improved spare part supply, improved documentation, improved support, etc.

Figure 11 depicts a generalized information flow system for RAMS information. However, the problem is often that in a company there are many systems used for information storage and flow. The product information is often stored in advanced databases, but many of the databases are not accessible to the design engineer or the design engineer does not know that the information exists in the company. Often the information is collected and stored by users and intermediaries, but not routed back to the engineers who can use it to improve the products or the design process activities. In the company studied almost 20 information sources were found which contained information related to the products and which could be used for product or process improvements. Many of them were not easily available for the design engineer. See Paper III for further details.

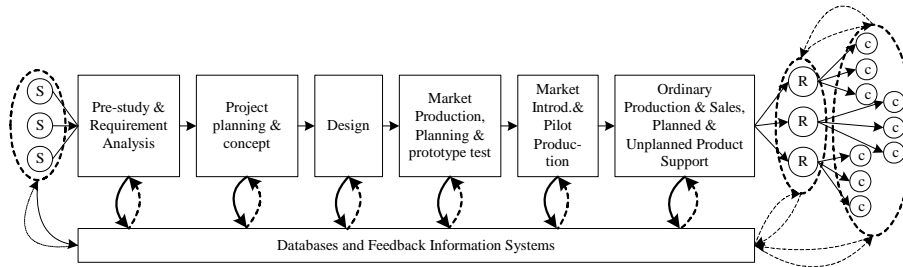


Figure 11: Flow of Product Related Information  
(S: supplier, R: regional office, C: industrial customer)

For the manufacturer it is not enough analyze the product characteristics and to implement RAMS in design. While dimensioning service strategies to support the product as well as customer, designers also have to analyze the company's own service delivery capability and the maintenance and service organization at the user's



end. This will help the manufacturer design the right support. As mentioned in the preceding section, this necessitates that manufacturing companies should analyze and understand their 'customer' before adopting any strategy for service delivery.

### 3.3 Enhancement of Product Performance

In the product exploitation phase, the ownership costs can be reduced by reducing operational and maintenance costs. Costs can also be reduced by using and maintaining the product according to the design specification, by training of operators and maintainers, by providing better documentation, by improving operational and maintenance strategies, and not least, by improving the after sales services from manufacturers.

Losses in product utilization time can be caused by not being able to take full advantage of the product's designed in capabilities and capacities, and by inadequate operation, maintenance, and support strategies. Reduced capacity and reduced output quality result in extra time needed to produce the lost output and in lost profit because the output quality is substandard, resulting in lower prices, and in the worst case, extra time for reproducing the product output at a satisfactory quality. This lost time could have been used for producing high quality products as fast as the market is able to receive them. A non-optimized maintenance and support strategy could cause the equipment to be unready when needed, or that the output is of reduced quality. Inefficient and ineffective maintenance support strategies may also result in increased costs. This results in potential profit loss. If the product is used for producing different kinds of output, it may have to be adjusted or calibrated before use. In this scenario there is time spent for ramping-up the production and switching between the different outputs. Inefficiency in switch-over and ramp-up production can result in time and profit loss.

#### 3.3.1 *Product Performance Utilization versus Time*

When a product is new to the owner, time is spent learning to use, operate and maintain it. As a result, it takes time for the customer to learn how to take advantage of the full capabilities and capacities they purchased. The customer therefore may become disappointed in respect to expected product performance. The result could be reduced customer satisfaction. The manufacturer could provide better training and documentation to compensate and enhance performance utilization. The customer should be able to utilize all of the product's capacities, and capabilities as soon as possible after receiving the product. The effect of enhanced performance because of improved training and utilization is shown in Figure 12. The area between the curves can be conceived as losses in LCP. Confer also Paper V.

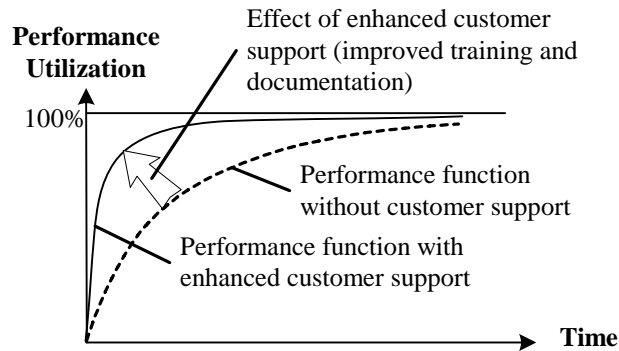


Figure 12: Product Exploitation Enhancement

### 3.3.2 Conventional versus Functional Product

An industrial customer is primarily interested in the benefits the product can generate in a production process, not the product itself. However, since maintenance and support needs can seldom be designed out of products, the product owner must have systems in place to do what is necessary to make sure the product will perform according to needs. These processes should make sure the product delivers the performance and generates as much profit as possible at lowest cost. In a conventional product scenario, the customer buys a product, operates and maintains it, as well as having a logistic support system in place for spare parts, maintenance tools, etc. The manufacturer designs, makes, and provides spare parts, expert assistance and other traditional after-sales services. The interface is between the manufacturer's after-sales department and the customer's maintenance department. The manufacturer generates profit from selling the product as well as the after-sales services. For the design engineers it is often difficult to obtain information from product exploitation. Experiences from using the product are stored at customer sites or even in the after-sales department, and therefore needs to travel further before reaching the design engineers.

Alternatively, the customer can choose to purchase only the performance (functional product). This is an advanced sort of outsourcing, now becoming an interesting alternative for many companies. In this functional product scenario, the manufacturer is responsible for designing, making, using, maintaining, supporting, as well as owning the product. The interface now is directly between the manufacturer's service delivery department and the customer's process owner. The need for support becomes a cost and liability for the manufacturer. Furthermore, since the customer will only pay for the performance, it is important for the manufacturer to reduce all costs and losses to gain maximum benefit from the relationship. See Paper V for further discussion.

### 3.3.3 Relationship between Design, Exploitation, and Services Work Processes

The processes involved in creating a product are closely interconnected with the processes to exploit it, as well as to the compensating service processes as shown in Figure 13.

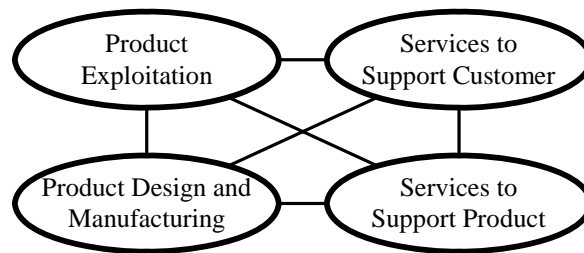


Figure 13: Relationship between product design and manufacturing, product exploitation and service processes.

In the design process the products characteristics are decided (hopefully together with the customer) and implemented in the manufacturing process. If the product cannot be made maintenance-free, product support will be needed. The product characteristics influence what type and how much support is needed. However, the need for product support is also influenced by type of application (or how the product is exploited) (e.g. operational environment, operator's skills, capacity utilization, operation and maintenance strategy, uptime requirements, etc.). Some degree of basic product support all customers require – dependent on how they treat and use their product, but also dependent on availability of support from manufacturer or third party. Moreover, dependent on needs and preferences, the customer may need extra support from the manufacturer to enhance the system/equipment/machine/plant operational or utilization performance. Consequently, the characteristics of the product, the customer, and the manufacturer strongly influence each other. Together they decide the product's total performance (see Paper V for further discussion). Hence, the delivery of services to support the product should be considered and negotiated in the design process.

## 3.4 Negotiation of Product Support and Service Delivery

Successful negotiation can create additional values for both parties. To negotiate successfully both parties need to be aware of the parameters that can influence the service delivery agreement. Such factors include planned and unplanned, tangible and intangible, and so on. Furthermore, other factors such as geographical location,

cultural influences, communication and interfaces, and so on, need to be considered. (For further details, see Paper VI.)

To make the negotiation process easier it may be beneficial to classify the services in more detail. Services and support that are not normally included in the order can be denominated explicit services. Typical examples of explicit services include special training during commissioning or use phase, modifications of equipment, performance evaluations, and so on. Expert assistance in diagnosing failures can be an example of implicit services that the customer often believes to be free and included in the original purchase agreement. This may however not always be the case, as it may be time consuming and costly for the manufacturer to supply these services. In the consumer market, the manufacturer may supply telephone assistance at expensive rates. However, both implicit and explicit services need to be discussed and defined in the initial life-cycle phase to avoid confusion and uncertainty over what is agreed upon in the contract. As mentioned above, the customer is interested in the total product performance including services that may or may not be needed (dependent on the type of customer). Examples of service classification are shown in Table 1.

*Table 1: Example of service categorization*

Category	Description
Implicit	Services the customer assumes are included in the original purchase agreement and which he does not expect to pay for
Explicit	Services explicitly defined as included, or not included in the original delivery agreement. It is clearly indicated in the agreement which services are included in the original delivery and which the customer should pay extra for.
Tangible	Services containing tangible elements (e.g. spare and warranty parts, use and maintenance documentation, training course documentation, etc.)
Intangible	Service content is mostly intangible (e.g. knowledge based expert assistance, telephone support, online support, advice, etc.)
Reactive/ corrective/ unplanned	Services needed as a result of a failure or changed perspective (e.g. corrective maintenance, modifications, upgrade, etc.)
Proactive/ preventive/ planned	Services based on weaknesses in product, in customer's skills/capabilities/resources, or in customer's wants/ needs/ preferences
Improvement of physical functional product	Improvement based on technological development or design errors, modernization of product, modification, product upgrade kits, etc.
Improvement of product capabilities	Modifications of product to reflect changed needs in, for example, capacity and/or capability, improvement of operational and maintenance strategy, improvement of operator's knowledge and capabilities, etc.
Unavoidable	Service cannot be avoided because the problem cannot be designed out of the product. Often referred to as product support/ support/ after sales service/ customer support
Avoidable	Optional services dependent on customer's needs/wants/preferences and capabilities/resources, etc. Often referred to as optional service/ consulting service/ professional service / supplementary service

Product support, and especially unplanned support, is a recovery process where the manufacturer, or third party, is attempting to recover the customer satisfaction after a product failure. Product reliability and service reliability are two different issues which are interrelated and which have influence on product availability. If the product reliability is according to what is designed into the product and according to predicted patterns/behavior, the maintenance and operational performance will follow predicted patterns.

Since product owners may need various kinds of services, performance and support for the various products throughout their service life, they need to have in place a strategy for which services may be received and how to receive them. Each owner therefore needs to develop a service reception strategy which will be closely linked to the maintenance strategy and concepts employed. The service reception strategy is further dependent on the kind of support to be received, such as planned and unplanned support, tangible or intangible support, support intended to support the product, and support intended to support the product owner's application of the product.

#### ***3.4.1 Service Reception Strategy versus Service Delivery Strategy***

Since the manufacturer's customers have various skills and capabilities the manufacturer needs to have in place a general service delivery strategy directed at all customers and a special service delivery strategy that fits the needs, demands, and requirements of individual customers. In addition, the product owner needs to have in place both a general and specific service reception strategy dependent of the kind of products it encompasses. Some products are more critical and complex and therefore need more maintenance and support. For these products, a specific strategy has to be developed. The service delivery strategy and service reception strategy is depicted in Figure 14.

The manufacturer's service delivery strategy needs to be closely aligned with the product owner's service reception strategy. If not, gaps between expected services and delivered services will develop because the supplier's service delivery will be perceived as insufficient (see Kumar and Kumar, 2003). This can lead to dissatisfaction for all parties involved (see Figure 15). The gaps between the various components will lead to gaps between the two strategies. The consequence could be a less than optimal relationship between the parties involved and a reduced possibility for creating a win-win situation.

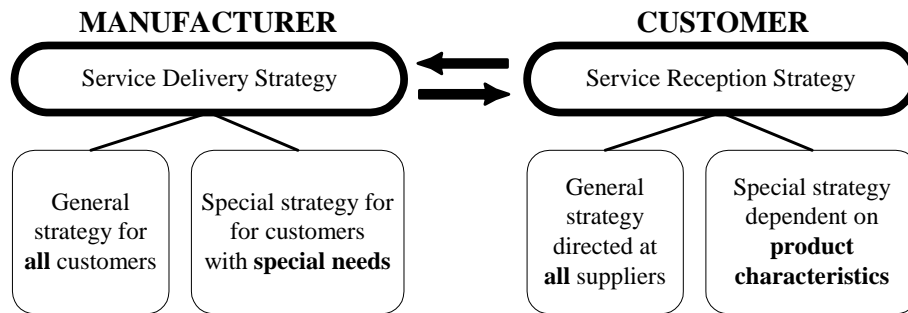


Figure 14: Service delivery strategy and service reception strategy

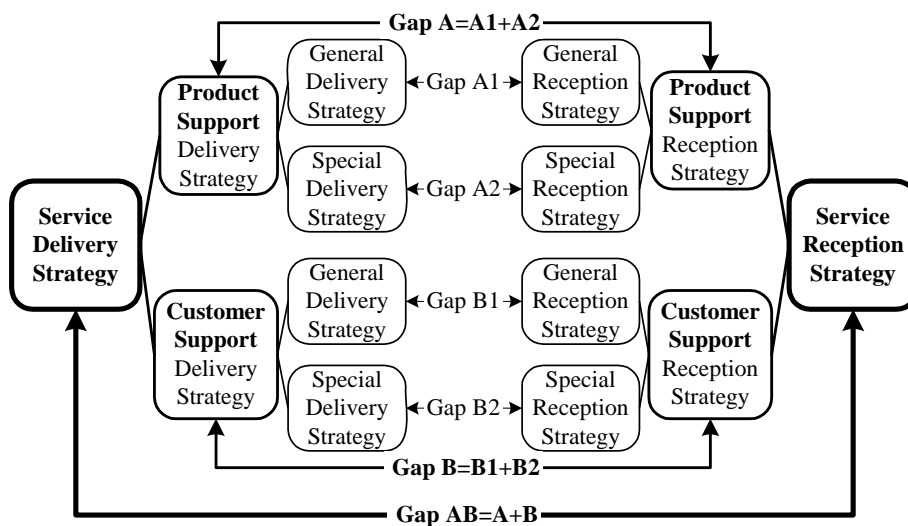


Figure 15: Service strategy gaps

The service reception strategy therefore has to be closely linked towards the various service delivery strategies of the manufacturers providing the support. To avoid conflicts and risk later in the exploitation phase, the service delivery strategy should be discussed and negotiated during the design process. Furthermore, the negotiation process should consider how to measure performance of the services delivered to enhance business opportunities. See also Paper VI.

### 3.4.2 *Performance Measurement*

The purpose of understanding, mapping, and controlling processes in a value chain or in a physical process (production line, plant, etc.) and how they affect the process output is to reduce the business risk. Business risks can be related to internal processes related to production of the output or organization, to external processes related to customer and market, to society in general, and so on. To assess this risk one is dependent on information gathered from experiences, knowledge about the process' input and output, and the process itself. To measure the process performance and to be able to compare the performance on a time basis, and a performance measurement system needs to be in place. See also Papers IV, V and VI. (In addition Papers IX and X discusses performance measurement systems). Such a performance measurement system needs to be able to measure the effectiveness and efficiency of internal and external processes and relate the process output to business values and goals (Liyanage and Kumar, 2003). Furthermore, information, data, experience, and expert knowledge is central in risk analysis. When attempting to improve a product and related processes, as well as to control processes, one is, in reality, attempting to reduce risk. Information therefore needs to be collected in a controlled and systematic way based on need and use. Furthermore, there must be a direct use and flow of information to the employees/sources performing the processes, where the information is to be used. See also Papers I and II.

## 3.5 Summary of Appended Papers

A brief summary of the published papers is given here with additional comments with respect to issues, opportunities, challenges, and practical implications.

Paper I discusses design alternatives with respect to product support, maintenance, and operations. Design with respect to RAMS characteristics are discussed with emphasis on costs and benefits. Available RAMS and risk analysis tools and methods are examined with respect life cycle costs and benefits. It is argued that integration of such tools and methods in the design phase in parallel to training of design engineers have the potential to reduce investment costs and lead-time, reduce ownership costs and increase product service life. The basis for this argument is the belief that costly and time consuming iterative work, normally identified and performed in the later stages of design, can be identified and addressed at a much earlier point in the process. This should therefore reduce the amount of rework and redesign. The normal belief is that the design with respect to maintenance and RAMS would cost more and increase lead-time for the manufacturer and only benefit the customer. In this paper, furthermore, design for diagnosability, modification, manufacturing, and human factors are discussed. We emphasize that tools, methods and necessary data need to be made easily accessible for the design engineers to succeed in reducing lead-time and costs. Testing and use of advances in information and communication technology are

also emphasized as important issues this respect. The paper provided the conceptual basis for the case study.

Paper II reports and discusses observations from the case study with respect to integration of RAMS in design. The concept of functional products describes the relationship between product characteristics, product support, and product application were considered. Product characteristics and the type of product utilization (use environment, operational and maintenance skills, use location, etc.) have a major influence on the need for product support. The paper suggests a model for a dynamic design process combined with the Stage Gate model and integrated information systems, RAMS coordination and support, Risk analysis, etc. It is as well important to identify RAMS activities and to include them in the Stage Gate model reviews. Moreover, we emphasize that the work processes are interrelated and should be started as early as possible and also include participants from later stage processes at the early design stages. Furthermore, training of employees with respect to design for maintenance philosophy along with training in use of RAMS tools and methods are discussed. Awareness creating efforts and training with respect to product and process improvements are also discussed. Motivation and attitude, as well as understanding of the importance of the issues involved is highlighted as important issues for succeeding in the efforts of providing customers with better products and support and to making the customers more satisfied. RAMS information need to be systematically collected and RAMS tools need to be made available for the engineers performing the design. This, we believe, should help reducing problems in the later stages of the product design processes.

Paper III emphasizes the need for data/information collection and discusses RAMS information integration in the design phase based on the case study. Data with respect to failure repair time, logistics waiting time, time between failures, etc., form the basis for reliability, maintainability, and product support statistics. Information about product performance and operational and maintenance practices are also important. The study indicates that there often exists an abundant amount of RAMS data and information that can be used to improve products as well as the processes involved in designing, manufacturing, assembling, testing, delivering, installing, and supporting the products. The problem is often that the information is not collected systematically, that it exists in many locations and databases/information systems, that it often exists qualitative formats, and that it is not routed to the personnel that could use it. The paper describes how the company studied attempts to identify, route, and integrate the information in the design process. Furthermore, it discusses the importance of coordinating the efforts of improving the products and associated work processes. The company's "RAMS information circulation systems" exemplifies how data and information is identified and routed to the engineers, used in a tool based on the FMECA methodology to improve their products RAMS characteristics, to serve as a basis for a simplified LCC analysis, recommended preventive maintenance,



product spare parts, and product support. The system is still under development and has many opportunities for improvements. The information could also be used to improve documentation, testing procedures, and to serve as guidance for deciding warranty strategies, maintenance, as well as product modifications and upgrading. Since the data and information identified in the study were located in many information sources/databases, we identified a need for integrating the information sources, and for making the sources accessible for the users. Furthermore, the company needs to collect information more systematically and to become more specific about what type of information is needed and in which format. Specifically in the company studied, we identified a need for integrating the information and data used in the FMECA tool with the ERP (Enterprise Resource Planning), PDM (Product Data Management), TQS (Total Quality Statistics), and the various customer feedback systems, to easier facilitate updating of information as the product components and subsystems are updated. This would also improve the analysis with respect to life cycle costs, and information flow with respect to customers, regional offices, and sub-suppliers. Since the company's regional offices often serve as main interface between the manufacturer and customer, much information existing at regional offices rarely is routed back to the manufacturer. Many customers also have extensive maintenance records either in hard copy or in CMMS (Computerized Maintenance Management Systems) systems. Much data and information stored in these systems is seldom or never fed back to the product manufacturers. Furthermore, since the company uses many sub-suppliers to manufacture parts and components, information related to product and work process improvements need to be better distributed to them too according to specified needs.

Paper IV discusses design and development of product support and maintenance concepts for industrial systems. The observations in the case study indicate that the manufacturer provides assistance to their customers throughout the products' service life. Support provided relate to 'hard' products such as spare parts, documentation, maintenance tools, etc. in the installation, commissioning, exploitation, and end of service life phase. Product support related to 'soft' issues are provided during the needs specification phase (e.g. advice in connection to specification of requirements, configuration, and interface with upstream and downstream systems), during installation and commissioning phase (e.g. configuration and testing assistance, clarification of documentations and testing procedures, routines, and guidelines), during exploitation phase (e.g. assistance in development of maintenance strategies, product diagnostics and repair, training of operations and maintenance personnel, product modification and upgrading, productivity and performance assessments, etc.), and during the end of service life phase (e.g. expert assistance related to disassembly, tools, recycling, removal, etc.). In the paper we classify support activities as services and thereby create a link to the service industry literature. Many of the services identified were by the company described as 'fire fighting' efforts/activities to resolve problems. This indicates that many of the services are reactive and the result of

'something gone wrong', and not proactive. Moreover, it indicates that it is a 'restoration of customer satisfaction' process, implying that it has an impact on market goodwill as well as customer satisfaction. The product that the customer buys is more than the 'hard' products, but also the compensating services related to product weaknesses as well as customers' skills, knowledge, preferences, etc. Maintenance and support issues are furthermore discussed with respect to possible improvements in the pre-exploitation and exploitation life cycle phases. The paper relates all these services, or support issues and activities, to characteristics related to the products as well to the customers. The service needs are therefore strongly connected to the activities during design and to the RAMS properties implemented in the product and the needs identified in the customer needs specification phase. Furthermore, supplying functional products in a 'functional product'/'delivery of performance' perspective where the customer only pay for the performance and the manufacturer owns the product and take full responsibility for operations, maintenance, support, and removal is introduced as an alternative. This has implications both for design, information feedback to manufacturers, product support, as well as for the customers who in reality first of all is interested in the function the product provide, not the product itself.

Paper V continues the discussions introduced in Paper IV about product support based on a case study in the same company. The company basically supplies/provides services in a conventional view of product and after sales service delivery. Based on the observations the concept of 'delivery of performance' is discussed in a life cycle costs and profit perspective. A product's functional performance is normally assessed with respect to functional, HSE (Health, Safety, and Environment), and economic criteria. Profits can be increased by reducing costs, enhancing performance, and/or extending a product's service life. Often it is found that the product owners are not able to take the full advantage of the products they have bought due to inability to use it correctly (i.e. according to specification), wrong use, wrong specification, etc. Moreover, one often finds that the requirements with respect to functional capability changes with time. Product owners therefore may need services to support the operations and maintenance of the products, to identify cost drivers and performance killers, to identify needs for capability modification/ upgrading, as discussed in the paper. Due to design constraints such as costs, state of the art of technology, etc. the need for maintenance often proves impossible to design out from the products. Product support therefore is needed to compensate for weaknesses. However, since a manufacturer profits from selling spare parts, after sales services, the incentives to improve the product with respect to maximizing customer's ownership profits are weak as long the product is not worse than competitors. If for example, spare parts were not needed, there would be no income from spare part sale. Income of spare parts depends in amount of spare parts and time duration. If the product needs reasonable amount of spare parts over for example 10 years, the sale of spare parts would provide a stable income, which is partly independent of market fluctuations

with respect to the manufacturer's products. However, if the customer is only buying the performance that the product delivers, and the manufacturer makes, owns, operates, maintains and support the product performing the function, profits and advantages the product provides would be as a result of its functional performance. The manufacturer would in this case not profit from services to support the product or to support the customer. Actually, the need for maintenance and product support would become a liability, cost, and an incentive to improve the product as well as all associated processes. By comparing conventional and functional products the paper identifies differences with respect to product ownership, product characteristics, customer/ manufacturer interface in the exploitation phase, process effectiveness and efficiency, profit generation, price, and service negotiation. The paper furthermore briefly discusses the concept of service delivery strategy and service reception strategy. The service delivery strategy necessarily must be related to characteristics describing the products as well as the customers. Similarly, the customer's reception strategy has to be developed with respect to their goals, capabilities, needs, and preferences. To avoid gaps leading to dissatisfaction, the service delivery strategy has to be aligned with the service reception strategy.

In Paper VI the service delivery agreements in a multinational environment are discussed with respect to negotiation. To develop a long-term relationship with the customer, gaps between what is needed, what is agreed upon, and what is actual delivered needs to be mapped and avoided. Product support can be divided into planned and unplanned support. Planned and unplanned support can for example be related to proactive and corrective maintenance. However, in the service delivery agreement also contingencies with respect how one is to go about to deal with situations that are unpredictable and unknowable at the time of negotiation need to be included. In a negotiation processes a successful long-term relationship and customer satisfaction is dependent on careful mapping of negotiation parameters such as customer's needs, product characteristics, user environment characteristics, types of services needed, future modifications, etc. Furthermore, to avoid agreement failures and conflicts, one need to make sure the input information and specification is correct. Some of the parameters that may influence the service delivery process are customer's requirements, geographical location/ infrastructure, customer's level of competence, cultural influences, as well as the interface between the customer and the service delivery organization. It therefore is important to consider these factors in the negotiation process. As product support needs are influenced by a products design characteristics, it is recommended that the negotiation process to be performed as early as possible in the design process. To further avoid gaps service agreement implementation, it needs to be followed up through monitoring according to some agreed upon criteria. These criteria also need to be considered and agreed upon during the negotiation process.

While addressing the objectives, the papers also makes an attempt to provide some form of understanding regarding issues, challenges, and opportunities related to dimensioning of product support in a holistic life cycle perspective.

## 4 Research Contributions

This doctoral study focused on dimensioning of product support for industrial products and presented an approach for dimensioning of product support in design stage based on a case study. Basic concepts of maintenance and support have been examined on the background of the research objectives and a case study. Issues, as well as challenges and opportunities related to dimensioning of product support are examined at depth.

Based on this research work, it can be concluded that it is essential to integrate RAMS issues early into design work processes to arrive at the best possible cost effective product support strategy for industrial products. This can be improved if RAMS information databases are integrated with design databases and other information sources. However, the RAMS integration process in design is not easy, mainly due to unavailability of customer field data and work process complexities. Surprisingly it was found that very few design databases are integrated with customers' and product failure reporting databases, thus making it difficult to arrive at the best design alternative from a product support point of view.

Furthermore, during the course of study we found that it is not enough to focus on services to support the product alone. Services to support the customers are equally important.

For the first time, to the best of our knowledge, the issues related to product support for 'functional products' is examined. Based on the study, we conclude that the strategy for the product support for functional products must be different from that of a conventional product.

We have also attempted to map issues that would influence service negotiation process, and conclude that a successful service negotiation process can create additional value for all parties. Furthermore we emphasize "the role of a service reception strategy (SRS)", a concept introduced during the course of this study. It is advocated that both the service provider and service receiver will gain immensely if

the customer has a service reception strategy. It is advocated that the existence of a SRS can create additional value for all parties.

## 5 Suggestions for Further Research

The area of product support is expanding quickly. In this study we have only explored and examined a few engineering parameters that directly affect the dimensioning product support. While considering product support issues, we have not made any quantitative analysis using operating environment, nor have we considered the impact of customers' organizational culture. While developing product support strategies, the operational environment and organizational culture must be considered to arrive at the best product support. This becomes especially crucial for manufacturers of industrial products as customers increasingly evaluate a supplier's support services to differentiate between suppliers of physical products equal in price, capability, and quality.

Moreover, it is not enough to consider product support strategy alone. One also has to focus on delivery and reception of services to arrive at the best possible performance for the individual customer in a multi-national environment. Factors affecting service delivery and reception therefore need to be studied in more depth.

Issues related to and implications of delivery of functional products, delivery of performance, and advanced outsourcing need to be studied in more depth. Furthermore, the issues of product support for consumer products when customer buys only the performance have to be analyzed as well.

Advancements in communication and information technology have opened up new avenues for performance surveillance. These, combined with advancements in sensor technology and expert systems, make it possible to remotely monitor performance and have real-time access to systems. This opens up interesting possibilities to reduce costs and time, and to increase effectiveness of product support during product installation and commissioning, exploitation, maintenance and support, as well as during the end-of product service life phase. Performance or diagnostics information also can be fed directly to the engineers at the drawing table.

In summary, based on the research conducted we find the following areas suitable for further research and development:

- Study of the impact of operating environment on the RAMS characteristics for the dimensioning of product support.
- Study of the impact of geographical location for the dimensioning of product support.
- Study the implications and effect of delivery of performance for industrial products and advanced outsourcing scenarios.
- Study opportunities and implications of delivery of performance for consumer products and associated product support issues.
- Study of the use of the service negotiation process as an engineering tool to improve engineering design.
- Study the possibilities for remote product monitoring and surveillance (including inspections) for performance prognostics and diagnostics, development of advanced communication and internet use to enhance operations, maintenance, and support using virtual product care centers.
- Study and analysis of organizational issues related to network and partnering with local agents/service providers to arrive at the best service delivery strategy at the lowest cost.



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# List of Papers

- Paper I Markeset, T. and Kumar, U. (2001). “R&M and Risk Analysis Tools in Product Design to Reduce Life-Cycle Cost and Improve Product Attractiveness”, In: *Proceedings of The Annual Reliability & Maintainability Symposium*, Jan 22-25, Philadelphia, USA: 116-122.
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- Paper VI Kumar, R., Markeset, T. and Kumar, U. (2003). “Negotiation of Product Support and Service Delivery Agreements in a Multinational Environment”.  
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- Paper IX Liyanage, J.P., Markeset, T. and Kumar, U. (2001). "On the Knowledge Driven Performance Management Grounded in Process Intelligence: with Applications to Asset Maintenance and Product Development", *IMSIO2: 2<sup>nd</sup> Conference on Intelligent Management System in Operations*, July 3-4, Salford, UK.
- Paper X Liyanage, J.P., Markeset, T., Kørte, J. and Kumar, U. (2001). "Value & Risk: A balanced Performance Assessment Criterion for Maintenance in Offshore Engineering Constructions", *The 11<sup>th</sup> International Offshore & Polar Engineering Conference (ISOPE-2001)*, International Society of Offshore and Polar Engineers (ISOPE), June 18-22, Stavanger, Norway.
- Paper XI Markeset, T., Kumar, R. and Kumar, U. (2003). "Trends in Product Support and Service Delivery Strategy for Mining Industry", *Accepted to The Geomintech Symposium on "New Equipment – New Technology, Management and Safety" in Mining and Mineral Based Industries*, 11-12 May, Bhubaneswar, India.



## Part II



# **PAPER I**

## **R&M and Risk-Analysis Tools in Product Design, to Reduce Life-Cycle Cost and Improve Attractiveness**

In: Proceedings of The Annual Reliability & Maintainability Symposium  
(RAMS2001), Jan 22-25, 2001, Philadelphia, Pennsylvania, USA: 116-122



# R&M and Risk-Analysis Tools in Product Design, to Reduce Life-Cycle Cost and Improve Attractiveness

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## SUMMARY AND CONCLUSIONS

While designing a product, one has the choice of either to design out maintenance or from a maintenance point of view to design for maintenance. Often when using the “design out maintenance” approach, which is greatly influenced by reliability characteristics, the costs turn out to be either very high, or it is impossible due to technological limitations of the product and related issues. Products therefore need to be designed for easy and cost effective maintenance. While adopting the “design for maintenance” approach one again has to consider reliability characteristics in conjunction with maintainability issues to balance the costs and benefits. Thus, the need to evaluate reliability and maintainability (R&M) issues in the design phase of a product is becoming critical for market competitiveness.

In this paper, the application of reliability, maintainability and risk analysis tools and methods to minimize life cycle cost of the system and to improve product attractiveness, will be discussed. The incorporation of R&M issues in the design phase will be examined and analyzed.

Furthermore, many product failures can be traced back to design engineers' inability to foresee problems that occur later in product life. The necessity of engineering training for integration of R&M considerations in the design phase, and for approaches for making provisions to incorporate new information technologies to facilitate easy learning and understanding will be discussed. The paper will also address the use of information technology for making R&M information, tools, and methods readily available to the designer at the working desk in order to ease the task of making R&M decisions.

*Keywords:* Reliability, Maintainability, Risk analysis, LCC, Design for maintenance, Design out maintenance, Product attractiveness, Engineering training, Customer needs, System engineering

## 1 INTRODUCTION & BACKGROUND

### 1.1 *The Customer's Needs, Requirements and Preferences*

Product quality is more than just conformance to customer requirements. The customer chooses the product that offers the best value per unit of price. It is, therefore, important to identify customer values to be able to improve shortfalls in product performance and to quantify the shortfalls. The customer values of a product can be divided into product performance, product service and product durability (Ref. 1).

System engineering approach is an effective approach to incorporate customer's specification. It is a top-down approach to product development, viewing the system as a whole, focusing on customer's needs, wants, preferences, and requirements - starting with the functional requirements and the functional performance of the product. The needs and requirements of the customer are translated into system requirements, which are used to define the requirements for subsystems and components. At the end the component, sub system and system are designed (Refs. 2 & 3).

### 1.2 *The Design Process and LCC Analysis*

The designer's goal is a product that will achieve the expected performance level satisfying the customers while limiting the impact on manufacturing cost to an acceptable level. Often for a given design, the cost of manufacturing increases as the reliability and maintainability characteristics are improved, which, in turn, improve the product performance. The serious consideration of reliability, availability, maintainability and supportability (RAMS) characteristics of the products make a significant positive contribution to the achievement of economic life cycle costs (LCC), and helps in increasing product performance and its attractiveness. To achieve the best economic life cycle costs, often an LCC analysis, including analysis of reliability and maintainability characteristics, is performed in the early design stages of the product life cycle. The LCC analysis is an engineering and economical optimization technique where the main goal is to identify and choose the alternative that generates the highest revenue over lifetime, or in other words, generates the lower life cycle cost. LCC can be used in the design process to evaluate the product cost over the total life span. To obtain better results, LCC analysis should be combined with risk analysis. An LCC analysis that does not include risk analysis can be incomplete at best and misleading at worst (Ref. 4).

The product life time can be divided into 5 distinct phases: the need analysis & specification phase, the conceptual design & preliminary design phase, the detail



design & development phase, the construction, production, installation & commissioning phase, and finally the system use, support, phase out, decommissioning & disposal phase as shown in Figure 1. The initial design iteration starts with customer specifications and a need analysis that is converted into design specifications. From the design specifications, an iterative process starts in which one tries to come up with several design alternatives or concepts, out of which one alternative should be selected. If the chosen design fulfills the need and specifications, the next phases are preliminary design and then final design. In the conceptual design phase much of technology, configuration, performance and cost start to become committed – not much is committed in the need evaluation definition phase of a design process. The ease of change of a design decreases rapidly as the design progresses in time. The system specific knowledge is low in the conceptual phase, but increases quickly as the design progresses in time. Incurred cost also is low in the beginning of the life cycle, but increases rapidly in the detail design and manufacturing phases.

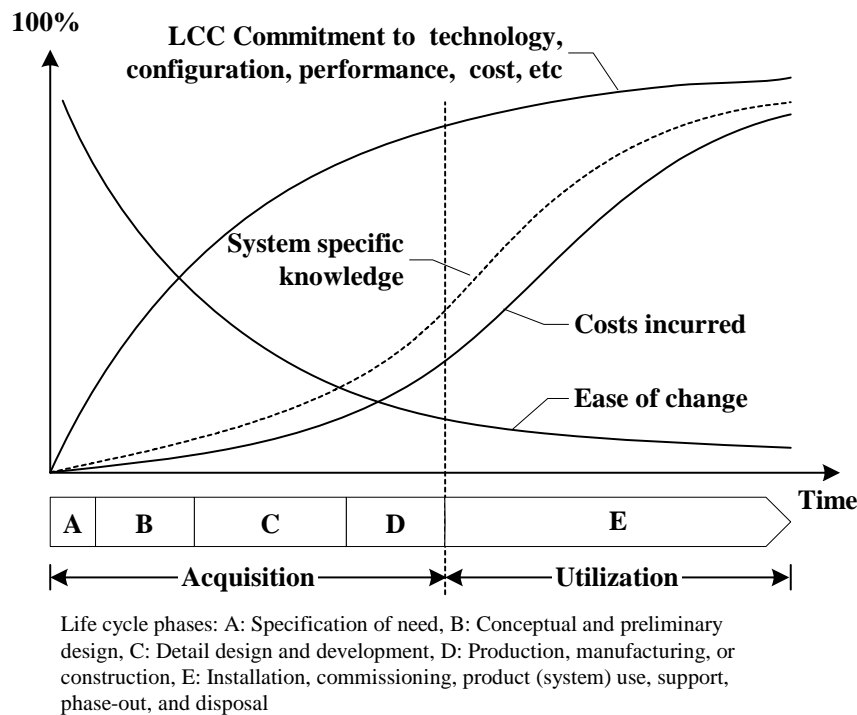


Figure 1: LCC committed, cost incurred, knowledge, and ease of change for various life cycle phases (adapted from Ref. 5).

Figure 1 also indicates that the earlier in the project maintainability and reliability is considered, the easier it is to change things because little is committed in terms of cost, technology, configuration and performance.

The life cycle span and related cost of a product can be illustrated as shown in Figure 2. The area depicted with a thick line, describe pre-exploitation costs and accumulated post-construction costs. If maintenance issues are being considered in the early phases of the product life cycle, the common belief is that the investment cost and the lead-time will increase, and the accumulated exploitation costs may be reduced at the same time as the product gain a longer life span. In general, inclusion of maintenance and reliability considerations in the design stages might not cause an increase in investment cost and lead-time, but rather a decrease, as shown in the figure by the dotted line (Ref. 6). If the maintainability and reliability issues are addressed early in the project, there will be fewer design iterations and design changes in the detail design stages, simply because issues are more thought through than they would be if not addressed. The costs and associated work needed to eliminate design flaws will be lower the earlier they are detected. In the car industry the rule of ten is used – the cost consequence of design changes caused by too low reliability performance increases tenfold by the end of each life cycle phase (Ref. 7).

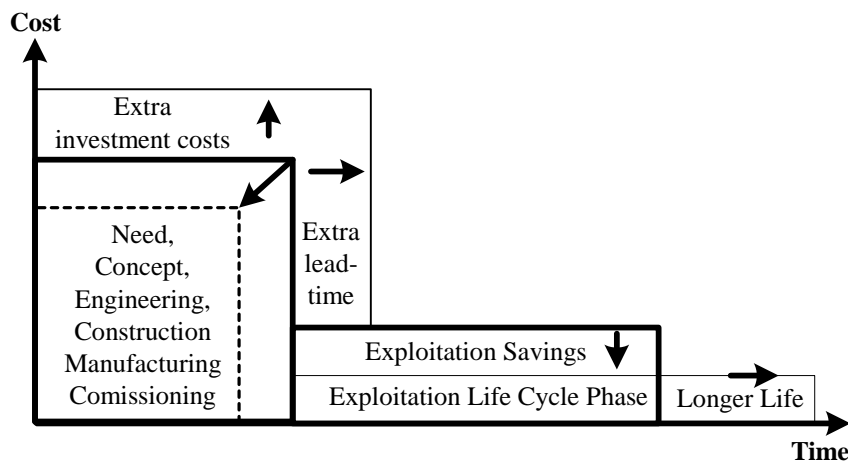


Figure 2: LCC with and without detail R&M considerations in design (adapted from Ref. 6)

Furthermore, the causes for maintenance and operation costs need to be studied in the initial phase of a project. By studying the operational and the environmental

characteristics, wear, tear, and degradation causes – cost drivers might be identified, studied, and evaluated. Corrective measures can be taken to avoid the induced maintenance costs by changing the design, choosing better material, removing rotating parts, choosing another design alternative, etc.

As mentioned earlier, the designer's goal is a product that will achieve an in-service reliability and maintainability level satisfying the customers while limiting the manufacturing costs to an acceptable level. Often for a given design, cost of manufacturing increases as reliability and maintainability characteristics are improved (Ref. 8). Thus to achieve the most economic life cycle cost, one has to analyze the R&M characteristics at the design stage and choose the best alternative that reduces the total costs. If one analyses the costs elements after acquiring of a system, one finds that the costs of maintaining a system are considerable. The specified customer's need at the most economic life cycle cost can be assured through an effective and efficient use of R&M tools and methods in combination with risk analysis methods. In this paper, we will be discussing the application of such tools in the design phase to improve the performance of the product and reduce the life cycle costs. Effective use of such tools is also expected to increase the product attractiveness to the customer.

## **2 SOME OF THE RAMS TOOLS, METHODS AND CONCEPTS**

Definition of failure acceptable performance level should be decided early in the design process. By mapping degradation mechanisms, work environment, common operational failure, and human errors, the design can be improved to increase maintenance characteristics affecting cost at a later stage in the life cycle. For new products, data and information may be missing or unavailable, but one still may be able to predict reliability and maintainability characteristics by comparing with similar systems, using experts and experience, and by using reliability and maintenance tools to analyze the system. The failure rate is very dependent on the quality of material used, manufacturing quality, maintenance philosophy, operational characteristics and profile, operator/maintenance personnel training, etc. The system may also be modified many times during its life cycle, which may affect the failure rate a great deal. RAMS analysis methods based on assumptions of various types of failure rates and mean times to repair and failure, should be employed with care because sometimes the assumptions may not be valid for the product analyzed.

Furthermore, one has to be clear about what the difference is between maintenance and maintainability. Maintenance is the act of repairing or servicing equipment, while maintainability is a design parameter intended to minimize repair time (Ref. 9). Maintainability refers, in other words, to the measures taken during

development, design and installation of a manufactured product that reduce the required maintenance, man-hours, tools, logistics costs, skill level, facilities, and ensure that the product meets the requirements for its intended use. Maintainability characteristics are considerably influenced by the level of reliability and availability to be achieved within a budget. Reliability can be defined as the probability that the equipment can perform continuously, without failure for a specific period when operated under stated conditions.

### *2.1 RAMS Tools and Methods*

Extensive literature exists which describes the philosophy behind design for maintainability and reliability, and many of the publications include various tools and methods for R&M analysis (see e.g. Refs. 2, 8, 9, 10, 11, 12, 13, 14, 15, 16 & 17).

Many of these tools and methods, for example, FMEA (Failure Mode and Effects Analysis), FMECA (Failure Mode, Effects and Criticality Analysis), FTA (Fault Tree Analysis), Failure Block Diagram Analysis, CCA (Cause Consequence Analysis), HAZOP (Hazardous Operability Analysis), used in RAMS analysis originate from the military, power plant, aircraft and space industry. By selecting the systems, which are critical with respect to R&M issues such as availability, maintenance, operation, production, and life cycle costs can be optimized. The methods can be made more effective and less time consuming by using computerized programs and trained personnel to conduct the analysis (Refs. 2, 17).

Reliability models are used throughout the design process to evaluate various design alternatives, and to help to visualize the system reliability. The analysis attempts to model the system and system functions using a block diagram. Individual quantitative measures can be assigned for each block to assess the system reliability quantitatively and to evaluate if the reliability objectives meet the overall system reliability. The method is time consuming, and can require much data input. However, using experts, experience, and comparing with similar systems/ components, the method can be used effectively to compare alternatives. Later on, as more data becomes available, the model can be improved (Refs. 2, 8, 10, 11, 12, 14 & 15).

The FMEA (and FMECA) method is simple to conduct and is effective, but the method can be very time consuming and is therefore used mostly for critical equipment. However, the method can be used effectively in the design evaluation if the study begins with the principal failure mode instead of on the most detailed level. By using engineering experience and FMEA, the most critical failure modes are identified, ranked, and required actions can be evaluated. The criticality is a function of the failure mode and the probability (Refs. 2, 8, 9, 10, 11, 12, 13, 14 & 15).

The Failure Mode and Maintenance Analysis (FMMA) is a method suggested for identifying areas of the design that should be especially considered where principal failure modes and repair actions are first identified and analyzed from a maintenance point of view. Suitable actions are thereafter taken to arrive at the best solutions. Preventive maintenance strategies such as condition monitoring or routine maintenance should be evaluated, even for later implementation if proven too costly at present (Ref. 11). If later implementation is an option, the product should be designed for preventive actions, e.g. by considering placement of sensors to measure bearing vibrations, temperature, pressure, flow rate, test point of for oil sampling, etc.

The fault tree analysis (FTA) is the most common analysis technique used in reliability and risk analyses. A fault tree is a logic diagram showing the connection between system failures (i.e. unwanted events in the system), subsystems, and components failures. Based on an initial event or failure mode, one attempts to identify the consequence of the event. The method is deductive and can be used in the early design stages to gain insight into critical aspect of various design alternatives if the data required to conduct an FMECA analysis is not available (Refs. 2, 9, 10, 11, 12, 14 & 15).

The hazard and operability (HAZOP) method is a systematic approach for identifying potential system weaknesses and dangers with respect to health, safety, and environment (HSE). Used in a multidisciplinary team setting, the method can be very effective. The team uses keywords in an attempt to identify scenarios that can result in dangerous situations or cause operational problems. The results should be documented and include a description of the situation, cause, consequence, and recommendations (Refs. 14 & 15).

The cause consequence analysis (CCA) is a general method that can be applied to a wide range of technical systems. CCA contains the event tree analysis method (ETA) as a special case. CCA combines cause analysis (described by fault trees) and consequence analysis and is both an inductive and deductive method. The starting point is an initiating event such as a technical failure or a human error, which brings the system out of equilibrium. The purpose of the analysis is to identify chains of events that can result in consequences of various kinds. If the probabilities of the events are known, the system reliability and risk can be calculated (Refs. 14 & 15).

There are methods that are used for systems and components that are dependent on physical factors such as: high voltage, temperature, strength, shocks, etc. Various stress-strength models are described in numerous references, (see e.g. Refs. 2, 11 & 17). These methods often involve advanced statistics and mathematics, and experts are usually needed to do the analysis. The methods are therefore only used for parts of larger systems that are critical to the product. Thompson suggests a method for finding the most reliable solution based on equal strength principle (Ref. 11).

## 2.2 Risk Analysis Methods

Risk analysis in general consists of answers to the following questions. What can go wrong that could lead to system failure? How likely is this to happen? If it happens, what are the consequences? Risk also expresses the danger that an unwanted event represents for humans, environment, and economical values. The risk of an unwanted event is often expressed by the event consequences and their respective probabilities for occurring (Ref. 14). Often the probability of detecting the occurrence of the unwanted event is also included in the risk analysis assessment. There is a strong correlation between cost, risk, and benefit; normally one can not reduce one of them without affecting the other two. A risk analysis based design approach provides insight into maintenance need from the perception stage to the disposal.

Risk analysis normally consists of the following steps:

- Identification of the undesirable event – failure mode and event analysis (FMEA/FMECA) can be used as an effective analysis tool.
- Identification of causes and likelihood of an event – for this step, often fault tree analysis (FTA) is applied as an analysis tool.
- Consequence analysis for identifying the consequence of the event and quantifying risk – for this step, cause consequence analysis (CCA) or event tree analysis (ETA) is employed as an analysis tool.

## 3 THE APPLICATIONS OF RAMS TOOLS AND RISK ANALYSIS

As mentioned earlier, LCC of systems and products is greatly influenced by the maintenance cost. While analyzing the reason for maintenance, (un)reliability of the products and the human error repeatedly are proven dominant causes. In the following, our discussion will be centered on the application of RAMS tools for improving the product LCC from a maintenance point of view.

Definition of failure and acceptable performance level should be decided early in the design process. By mapping degradation mechanisms, work environment, common operational failures, and human errors, the design can be improved to increase maintenance characteristic affecting cost at a later stage in the life cycle. Once the failure development process is identified in a product or a system, attempts are made either to eliminate the failure, i.e. design out maintenance, or to make it easy to repair as and when failure takes place, i.e. design for maintenance.

### 3.1 Design Out Maintenance and Design For Maintenance

When considering maintenance in design, one generally has two options: either one can try to design out maintenance (Figure 3) or one can try to optimize the design with respect to maintenance issues (Figure 4) (Ref. 18). After having identified maintenance characteristics one has the possibility to try to eliminate those characteristics that would cause maintenance costs. However, if maintenance is to be designed out, one has to consider the cost of reliability throughout the product's life cycle.

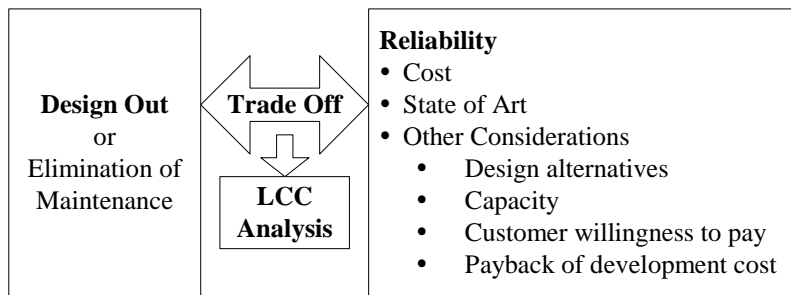


Figure 3: Design out maintenance.

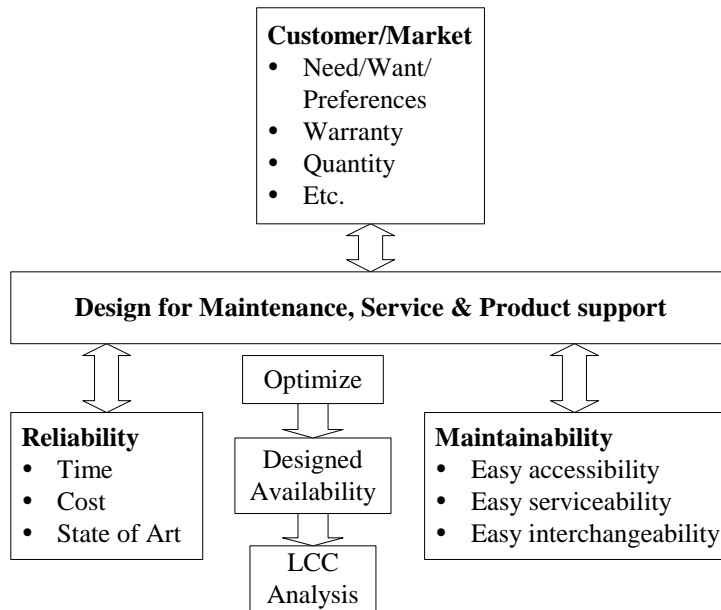


Figure 4: Design for maintenance.

One also has to consider the state of the art of technology – lack of available technology might not allow the elimination of maintenance, or it might be too costly. There are also other considerations such as product capacity, design alternatives, and payback of development cost, etc, to evaluate. There will always be a trade-off between these considerations. LCC analysis might be used to compare design alternatives. The LCC analysis results have to be balanced against market need, customer willingness to pay, customer preferences, etc. In designing out maintenance, one has to use the RAMS tools like FMECA, FTA, and risk analysis to arrive at the best LCC alternative. If the life cycle cost of design out maintenance is higher compared to the alternative design for maintenance then one naturally prefers the latter.

The objectives of maintainability analysis is to reduce product maintenance time and cost, and to determine labor and other related costs by using maintainability data to estimate item availability. The result should be reduced downtime, more efficient restoration of the product to operating condition, and a maximization of operational readiness. If the reliability is too low, maintainability issues such as accessibility to parts that need to be maintained, serviceability and interchangeability of parts and systems, have to be considered. Warranty and life span is also an issue to be evaluated. Who will be responsible for maintaining the product? Is it the customer or the manufacturer?

Often it is not possible to design out maintenance because of lack of technology, and one end up trying to balance reliability, cost, and availability. Other ways to reduce the future maintenance need is to reduce capacity, to substitute/ eliminate the weak functions, or to replace weak components by ones that are more robust. If we allow the system/component to fail due to various limitations then we need to have provision for easy quick repair/ replacement. Thus, when designing for maintenance, one will first have to examine the reliability characteristics, and thereafter decide the maintainability characteristics. Both R&M are traded off to meet the design requirement. LCC analysis, in combination with risk analysis methods, could be a viable tool for evaluating these issues (Refs. 2 & 5). Some of the guiding principles in design for maintenance are simplicity and elegance, minimum number of parts, modular construction, easy accessibility, sensibly sized components, ease of adjustments, minimum number of moving parts, use of known technology, human error considerations, etc (Ref. 11).

The system requirements can be divided into mandatory and preference. Mandatory requirements are the ones that must be used to perform the intended function. These requirements cannot be traded off. Preferential requirements are requirements that would make the customer happier (Ref. 19). These are requirements that can be traded off to improve costs, but, by trading them off, it may make the product less attractive and competitive. Design for human factors, modifications, and



diagnosability are some of the factors that can be considered as preference requirements, which can be traded off, but, which also may attract customers, and make the product more competitive with respect to life cycle costs.

### 3.2 *Design for Diagnosability*

As products become more complex, failures and faults become harder and more time consuming to diagnose. The designer's goal with respect to design for diagnosability is to make the process of determining the parameter(s) that are not at the designated state easy. Once the parameter(s) not at the intended state are isolated, a repair action can take place to return the parameter to the design state (Ref. 20). Automated sensor based diagnostics systems have been the focus in work conducted towards diagnostics in mechanical systems (Ref. 20). Today, advances in sensory equipment and tools such as vibration analysis, oil sample analysis, thermal imaging, can help in predicting system performance. Advances in Computer Maintenance Management Systems (CMMS) also have made tracking, storing, and using maintenance data easier. By using built in test equipment, the diagnosability of systems is increased by using sensors to obtain information about the system. Advances in sensors and sensory equipment, information technology, and communication technology today make it possible to have two way communication between the computer and sensor. Remote diagnostics and maintenance are possible by using advanced communication technology to transmit the data from equipment to appropriate information systems (often databases). Maintenance, operations, and support can then be planned at service centers based on updated data and need without testing the equipment. The data can also be used for improving later designs.

The use of wireless application protocol (WAP) for communication between for example personal digital assistants (PDA) and CMMS systems has opened up new avenues for development in the field of online conditioning monitoring. The interface enables the user to enter data at the product site and transfer it to the CMMS system. This technology could improve the speed of ordering spare parts and repair actions, enable the user to work with key issues at site, and to save time. It also means that it should be possible to sit at your desk using your CMMS system to collect, store and to analyze information and data from sensors located on equipment far away. These data can then be used to predict the performance of the equipment and to diagnose failures much faster and more reliable. By using the technology, the manufacturer and operator can follow the performance of the equipment from far away and provide the best maintenance for the product. The decision for incorporating diagnostic systems is decided by using either RAMS tools (to determine the criticality of the component and the function to be performed) or risk analysis. The implications are that it can change the maintenance strategies in ways that have never before been possible.

### 3.3 *Design for Modifications*

Design activity relates either to design of new products or modifications of existing products. Reasons for modifying products, processes, or systems, includes inefficiency in operations, advances in technology, changed specifications demand, or wear and tear. Both design activities, however, create an opportunity to improve performance effectiveness in a life cycle perspective. Many systems are performing ineffectively today due to technological advances. It, therefore, is necessary to consider this issue in design. Is the life span of the product of such length that the product will be outdated before its designed life span is reached? If this is the case, a shorter life span should be considered to reduce cost. An alternative is to design the product for upgradeability, i.e. flexibility toward technical improvements, or adaptation to changing operational requirements. RAMS tools in combination with risk analysis methods can help arrive at the correct decision concerning this issue.

### 3.4 *Design for Manufacturing*

Design for manufacturing is another issue that needs to be addressed at an early design stage. The choice of manufacturing method often affects the life cycle cost of a product. If the design is not suitable for existing manufacturing technology, it may increase the costs of maintenance considerably. For example, if in a particular case a welded joint is critical to the strength of the component, it is important that the welder or welding robot is able to access the welding spot in a correct way to produce a high quality welding. If not, the result may be a poor quality weld that could fail under load. Choice of design alternative from manufacturing point of view can be selected by using RAMS tools and risk analysis.

### 3.5 *Ergonomical Consideration in Design: “The Human Factors”*

Many failures occur due to human errors in operation and maintenance. Research also shows that also many accidents and problems are related to lack of personnel training, improper operation, operator failure to follow instructions, incorrectly conducted maintenance and start-up of systems after maintenance, or after system stoppage (Refs. 2, 9, 10, 14, 16 & 17). These failures can be traced back to the design engineer’s failure to foresee the product in operation and under maintenance. The maintenance and operation instructions should be clear, concise, correct, and complete to ensure proper understanding and utilization. The product also needs to be designed for ergonomics. A product designed with respect to ergonomical considerations will enhance customer satisfaction, market attractiveness, and the value for customers. Effective use of maintainability index developed by various organizations can be useful in improving and incorporating ergonomical considerations in design. The Bretby Maintainability Index (BMI) method, for example, is very useful for incorporating ergonomical considerations in design for

mining equipment / systems. The BMI method is suggested to be used in conjunction with design guidelines as a method for applying ergonomic principles for reducing cost and accidents in maintenance operations. By using the BMI method, aspects of a maintenance task or activity that are demanding and/or time consuming, or likely to result in errors or safety implications, are highlighted (Ref. 21)

### 3.6 Engineering Training

The experience and training of the design team members and their ability to be innovative and creative is becoming increasingly important. If, for example, the team members are trained in application of RAMS tools in design phase, the lead-time will be reduced since R&M evaluations should be conducted more efficiently. This also will lead to fewer design iterations in the detail design. With advanced computer modeling, virtual prototyping, and by simulations, complex designs can be tested with respect to ergonomics, manufacturability, maintainability, safety, and style (Ref. 22). It is believed that internet and intranets can be used successfully in the design process, both to ease the task of training personnel and to shorten the time and cost of training by using interactive training programs on the web. By training employees in RAMS tools, methods and design, as well as making design tools available at their working desk, design cost and time can be considerably shortened.

## CONCLUDING REMARKS

Based on the discussions in this paper it can be concluded that application of RAMS tools in combination with risk analysis methods in the design stage, can considerably reduce the LCC and improve the product attractiveness. Some of the RAMS tools and methods can be employed without detailed knowledge of the system being analyzed. However, many of them require specific input data and detailed knowledge, which may not be available in the early phases of a design life cycle. However, by using trained personnel, available experience, experts, and by comparing with similar systems, the tools and method may still contribute to increasing the reliability and maintainability of systems and reducing the system life cycle costs.

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# **PAPER II**

## **Integration of RAMS and Risk Analysis in Product Design & Development Work Processes – A Case Study**

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# Integration of RAMS and Risk Analysis in Product Design & Development Work Processes – A Case Study

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## **ABSTRACT**

Most industrial customers are looking for products that meet functional performance needs and have predictable LCC. Due to design problems and poor product support, these systems are not able to meet customers' requirements. Major causes of customer dissatisfaction are often traced back to unexpected failures, leading to unexpected costs. However, with proper consideration of Reliability, Availability, Maintainability and Supportability (RAMS) in design, manufacturing, and installation life cycle phases, the number of failures can be reduced and their consequences minimized.

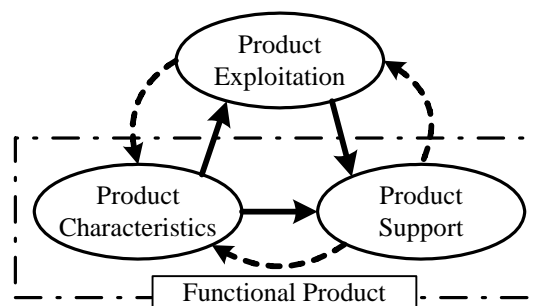
Based on a case study in a manufacturing company, an approach for integration of RAMS and Risk Analysis in design, development and manufacturing is presented. The importance of Life Cycle Cost (LCC) analysis, use of feedback information, and integration of various information sources to facilitate easy RAMS implementation, in combination with risk analysis in the design phase, is discussed. An approach for integration of RAMS in the Stage Gate Model for project and work process management, coordination and control, to reduce risk, is furthermore discussed. A training program, developed and implemented during the study to create awareness and to improve learning and understanding of RAMS' aspects of existing and future products and processes, is also presented.

*Keywords:* RAMS, LCC, Risk analysis, Functional product, Stage Gate Model, Customer needs, Information flow, etc.

## **1. INTRODUCTION AND BACKGROUND**

Manufacturers of industrial systems/machines experience increased pressure from customers to deliver customized products with documented RAMS characteristics and

LCC, with improved quality, at a lower price, and in a shorter timeframe. The customers demand products that meet the functional performance needs and have predictable performance and cost throughout the service life cycle. However, due to design problems, these systems are not able to meet customer requirements in terms of system performance, effectiveness and efficiency. This is often due to poorly designed RAMS characteristics combined with a poor maintenance strategy. This has given a new dimension to the problem of effective and efficient service and maintenance management of industrial systems/machines. To avoid the complexities of maintenance management, many customers/users prefer to purchase only the required FUNCTION, not the machines or systems. Thus, the responsibility of maintenance and product support lies with the organization delivering the required function. With the advent of this trend, focus has shifted to the design of functional products. The definition of a functional product is that the user is not buying a machine/system but the function it delivers. Figure 1. illustrates the definition of a functional product and depicts the relationships between product characteristics, exploitation, and support. The continuous and broken lines indicate primary and secondary relationships respectively. Designed product characteristics (hardware and software) define the types of exploitation the product can be subjected to and the type of product support needed to achieve the expected function and performance. Furthermore, the users and operating environment can also influence the degree of support needed to achieve the expected performance level (Markeset and Kumar, 2003a).



*Figure 1: Functional Product*

Major causes of customer dissatisfaction are often traced back to unexpected failures, leading to unexpected costs. In general, product failures are often caused by the design engineers' and manufacturers' inability to predict problems that may occur later in the product application phase. However, with proper consideration of RAMS in design, manufacturing, assembly, testing, and installation, the number of failures can be reduced and their consequences minimized considerably. It is argued that if due attention is paid during the design phase to the 'maintenance needs' of the

system; considerable savings can be made in the operation phase. Manufacturing companies can gain much from improving the work processes involved in design, manufacturing, assembly and delivery processes, by integrating 'the maintenance needs analysis' at the design board stage.

Design is a process of balancing needs and functional requirements against various constraints such as material, technological, economical, physical, functional, operational, environmental, legal, and human/ergonomical factors (Pahl and Beitz, 1996, Volland, 1999, etc.). It is a decision making process where engineers have to make decisions concerning the translation of customer needs, desires, and wants into a product that can fulfil the functional requirements in a reliable and consistent way over time. This process should ensure a product of satisfactory quality in an effective and efficient way. Product complexity caused by integration of electronics, data processing, processing controls, aspects of product acceptance and environmental concerns, is steadily increasing, resulting in an ever-increasing number of questions and problems to be considered in the design phase. This necessitates interdisciplinary cooperation and creativity among specialists, creating new demands on organizations and individuals (see e.g. Pahl and Grote, 1996, Thompson, 1999, and Volland, 1999).

The discussions in this paper are based on a case study performed for a manufacturer and supplier of industrial systems, with customers and distributors worldwide. The company has recently experienced that customers increasingly emphasize demands on product reliability, maintainability, support, and life-cycle costs, and has realized that documented and predictable reliability, quality, maintainability, and LCC for the product could be a competitive advantage. In addition, customers demand the products be delivered with a shorter lead-time, with a shorter commissioning phase, and improved after-sales support. As a result, the company sees the need to implement and integrate systematic and formalized RAMS synthesis and analysis, by incorporating RAMS data analysis together with Risk Analysis, into their design approach.

With this background, we will discuss fundamental issues related to implementation of RAMS in product design and development, and related to integration of reliability, maintainability and risk analysis tools and methods to enhance performance efficiency, to reduce product LCC and delivery time, and to increase customer satisfaction and product attractiveness. This approach is expected to create a win-win situation for both manufacturers and customers.

## 2 INTEGRATION OF PRODUCT PERFORMANCE REQUIREMENTS INTO THE DESIGN PROCESS

A product exists because there is a customer who is willing to pay for and use the product. A manufacturer exists because the product needs to be made and because there is a market and customer for his product. In order to deliver the product or the required function, the manufacturer has to design the product, manufacture it, and provide any required support to meet expected performance demands. These work processes need to be managed and organized. Suitable organizational systems and leadership therefore have to be in place to manage the work processes. This can be referred to as 'customer pull' of the product development process. In this case, the product and the product delivery system is created and formed on customers' terms (see Figure 2.). Customer needs, wants, and preferences are in this case integrated into the products and serve as drivers of product and organizational development. In the other extreme the manufacturer can 'push' products on the customers, based on what is technologically possible, and, moreover, form the organization without taking customers needs, wants, and preferences into consideration. This reverse relationship is what we refer to as 'technological and organizational push'. However, whether the driver for product and organizational development is a pull or a push process, the increased market pressure in respect of cost, time and performance, forces a need for effective and efficient distribution of, and access to, product and work process related information, and for more proactive, reactive, and interactive information use.

It is important to integrate customer needs, wants, preferences into design as early as possible, as it during this stage is easier to influence product LCC and customer satisfaction. We argue that integration of RAMS and LCC in combination with risk analysis in the design and manufacturing process is fundamental in accomplishing and ensuring the success of new product development and for reaching the goals set at the outset.

There exists a large volume of literature discussing RAMS analysis for different types of products and applications under varying conditions (e.g. Barlow and Proschan, 1981, Blanchard et al, 1995, Dhillon, 1999, Kumar, 1990, Kumar et al. 1992, etc.). However, to our surprise we did not come across any literature where the issues related to implementation of RAMS and risk analysis in design are discussed. Some of the notable exceptions are Blanchard and Fabrycki (1998), Dhillon (1999), Markeset and Kumar, (2001), Sandberg and Strömberg (1999), Van Baaren and Smit (1998), Warburton et al. (1998). For a mechanical system Warburton et al. (1998) demonstrate a methodology for providing the design engineer with the tools to understand and model mechanical failure characteristics and thereby simulate product behavior in terms of design, operational, environmental and material parameters based on mathematical models expressing underlying failure processes and parameters. Moss (1985) describes how to design for minimal maintenance expense

through the use of LCC analysis. However, this is difficult due to uncertainties and lack of data. Furthermore, product support is often not considered early enough in the design process. If it is, there usually is a lack of quantitative design goals. Often the cost of support is not fully understood at the design stage of developing new products (Goffin, 1998). It seems little research has been reported on how integrate product support in design (Goffin and New, 2001). Support is needed to compensate for product unreliability, loss of product performance quality and effectiveness, reduced product output quality, lack of usability, etc.

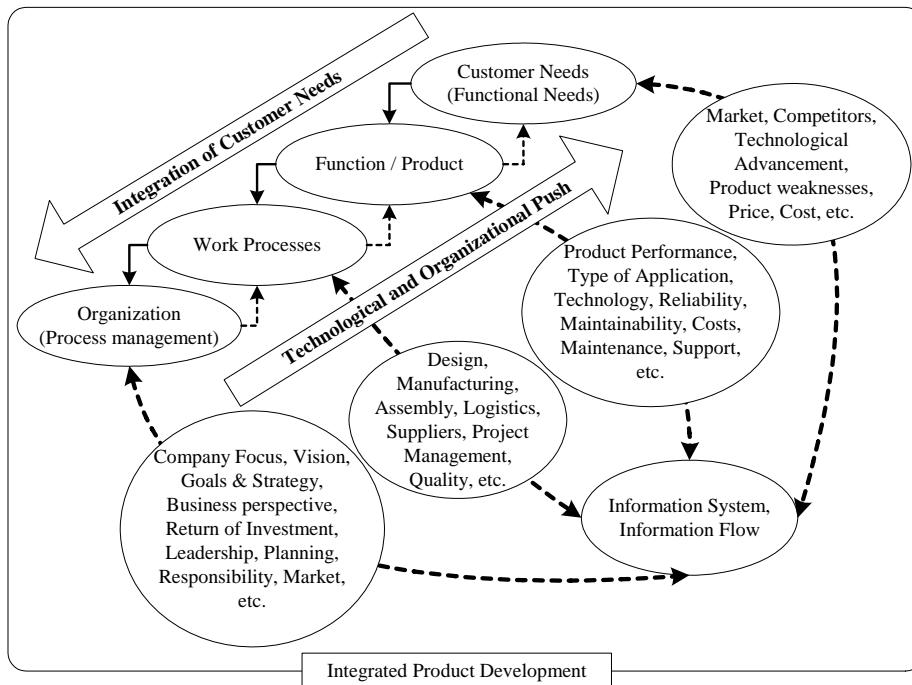


Figure 2: Integrated product development facilitating interactive information flow.

### 2.1 Tools, Methods & Models in RAMS and Risk Analysis

There are many tools and methods available to assess RAMS, LCC and to apply risk analysis during product development (see e.g. Blanchard et. al., 1995). RAMS tools like FMECA (Failure Mode Effects and Criticality Analysis), FTA (Fault Tree Analysis), and ETA (Event Tree Analysis) are useful in the dimensioning of product characteristics and product support. As the demand for shorter delivery cycles

increases, more effective and efficient work processes are more important than ever to examine factors affecting product performance, maintenance, and support. We believe that routines for integrating such assessment in the earlier phases of product development processes is important to gain better control of product LCC. To be able to sustain competition, to deliver a superior product, and to continue growing, companies need to focus on making the design process as effective and efficient as possible. The Gate Model introduced by Cooper (1990) is one method used to define routines and procedures, to control product development, and to reduce risks in complex processes, and thus help create focus on the value creating activities in a value chain. In the Gate Model, a set of gates is assigned to various phases of a project. In each phase, a number of checkpoints and tasks are evaluated and approved before the project is allowed to enter the next phase. The idea is that by going through the checks, and by making sure the tasks are evaluated, the project risks should be better controlled and reduced.

During design there are many interrelated processes and activities that are implemented for a purpose and lead to a common goal. The inputs to the work process are customer needs, wants and desires, and the output is the product and services produced. Sometimes companies experience problems with integrating design concepts and output from various groups, disciplines and work processes into the product to fit the customer requirements. If the different groups are focusing only on their own functions and do not try to integrate their solution into the solutions from other disciplines, the end-result could be less than optimal. Integration of solutions needs to be done as early as possible in the design process. The overall product delivery process is composed of many sub-processes. If these sub-processes are considered as functions (or disciplines/groups), and there is competition between them because of result requirements to justify their existence, each of the functions will often attempt to optimize themselves to look the best in the eyes of the business management. However, it is important to realize that it is the overall goal that is important, and which everybody should work on to reach and to optimize together. This is a direct parallel to 'systems thinking' in which the focus is not on optimizing the pieces, but rather on the fit between the pieces of the system (Liker et al. 1995). We believe that 'systems thinking' is important and valid both for work processes and for the product itself. It does not if a component/subsystem is designed to perfection if the rest of the system/product is not. After all, what the customer is primarily interested in is the functional performance of the product and the total product offered and delivered, not the individual components.

### **3 RESEARCH METHODOLOGY & APPROACH**

The study was conducted in two phases, namely a preliminary study and a main project phase. In the preliminary study we aimed to become acquainted with the

employees, to understand the work processes involved in design and manufacturing, and to identify factors and areas that affect product design characteristics and service life performance. In the main project phase we selected some areas and work processes for a more detailed study.

The main goal and purpose of the study was to identify areas where the company should focus for improvements in respect to the products and work processes involved in product design, development, delivery, and support. One of the goals was to evaluate information sources and to identify information needs not covered in the company's existing databases. Furthermore, we wanted to evaluate how RAMS and risk analysis can be integrated in work processes. The study also aimed to motivate and provoke a discussion within the company about the design process and related problem areas, and to make the employees involved aware of the issues and complexities involved.

The project goals were accomplished by the use of interviews, surveys in the form of questionnaires, data collection and analysis, discussions, participation in projects and meetings, etc. To get a holistic view of the company we selected employees from all departments and groups to participate in the surveys. SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis methodology was applied in both the preliminary and main study to organize and categorize information.

The study can be characterized as action research methodology, where the researcher participates in the processes and operations under investigation (Westbrooke, 1995).

#### **4 CASE STUDY: STUDY AND ANALYSIS OF DESIGN AND MANUFACTURING PROCESS**

The company observed in the study, produces various types of flexible, advanced, integrated, and automated production systems based on advanced technology. The systems are powered by electrical motors and are controlled by advanced software solutions, electronics and sensors. Their customers are using the products in high performance production lines where uptime is critical. Even though the company has not been able to design out all needs for maintenance, the products are very reliable, dependable and durable. Through an excellent supply and support network, their customers trust the company to provide necessary support when needed. However, if a production system fails unpredictably, the consequences can be very costly for the customer. Many of the customers therefore demand products which have documented and predictable service life performance, a high technical performance and reliability, are durable and dependable, comply with health, safety and environmental standards, and are cost effective. Normally the customer purchases a production system to fit

into their production line from the Industrial Group's closest Regional Office. If the Regional Office is not able to assist and resolve problems, the customer communicates with the manufacturing company directly.

Products are categorized as standard products, customized products, and development products. The products are designed to last for 50,000 hours of continuous use. The owner will need spare parts and may also need to upgrade the product due to any weaknesses discovered and/or technological developments that increase product performance or maintenance effectiveness and efficiency.

#### *4.1 Work Processes in Design and Manufacturing*

The employees are organized in functional departments and sub-groups according to specialization. Both the products, and the work processes necessary to produce the products, have evolved in advancement and complexity resulting in a higher demand on employee specialization. One of the results of this evolution is that fewer employees than before have a full understanding and overview of the complexity of the products and the work processes. As the customers demand improved products in respect to quality, reliability and performance, delivered with shorter lead-time and at lower costs, work process effectiveness and efficiency is becoming increasingly important. Standard product orders are handled directly by the production department, while projects involving customization, new technical development or product improvements, are handled by the research and development department.

The study indicates that some work processes are not properly defined, or have procedures, routines or checklists that are not followed or are not easy to follow. Even if many of the required procedures, routines and checklists are in place, time-pressure occasionally makes them difficult to follow. Procedures, routines, and checklists are used to coordinate and control the work process to ensure that the actual output meets the expectations (or is according to specifications and quality). The work processes need to be understood and formalized to maximize the output. It is important to consider the coordination among work processes to be able to achieve optimal result.

Product reliability and maintainability characteristics are designed into the manufacturing and assembly specifications in the form of drawings, manufacturing and assembly procedures and methods, choice of materials, etc. The output from the engineering design stage is therefore the foundation for product reliability and quality. If too tight tolerances are given, or if the component is difficult to manufacture and assemble, errors may be introduced in manufacturing and assembly, causing reduction of the designed-in reliability and increased quality problems. However, to produce the drawing, the engineer may need input from the manufacturing department about critical inputs that may make the component difficult to make, which further down the line can influence quality and product RAMS.



Many work process and product problems are caused by a lack of understanding and awareness of why things are done in the way they are done. Often when people communicate they talk about the same thing but use different terminology/language, or discuss different things using the same terminology. To avoid confusion and misunderstanding there must be focus on having the same understanding and on using the same and agreed terminology. There must be a common understanding of why things are done the way they are, and of the purpose of the activities. In this study, there are several indications of anomalies in perception between department managers and employees, and also between different departments. Focused training and follow-up are important for understanding and awareness, and also affect motivation, attitudes and teamwork abilities. The training undertaken in this project has given positive responses with respect to this. In the training sessions given, the seminar started with a general introduction from one of the company managers, followed by a presentation of general theory explaining the background, foundation and basic philosophy of RAMS integration, which was followed by a relevant application. Throughout the seminars, the participants were encouraged to comment on the issues presented and to participate in discussions. The result was a better understanding of the topic and, hopefully, more motivated employees.

#### *4.2 Software systems, Databases, and Information Sources*

The company uses advanced software systems for product design and analysis, for administration and management of related documentation and analysis, and for the production of their products. They also have in place many databases and information systems to manage customer feedback, complaints and resolution of customer product problems, quality assurance and control, field service reports, information provision to customers with respect to product problem solutions, etc. Some of the employees complain that there are too many information sources, and no easy accessible overviews and explanations of where to find and how to use the different kinds of information. Although there is an abundance of information available, it is often difficult to obtain useful, relevant information when needed.

It was observed that many of the information systems were used for reactive and not proactive improvement purposes. As data and information accumulates, the data should be identified and trended to identify weaknesses and opportunities for improvement, and to avoid repeating mistakes. The databases can also be used as a source of information when solving similar problems, or during design and development of new products and models. There seems to be a lack of information system integration and holistic perspective of possible use. Some of the information systems are difficult to use and are error prone. Sometimes it is also difficult to access the databases. Common to many of them is that the information in them is of a qualitative format, which makes it difficult to search, filter and find information if

needed. It also makes statistical analysis and trending in the worst cases impossible, and at best difficult, cumbersome and work intensive. More quantitative information is needed for producing better LCC analysis and availability estimates for standard products. Many of the information sources and the information therein, are intended for product improvements and not so much for improvement of work processes. Improvement of products and work processes are intertwined and complementary activities, not mutually exclusive.

### *4.3 Product Development and Testing*

The company develops products in an iterative and evolutionary process, partly as a result of attempts to remove or design out product weaknesses, partly as a consequence of advancements in technology, partly as a result of comparison with competitors, and partly as a result of customer and market demands. Many product development efforts are a result of product customization efforts toward special user needs evolving from cooperation with customers and suppliers. The customer demands reliable, durable, and dependable products. As products become increasingly advanced, complex, and integrated, the number of ways they can fail increases as well. As changes or new technology are introduced to existing products and new products are developed, new possibilities for weaknesses, failures and errors are also introduced. It was observed that many projects had insufficient time to test all new changes and to optimize the design by designing prototypes, using laboratory testing-facilities to improve maintainability, etc. before being completed and introduced to the customers.

### *4.4 Training*

The company offers training programs for their employees and customers. All the company employees need to be trained in respect to design for maintenance issues and in utilization of new RAMS tools and methods. There was also observed a need for training of manufacturing and assembly personnel with respect to implementing new design solutions.

## **5 INTEGRATION OF RAMS AND RISK ANALYSIS IN DESIGN WORK PROCESSES**

### *5.1 RAMS Activity Coordination and Integration*

The company has realized that both their products and work processes involved in designing, manufacturing, installing and supporting the products, and the products themselves in parallel, have become increasingly advanced, complex and integrated.

To stay competitive it is necessary to deliver products with documented quality, reliability, maintainability and competitive LCC. Therefore an RAMS Coordinator position was created in the company. Since an RAMS Coordinator deals with product and work process improvement with respect to RAMS issues, it is a cross-functional and partly independent position. This reduces the focus on interdepartmental optimization, and instead creates a holistic view on product and work process improvements.

The coordinator is responsible for coordinating efforts focused on integrating RAMS into design work processes, development and use of RAMS tools and methods, utilization of information sources, data, and experience which can be used to improve product reliability, and not least, training of employees in respect to these issues. The goal is to systematize and formalize the design methodology in respect to RAMS, to focus on product and work process improvements, and to make the product performance more predictable. When a product problem is identified, the goal is to find the root cause and prevent it from reoccurring. At least it should be possible to reduce the problem consequences by making the problem predictable and by including maintenance and support compensation activities. Efficient and effective use of the testing laboratory is also part of the RAMS Coordinator's responsibility. The goal is to be able to use the facility more proactively and interactively during design, to reduce design iterations and rework, to reduce cost and lead-time, to improve both reliability and maintainability, and hence downtime and costs for the customer. By creating the RAMS coordinator position, the company has managed to bring focus on the integration of RAMS and risk analysis in the work processes.

## 5.2 *RAMS Tools and Methods*

Central in the efforts of integrating RAMS into work processes is the development of a computerized design tool based on the FMECA methodology. FMECA is a powerful analysis method involving two elements of risk, namely failure frequency and consequence. Sometimes the possibility for detecting the failure also is included. FMECA analysis concentrates on identification of the events and frequency resulting in failures and analyzing their effects on the components and systems. Information about possible ways the product can fail and product weaknesses, originates from experience, feedback from customers and suppliers, testing, analysis, spare part and warranty data, project review reports, etc. If a failure mode is identified, its risk is predicted by estimation of failure frequency, consequence, and detectability. If the risk proves too high, efforts are initiated either to reduce frequency and/or consequence, or by increasing the detectability to make it possible to avoid the event, or at least to reduce the severity of the consequences. The analysis and design out of the failure cause, or corrective action, has to be done in product design (Carter, 1997). The intention of the FMECA tool is to formalize and standardize design processes with respect to RAMS, to meet demands from customers in respect to documented

reliability analysis, and to make it easier to identify product improvement opportunities. The computerized tool is now starting to be used actively in the design process. Although FMECA analysis has been performed in the company for many years, only recently have efforts been initiated to formalize and systematize the analysis process.

The results from the analysis are gradually becoming popular and used more frequently. Such results provide a basis for decision-making such as recommendations for preventive maintenance, spare parts and maintenance tools (both for commissioning and exploitation phase), documentation (including procedures, routines, and checklists for installation, failure diagnosis, maintenance, etc.), and LCC predictions. The analysis also serves as a basis to evaluate warranty considerations, maintenance programs, modifications and upgrading of existing products, customer training, and feedback to involved parties, etc. The vision is to be able to design out all product characteristics leading to unplanned corrective failures and warranty costs. Corrective or unplanned maintenance is needed when the product fails either intentionally, as sometimes is the chosen strategy for components that can fail but which are not critical, or unintentionally as a result of overload, wrong use, design errors, etc. The whole point is to improve product performance, reliability and predictability, reduce costs, increase profit margins, and thereby to increase product related performance and customer satisfaction.

### 5.3 *RAMS Information Sources*

As mentioned above, there exist many possible sources of information that can be related to product and work process improvements. The problem is to identify and route the interesting information to RAMS improvement activities, and to the RAMS tools and methods. To make efficient and effective use of the information sources, demands must be specified with respect to use and needs, information type and format, how it is to be accessed and by whom, how the information is to be routed to fulfil the various purposes, etc. In this study, several new ways to use databases and information sources to improve products and work processes were identified. For example, many concrete information system improvement possibilities are identified in the mapping of RAMS information flow. The service reports have been improved somewhat as a result of suggestions from the employees and new information uses. This can be considered an added benefit of the RAMS coordinator's efforts of identifying information sources with information relevant of product improvement.

Even though much of the information is focused on the products, often the root cause of a product problem recorded can be traced back to work processes, activities, procedures, routines, or checklists in use during delivery of the products. This information must therefore be used and discussed with improvement of both processes and product in mind. The company has used an intranet for some years for

providing easy access to information sources, and has recently also started to use the Internet to facilitate easy access to information and distribution of information. It is believed that integration of the Internet and intranet applications with the Stage Gate Model can support and accelerate new product development (see Howe et al. 2000).

#### 5.4 *Work Process Management and Control: The Stage Gate Model*

Recently the company has started to use a modified Stage Gate Model to improve project management and control, in parallel with traditional project tools and methods. In this model, projects are divided into sequential stages, or phases, with go/no-go gates at the end of the phase. The purpose of the gates is to avoid a project entering the next phase before the goals of the first phase are accomplished. The gates provide an opportunity to review what has been done to date and to adjust performance gaps, or to stop the project if the results are not as anticipated and too much money has been spent. In this way the project can become easier to control and business risks reduced.

Recent developments in information and communication systems has made it possible to perform design and manufacturing processes simultaneously, and hence more effective and efficient, resulting in reduced lead-time and costs (Yazdani and Holmes, 1999). To improve products, RAMS related activities need to be performed and evaluated as early as possible, preferably already in the specification phase. As mentioned previously, the foundation for a reliable product is laid in the design phase. Product reliability cannot be improved in the later stages of production. In these design implementation (manufacturing, assembly, etc.) stages there are many opportunities to reduce the inherent and designed-in reliability by not conforming to specifications given. The introduction of the Stage Gate Model results in that representatives of later stage functions, or work processes, have the possibility to influence the design at a much earlier stage, through the gate reviews. This also forces, and gives an opportunity for, inter-disciplinary cooperation and coordination, which is both recommended and in many cases required. As Pahl and Grote (1996) point out "teamwork and individual work are complementary in an integrated and interdisciplinary development process". Furthermore, a risk analysis based on various factors such as economical, environmental, support, planning, etc., thought to influence project feasibility, success and results, is performed at the beginning of the project. This analysis is updated before the gate reviews and functions as a basis for decision-making. To ensure that RAMS issues are considered at various design and manufacturing stages, the company has started to use an RAMS activity template to define activities and tasks to be performed at each project stage.

### 5.5 *RAMS Activity Template*

The template is meant to include RAMS gate activities to check and control if the goals have been reached at the various project stages. RAMS goals must reflect real customer needs, available technology, and customer willingness to pay. They also have to reflect what is necessary with respect to market competitiveness. It is important to consider the coordination between work processes to be able to get an optimal result. The FMECA tool is used in all project meetings and is used as a checklist to ensure that identified improvement actions identified are implemented and followed up. The end result is that the design process becomes even more concurrent and dynamic, involving increased informal and formal information exchange. This has a positive effect on employee motivation and increases the understanding of how their contribution fits into the big picture. The holistic view should be that all activities contribute to customer satisfaction.

### 5.6 *RAMS Training*

Many work process and product problems are caused by unawareness and a lack of understanding of purpose and goals. Part of the RAMS coordinator's job is to motivate the various employees to take part in improving the products and to use the tools available. As such, focused training and awareness-creation efforts and coordination are of the utmost importance and can have a tremendous impact – both with respect to improve understanding and knowledge of the issues involved, to improve motivation, attitude, and teamwork abilities, and to create a holistic view of the products and work processes. Part of this is the effect of gaining a common understanding of goals, focus areas, work processes, problems, and finally, but maybe most importantly, customer satisfaction. With better training, the employees should be able to design for RAMS at an earlier design phase and reduce the number of design iterations necessary to produce a final and acceptable design. Project risk may also be reduced.

To improve the design in respect to reliability and maintainability, the employees need to be trained in RAMS tools, methods and terminology. All employees need a similar understanding of what design for RAMS means and to use the same terminology. During the study several courses were arranged for the employees to create awareness.

Figure 3. depicts a general dynamic product development process controlled by the Stage Gate Model, together with support activities to integrate RAMS in the design process. As shown in the figure, the product development processes are started simultaneously. To be able to include results and information from later stage work processes early in the product development process, information sources and support activities must be available and facilitated. Furthermore, facilities like Internet,

intranet, video conferencing, etc., need to be in place for continuous communication with customers, regional offices and suppliers. In simultaneous processes like these, the use of cross-functional and multi-skilled integrated teams and facilitation for intensive communication between work processes involved (depicted by many short, vertical, and bi-directional arrows in Figure 3.) are of the utmost importance to coordinate and control the process. The participants also require an understanding and knowledge of the work process and a holistic view of the goals.

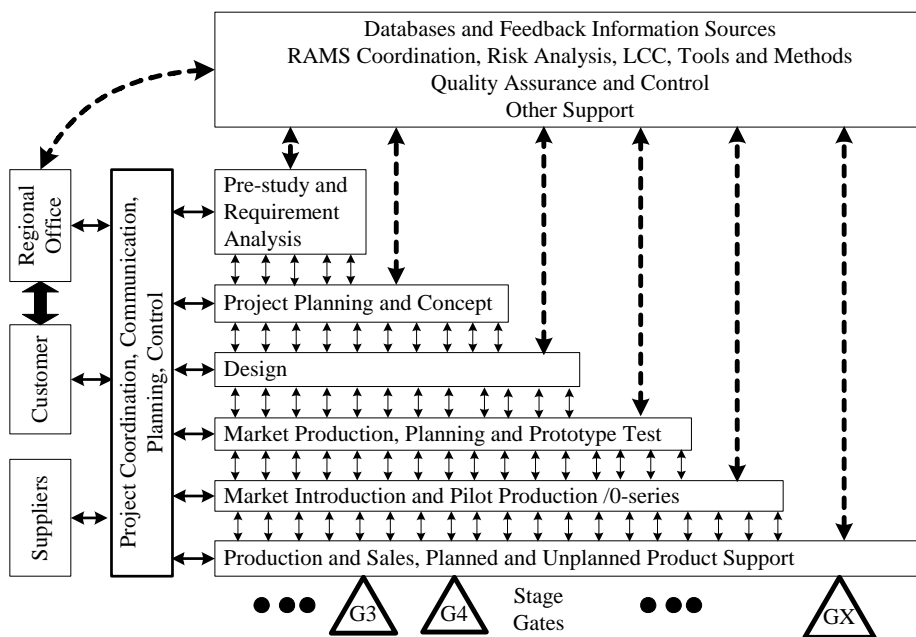


Figure 3: Dynamic product development process including Stage Gate work process control and proactive, reactive and interactive partner communication.

## 6 DISCUSSION

Customer feedback is important for having good input data for reliability, maintainability, and LCC calculations, for product improvements, customer satisfaction measurements, and for sales of new products and services. Normally, it is difficult to get systematic feedback from customers. However, since many of the customers come back to buy new products, they also have an interest in the manufacturer improving the products characteristics. Manufacturers and customers

are mutually dependent on each other – the manufacturer needs feedback from customers on product behavior to improve the next product generation or version, while the product user may need spare parts, expert advice and help in maintaining the product, training, documentation, etc. Somehow the manufacturer and customer have to create a relationship to take advantage of each other's information, knowledge and intelligence (Liyanage et al. 2001). The recent development of communication and information systems has made it much easier, quicker, and simpler to retrieve information directly from customers and products, to provide remote monitoring and support, to interact with customers, suppliers, and service personnel at remote locations, and to increase the speed of product development and delivery.

Product design characteristics and built-in reliability are dependent on how the products are to be manufactured, assembled and installed. If, for example, a component is difficult to design and manufacture, there is a higher chance of making mistakes, which may result in the component being weaker than intended or having damaging/detrimental effect on other components, etc. It is, therefore, important to consider how the product design is to be implemented in manufacturing and assembly to avoid errors caused by unnecessarily complicated operations and tasks. Therefore the manufacturer needs to have in place effective and efficient routines for integrating RAMS in the design and manufacturing processes, for obtaining data and information from the customers throughout the product service life, and to cooperate with the customers in maintenance and support planning from the early concept phase to the end of the product service life. (See also Markeset and Kumar, 2003b).

Some of the pieces of the puzzle related to integration of RAMS and Risk analysis discussed in this paper are shown in Figure 4.

## **CONCLUDING REMARKS**

The company studied is still in an early phase of integration of RAMS in its work processes related to design. This is being implemented gradually and phase-wise with feedback to monitor the effects. By integrating RAMS in the work processes involved in delivering, installing, and supporting products, it is believed that business risk will be reduced. The company sees the need for implementing training programs with focus on integration of RAMS considerations in the design phase in combination with risk and LCC analysis. A need for effective and efficient control of the information flow and the work processes involved in the design, manufacture, delivery, commissioning, and after sales support was identified as critical to successful integration of RAMS and risk analysis in work processes. The company also has initiated measures to coordinate RAMS activities being implemented in different sections and departments.



We believe that successful integration of RAMS will provide the company with a competitive edge and the successful implementation will mainly depend on the company's ability to create awareness and understanding of the issues involved. The employees need to be trained to use the appropriate tools and methods, and an infrastructure needs to be in place to make these tools and information sources available when needed. It is important to consider the coordination between work processes, tools, and information sources to be able to get an optimal result. Procedures, routines, and checklists need to be in place where they are needed; they need to be clear, concise, concrete, and precise to be efficient and effective. They also need to be updated regularly to reflect changes in needs and uses. However, one must be careful not to introduce too much bureaucracy into the organization, as it tends to kill creativity and innovation.

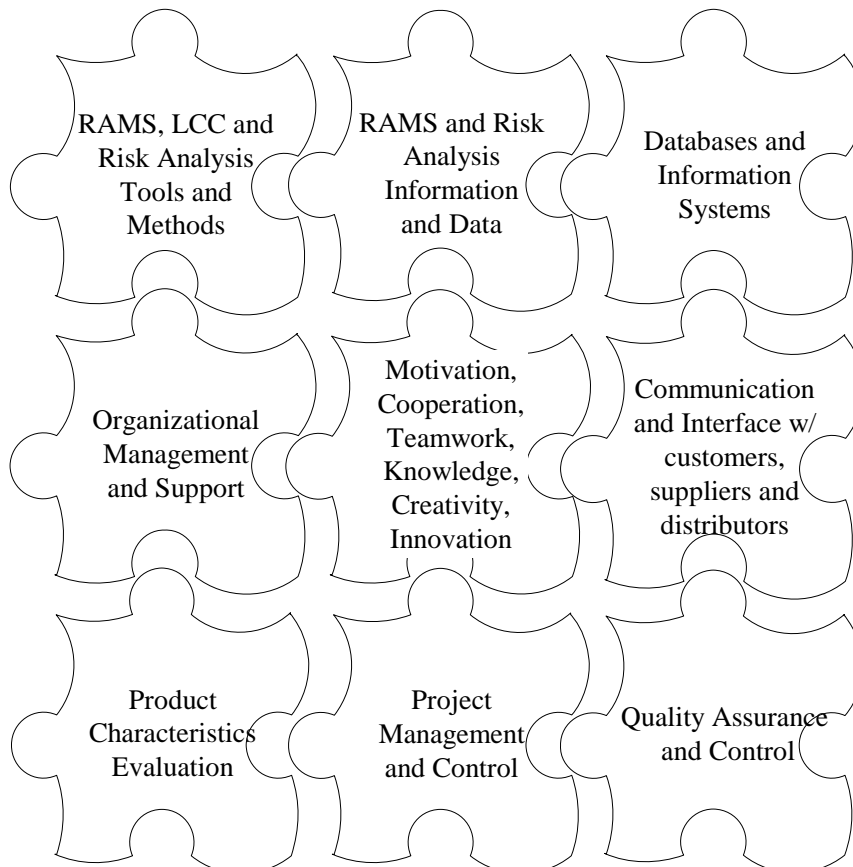


Figure 4: An illustration of components of RAMS integration process.

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# **PAPER III**

## **Integration of RAMS Information in Design Processes – A Case Study**

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# Integration of RAMS Information in Design Processes – A Case Study

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## **SUMMARY & CONCLUSIONS**

The discussions in this paper are based on a case study on a manufacturer of advanced technological industrial systems with a global customer's base. The company wants to further improve the performance of their products with respect to quality, reliability, and maintainability, and to improve their work processes by integrating RAMS design methodology and philosophy. Currently their focus is to “Design and develop products for performance and effectiveness with the lowest cost”.

Even though RAMS philosophy/methodology/tools have been applied in the company for some years meet the demands of documented RAMS and LCC analysis and to improve the quality of existing and new products, it has not been applied in a systematic and repeatable way. However, recent development in information and communication technology has made it possible to use RAMS tools and philosophy in a more systematic and repeatable way.

We found that there within the company existed almost 20 information sources and databases that contained RAMS data and information that in one way or another could be related to improvement of products and design, manufacturing, and product support work processes. Most of the information within them was in qualitative format and unsuitable for statistical analysis. Moreover, many of the information sources were neither integrated nor user friendly. As a result, most of the information and knowledge were not integrated into the design and manufacturing processes.

The study concluded that there exists a need for controlling the information flow and the work processes involved in the product design, manufacture, delivery, commissioning, and after sales support life cycle phases. Additionally, the information sources and databases need to be related to type of use and users' needs to create the next leap forward in product and work process improvement. Furthermore, a need existed to reduce the number of information sources and to

integrate them with in the main information systems and work processes. The system has to be more accessible, user friendly, effective and efficient. A RAMS coordinator position was created for facilitating design for performance issues, streamlining the routing and flow of information, making RAMS tools available and easily accessible, training of engineers, and for facilitating more use of product testing facilities.

*Keywords:* RAMS Information Management Systems, FMECA, Databases, RAMS Integration

## 1 INTRODUCTION AND BACKGROUND

“Organizations compete based on their value chain, the series of processes that create products and services external customers pay for. Competitive advantage occurs when a firm’s value chain generate superior product and service features...” (Ref. 1). To facilitate creation of superior products, integration of RAMS data and information systems with RAMS design processes is critical (Ref. 2). Such database/information systems can provide a better understanding on an online basis.

Customers are demanding products that meet the functional performance needs and have predictable life cycle cost (Ref. 3). However, due to design problems these systems are not able to meet customers’ requirements in terms of system performance and effectiveness. This is often due to poor designed RAMS characteristics combined with poor maintenance strategy, often leading to unscheduled stoppages (failures). Major causes for customer dissatisfaction are traced back to unexpected failures leading to poor product performance and unexpected costs. In general, design engineers and the manufacturers’ inability to predict problems that occur later in the product application phase often cause product failures. To meet customers’ requirements designers need to design products that perform according to customers’ specifications and needs. This process has to be supported by tools readily available for the design engineers.

To improve products and work processes one is dependent on information and knowledge about existing products in use. In fact, field experience data is the key to improve products, product design and related work processes. Feedback of information from the existing systems and field applications is therefore needed on a continuous basis. Thompson (Ref. 4) discusses some of the pitfalls of information feedback for design and manufacturing processes. Molenaar et al. (Ref. 5) reports a model developed for improving functionality, reliability, and cost efficiency of products based on a case study. They furthermore discuss why quality and reliability feedback loops not always work in practice.

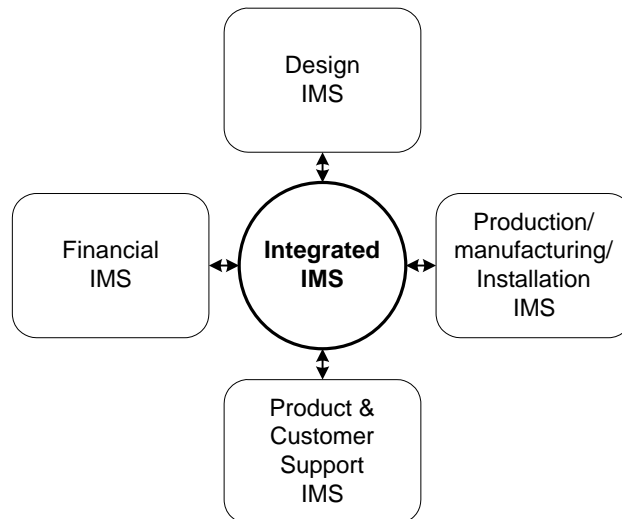


Customers' perception of product quality is affected by how well the product delivered conforms to the specification and fits for the intended use and by product reliability over time (Ref. 6). Customers are becoming over sensitive to the quality for not only services provided but also how they are delivered (Ref. 7). For a manufacturer product quality often means conformance and performance according to specifications. These parts need to be delivered and produced according to specifications to perform the intended function within the accepted tolerances. Product RAMS characteristics are an important part of this kind of quality. Product reliability is closely related to quality—not only reliability of the product itself, but also of the processes and services involved in delivering and supporting the product. The work processes producing the product preceding sales influence customers' quality perception as well.

Data and information collection, storage, distribution and their usage is a process that needs to be managed. This can be seen as a cognitive activity of interpreting, understanding, and making sense. Data (or raw facts) does not constitute information if it is not seen in a defined context and perspective. Moreover, what is encoded from information can only be considered knowledge if it is subjected to a learning process (Ref. 8). Furthermore, knowledge known at a given point in time needs to be used intelligently to justify the resources employed in the knowledge management processes. Data and information collected about various users' system applications and the support activities of maintaining, servicing and supporting these applications over time, adds up to a considerable knowledge about existing systems. This knowledge resource can be explored and used intelligently – not only for a company's own purposes like development, marketing and sales of new and improved systems, but also for optimizing customers' needs. To make the information management process practical, effective, and efficient, there needs to be in place information systems that make it possible to integrate information from various sources and product life cycle phases as shown in Figure 1.

### *1.1 RAMS & Quality Data and Information*

Product development is often evolutionary in nature. Introduction of a new product model, a new product generation, or even a new product, is based on experience gained from existing products, similar products, competing products, or by combining product ideas with knowledge, experience, information and data. It is therefore critical to obtain data and information from users regarding existing products to improve knowledge about existing systems as well as systems to be developed.



*Figure 1: Integrated Information Management System (IMS)*

Information and data is of no value if it is not used for a purpose. Data that is time stamped, collected with a defined context and background helps in understanding the process. In other words, information and data can have different meaning depending on the purpose, context and the person using it. If information is studied in a systematic way for identifying trends, specific characteristics, attributes, etc., much can be learned, and both products and work processes can be improved. Knowledge gained can be used, taught, distributed and used as a basis for procedures, idea creation, and innovations. In addition, suitable data analysis tools (e.g., statistical tools, FMECA, FTA, ETA, etc.) need to be available for this purpose.

Examples of possible usage of RAMS information and data includes:

- Design and development of new models.
- Reduction of spare parts and warranty costs.
- Selection of sub-systems, parts and components, vendors.
- Identify the focus for product improvement.
- Identify the focus for product support (after sales service, client support) improvement.
- Identify reliable/unreliable items.
- Design of preventive maintenance strategies.
- Design of products with respect to upgradation and modifications.

- Design of maintenance related sensors and remote surveillance (diagnosis, failure prediction, load and stress recording, product use and operational loads monitoring).

For the manufacturer the data are valuable because the data can help him to improve the product—something the product owner may be interested in as well. Distributors can use the data to predict logistics, costs and service, while suppliers can use the data for improving the components and parts.

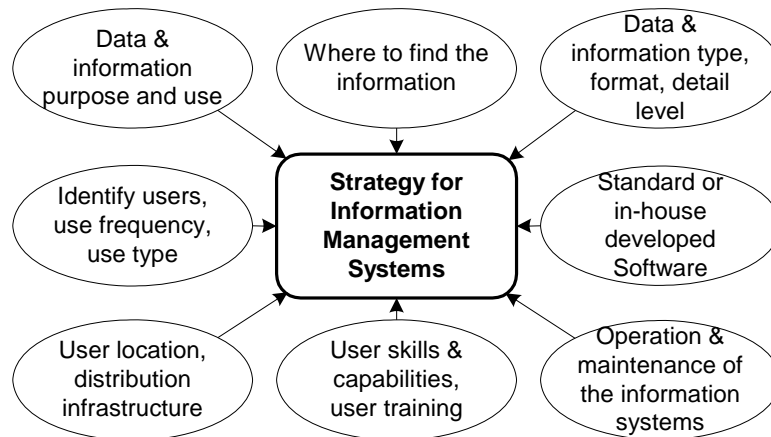
If the data and information (qualitative as well as quantitative) are found in various places, in various formats, and in various degrees of completeness, it will be hard to get a holistic view of what the data and information system incorporates. The right data has to be available for the right user in the right format at the right time. The use of data in product design has to be effective as well as efficient. To improve the physical product information and data regarding reliability, customer satisfaction, maintenance, operations, service, market, management focus, market performance, etc., needs to be available to the correct users (effectiveness). Furthermore, the data need to be stored in systems that make it easy to retrieve, analyze, and draw conclusions on a continuous basis (efficiency). Questions that may require an answer to define the purpose of collecting data and information could be:

- What is the purpose of the database?
- The database is directed towards which use?
- What type of information should the database contain?
- In what format should the information be?

Some of the factors influencing strategies for management of RAMS data and information systems are shown in Figure 2.

The strategy is to learn from the field data in order to gain knowledge, which together with intelligence can be used to improve products. Various sources for information could be: warranty claims, previous experience with similar or identical equipment, repair facility records, factory acceptance and testing reports, records generated during the development phase, customers' failure reporting systems, tests (field demonstrations, environmental qualification, and field installation), and finally, inspection records generated by quality control/manufacturing groups.

Dhillon (Ref. 9) asserts that "...the fundamental goal of a failure collection and analysis system is to convert the relevant information accumulated in various sources into an effectively organized form so that it can be efficiently used by individuals with confidence in conducting assigned reliability related tasks".



*Figure 2: Factors influencing strategies for Information Management Systems*

In this paper, we will be discussing the collection, storage and rationalization of RAMS data and information. Furthermore, we will discuss information flow and integration of various RAMS information to facilitate product and process improvement.

#### *Acronyms*

RAMS	Reliability, Availability, Maintainability and Supportability
LCC	Life Cycle Cost
FMECA	Failure Mode Effects and Criticality Analysis
FTA	Fault Tree Analysis
ETA	Event Tree Analysis
FRACAS	Failure Reporting, Analysis, and Corrective Action System
SWOT	Strengths, Weaknesses, Opportunity and Threats Analysis
IMS	Information Management System

## **2 THE CASE STUDY**

This study is part of a larger project initiated by the company to analyze the work processes involved in designing, manufacturing, delivering, and supporting the products to identify areas for improvements. The case study was conducted to map and evaluate information sources and user friendliness of RAMS databases for design related work processes. Furthermore, we wanted to identify information needs not covered in the databases. The goals were accomplished by studying the existing

databases and applications by the use of interviews, surveys, discussions, and participation in projects and meetings.

The case study consisted of a qualitative analysis of the design and manufacturing processes and information flow related to RAMS and product design. We interviewed a large number of employees and conducted a quantitative as well as qualitative assessment of the information sources. The survey focused on identifying factors that affected the product design characteristics and service life performance. We knew much of information was available in various sources such as databases, reports, documents, etc. However, much information and knowledge were only available in employee's mind as "biological" or "mental" knowledge and therefore not documented. We therefore wanted to map the information and knowledge, and to make the information systems more transparent. Furthermore, we wanted to integrate RAMS related information in the work processes to manufacture the products and supporting the customers.

To get a holistic view of the various work processes we selected employees from all departments and groups to participate in the surveys. SWOT analysis was applied to organize and categorize information. The study can be characterized as action research methodology where the researcher participated in actual processes and operations under investigation (Refs. 10 & 11).

### *2.1 The Company and Products*

The company observed for the study manufactures flexible, advanced, integrated, and automated production systems. The systems are powered by electrical motors and are controlled by advanced software solutions, electronics, and sensors. The customers used the products in production lines where uptime and precision is critical.

The products have been very successful, resulting in business growth and further product development. Even though they have not been able to design out all needs for maintenance, the products are very reliable, dependable, and durable.

Products are categorized as standard products, customized standard products, and development products. These products are designed to last for at least 50,000 hours of continuous use. During the product exploitation phase, the product owner will need spare parts to counter life cycle wear, tear and degradation. Since the product is highly complex and integrated, expert assistance is occasionally needed for diagnostics and problem resolution. The interaction with the customer is considered critical for success and new product development.

## 2.2 *Data and Information Sources*

We found that the company has many data sources where information relating to RAMS design performance and design maintenance was available. Some of them are:

- PDR (Product Defect Resolution Process): “Describe product errors which are discovered in the market and which have unknown solution. Days are counted to show how efficient the company is to resolve the activated problems”.
- ZD (Zero Defect to regional office): “Show product defects, and shortcomings arising in the installation phase of new products”. The manufacturing department uses and maintains the database.
- CCRP (Customer Complaint Resolution Process): The database provides feedback of any form from the end user.
- HD (Help Desk): Records information, actions and status of online customer support cases.
- TQS (Total Quality Statistics): “Database for reporting of defects internal, to supplier and return from market”.
- PDM (Product Document Management system): Registration of all documents related to the product.
- ERP (Enterprise Resource Planning system, AS400).

Other information/data sources found were: register for spare parts and warranty parts (in ERP system), product documentation, service reports, market reports, supplier data, quality reports, and project review reports.

We observed that neither distributors nor suppliers were used as RAMS information sources in the design phase for feedback of product operational experiences. Since distributors keep the main contact with the customers both during product design and utilization phases, much unexploited data and information may exist externally. Examples may include: maintenance data, reliability data, service data, customer product use data, warranty and spare parts, cultural knowledge which can influence product application, and knowledge about customer capabilities and resources. Suppliers may be used as valuable sources for RAMS information such as: warranty and spare parts statistics, reliability data, maintenance specification data, service data, product use data from various customers, quality data, and product attributes.

Further on, they used advance software systems for product design and analysis, for administration and management of related documentation, and for production of the their products. Databases and information systems to manage customer feedback, to resolve complaints and product problems, to assure and control quality, to report field service actions, and to provide information to customer about new and improved product solutions. They as well have in place telephone help-lines and online Internet support to speed up problem resolution.

As observed, there existed many possible sources of information that can be related to product and work process improvements and integration of RAMS in design and manufacturing process. The problem is to identify and route the interesting information to RAMS improvement activities, and to make it ready to be applied in RAMS tools and methods. Many of the information systems were used for reactive and not for proactive improvement purposes. As data and information accumulates, the data should be identified and used to identify weaknesses and opportunities for improvements, as well as to avoid repeating mistakes. The databases can also be used as a source of information while solving similar problems or during design and development of new products and models. There seemed to be a lack of information system integration and holistic perspective of possible use. Some of the information systems were found to be difficult to use and error prone. Often it was difficult to get access to the databases as well. Common for many of them was that the information was in qualitative format, making it difficult to search, filter, and find information when needed. This also makes statistical analysis and trending in most cases difficult, cumbersome and work intensive. More quantitative information was needed for producing better LCC analysis and availability estimated for the standard products. Many of the information sources and the information therein were intended for product improvements and not so much for improvement of work processes. Improvements of products and work processes are intertwined and complementary activities, not mutually exclusive.

Though the most of the information focused on the products, often the root cause of a product problem recorded in a database were traced back to work processes, activities, procedures, routines and checklists in use during product development and delivery. However, the information was not systematically used for this purpose. To improve the processes the information need to discussed and used with improvement of both processes and products in mind. They have used intranet for some years for providing easy access to information sources, and have recently also started to use the Internet to facilitate easy access and distribution of information.

### **3 IMPROVEMENT EFFORTS INITIATED**

#### *3.1 RAMS Activities Coordination and Integration*

To increase focus on RAMS integration a RAMS coordinator position was created in the company. The position was cross-functional and partly of independent position to facilitate easier integration of various work processes in product development and to avoid sub optimization at various levels.

The coordinator was responsible for coordinating efforts focused on integrating RAMS into work processes, development and use of RAMS tools and methods, utilization of information sources, data, and experience which can be used to improve product RAMS characteristics, and, not the least, for training of employees with respect to these issues.

An added benefit of the case study and the RAMS coordinator's efforts of identifying information sources with information relevant for product improvements was that it provided an opportunity for identifying improvement possibilities of the information sources. For example, many concrete information system improvement possibilities were identified in the mapping of RAMS information flow. The field service reports have been improved as a result of suggestions from the employees and from identification of new information usage. To make effective and efficient use of the information sources, demands must be specified with respect to use and needs, information type and format, how it is to be accessed and by whom, and how the information has to be routed to fulfill the various purposes, etc. In this study, several new ways to use databases and information sources to improve products and work processes were identified. To achieve the goal of design for performance and effectiveness it is necessary to deliver products with documented quality, reliability, maintainability and competitive life cycle cost.

### *3.2 RAMS Tools and Methods, Information Flow and Circulation*

Central in their efforts of integrating RAMS into work processes was the development of a computerized design tool based on FMECA methodology. Information about possible ways of the product failure and product weaknesses originated from many sources as shown above. The intention of the FMECA tool was to formalize and standardize design processes with respect to RAMS, to meet demands from customers with respect to documented reliability analysis, and to make it easier to identify product improvement opportunities. The computerized tool was used actively in the design process.

Even though FMECA analysis has been performed in the company for many years, only recently efforts have been initiated to formalize and systematize the analysis process. The results from the analysis have gradually become popular and used more frequently in decision making. Such results provided basis for decisions making, such as recommendations for preventive maintenance, spare parts and maintenance tools (both for commissioning and exploitation of life cycle phases), documentation (including procedures, routines, and checklists for installation, failure diagnosis, maintenance and service), and life cycle cost predictions. The analysis also has served as a basis to evaluate warranty considerations, maintenance programs, modifications and upgradation of existing products, customer training, and feedback to involved parties. The vision was to be able to design out all unplanned corrective



failures and warranty costs. The focus was on to design the product for improved performance and to achieve higher added value for the business. To facilitate achievement of this goal we realized that field data and information must be integrated in the design and development work processes in an effective and efficient way.

The central idea for information flow could be depicted as an information circulation system where the information is routed from the sources to the processes where it can be used. A framework for FMECA analysis as illustrated in Figure 3 is currently being implemented by the RAMS coordinator and practiced by the company. The company calls this the "RAMS information circulation system". The continuous lines indicate established channels/links whereas broken lines indicate potential, but yet unused, flow of information.

The information circulation system could be compared with the "blood circulation system" for a living organism in which a heart pumps blood through arteries and veins to the various organs. Similarly, the RAMS tool FMECA is functioning as a pump circulating the information around the system. Often companies have departments or disciplines performing special functions that create, use, collect and store information related to their output product and work processes. However, as often found in many companies, the data and information collection was disorganized, unsystematic and many separate databases, reports, and documents were used for storage and distribution. The result was that the information systems was neither transparent nor accessible, and that data and information were not routed to the work processes where the information could be used in innovative and creative ways to improve products and processes. The RAMS methodology calls for and demands the same "blood" as in the common circulation system. Such a system is in reality a closed loop system similar to the well-known FRACAS methodology. Since improvement of products and work processes often have to be connected and complementary, the FRACAS methodology could be expanded to also include information related to work processes, online condition monitoring and diagnostic systems.

Since there are almost 20 different databases and information sources related to RAMS and design processes, there obviously exists a need to evaluate information sources that could be combined, integrated, improved, or removed. The company therefore has started to evaluate the databases and information sources to assess their quality in order to avoid duplicity in content, use, and not the least, to reduce operation and maintenance related costs.

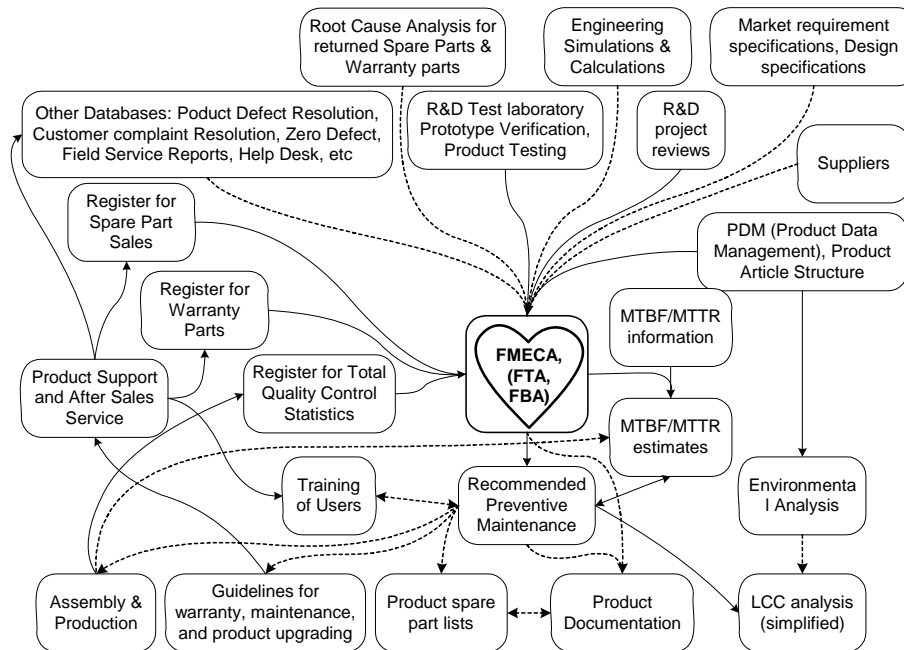


Figure 3: Integration of RAMS Information System and Infrastructure as implemented in the company

#### 4 DISCUSSION AND CONCLUDING REMARKS

Advanced computer technology makes it now possible to collect any amount of data one may want, and advanced storage, internet, and communication technology makes it easy to transport, distribute, and access the data as and when needed. However, collection of historical system data and information is useless unless it is used for something. Much data could be collected to be stored in growing databases never to be accessed, analyzed, trended or used again. The product owner must be willing to share the data with the parties who are in need of them. In the end, it would lead to better use, support of existing product and improved next generation product. To avoid collection of too much data, the wrong data, or data that cannot be analyzed because of missing background information, all involved parties need to agree about which information/data to collect, how to collect, store, distribute it, and how to share the costs. Today advanced inexpensive sensors; computers and software are available for recording information of product performance during real transportation and real use. It is up to the involved parties to use it intelligently and wisely.

For the manufacturer often the only source of product usage data and product performance experience is warranty and spare parts data, customer complaints, and information from service personnel. The weakness using this kind of system could be that data collected from one product owner may not be applicable to another, or that the manufacturer does not know anything about the data background, context, influences, and so on.

From the case study we conclude that to achieve the specified performance, it is important to integrate RAMS information with design to facilitate easy retrieval of information when ever needed without any complexities. Often there is no shortage of data and information—what is lacking is the routing of the information to the interested parties and to translate the data into information and from information to knowledge for correct decision making. While designing products, one has to rely on correct information about the performance of existing products. The key is the right flow of useful information in design and manufacturing processes. Data and information systems constitute the basis for the organization's collective knowledge and intelligence. In short, the information infrastructure systems need to become more transparent to create total information awareness and transparency. In addition, companies needs to focus on RAMS data and information integration in the design process.

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# **PAPER IV**

## **Design and Development of Product Support & Maintenance Concepts for Industrial Systems**

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# Design and Development of Product Support & Maintenance Concepts for Industrial Systems

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## ABSTRACT

Product design and service delivery both affect service performance, and therefore a product support strategy must be defined during design stage, in terms of these two dimensions, to ensure the delivery of 'promised product performance' or the functional product to customers. Furthermore, product support strategy should not only be focused around product, or its operating characteristics, but also on assisting customers with services that enhance product use and add additional value to their business processes.

In a study conducted in a manufacturing company, we examined various issues such as reliability, availability, maintainability, and supportability (RAMS), etc., which directly or indirectly affect product support, maintenance needs and related costs. The purpose was to analyze issues related to product support and service delivery strategy as being practiced by the company, and to suggest means for improvements.

On the basis of the case study, we present an approach for design and development of product support and maintenance concepts for industrial systems in a multinational environment. We emphasize that the strategy for product support should not be centered only on 'product', but should also take into account important issues such as the service delivery capability of the manufacturers, the capability of users' maintenance organization, logistics, etc. Furthermore, our discussion also focuses on issues related to product upgrading and modifications, remote product surveillance, etc., to improve the impact of the existing product support strategy and practices.

*Key words:* Maintenance & product support, Functional products, Reliability and maintainability, Failure diagnostics & prognostics, Life cycle costs, Maintenance strategies, Service delivery strategy, Service reception strategy

## 1 INTRODUCTION

Most physical products and systems wear, tear, and deteriorate with age and use. In general, due to cost and technological considerations, it is almost impossible to design a system that is maintenance free. In fact, maintenance requirements come into consideration mainly due to a lack of proper designed reliability and quality for the tasks or functions to be performed. Thus the role of maintenance and product support can be perceived as the process that compensates for deficiencies in design, in terms of unreliability and quality of the output generated by the product. Other factors such as human error, statutory requirements, accidents, etc., also influence the design and development of product support and maintenance concept.

Product support and maintenance needs of systems, are more or less decided during the design and manufacturing phase (see e.g. Blanchard, 2001, Blanchard and Fabrycki, 1998, Goffin, 2000, Markeset and Kumar, 2001, Smith and Knezevic, 1996). Often the reasons for product failures can be traced back to design engineers' and management's inability to foresee problems. Furthermore, the strategies adopted by owners/users concerning systems operation and maintenance, also considerably affect maintenance and product support needs. Hence, we can assert that product design and service delivery both affect service performance, and therefore product support strategy for customers must be defined in terms of these two dimensions. See Cohen and Lee (1990) for further discussion.

Service delivery performance in the operational phase can be enhanced through better service delivery of spare parts and improvement of the technical support system. However, to ensure the desired product performance at a reasonable cost, we have to design and develop maintenance and product support concepts right from the design phase. The existing literature appears to have paid little attention on the influence of product design characteristics in dimensioning product support.

### *1.1 Product Support: Some Basic Concepts*

Traditionally, support merely constituted maintenance, service and repair. However, as the scope of product support has broadened over the past decade, it has also been included such aspects as installation, commissioning, training, maintenance and repair services, documentation, spare parts supply and logistics, product upgrading and modifications, software, and warranty schemes, telephone support, etc. (Blanchard and Fabrycky, 1998, Goffin, 1999, Wilson et al. 1999).

Product support, in respect to maintenance needs, can be classified as tangible and intangible, as well as planned (proactive) and unplanned (reactive). It is tangible if there is an exchange of physical parts (e.g. spare parts, tools, printed documentation, training manuals, etc.) involved. If the rendered service involves only intangible

support (e.g. expert advice, training, online support, etc.) pricing is more complicated. Planned support is often related to preventive maintenance, training, installation, commissioning, etc., while unplanned support is often connected to unplanned corrective maintenance activities where the product fails unpredictably (we exclude here planned corrective failures of non-critical parts, components, and sub-systems). Unplanned support can also be the assistance needed to resolve problems related to planned maintenance and service, but where the documentation is inadequate, the recommended spare parts or tools are unavailable, etc. Common for unplanned support and maintenance is that it is often very inconvenient, costly and time consuming for all parties involved.

As customer satisfaction is crucial to business success, product and service strategies should be aligned to customers' needs. Staying close to customers and providing superior services create more loyal customers and increased customer satisfaction (Fites, 1996). Improved customer satisfaction and increased repeat sales can be achieved by matching service and product support delivery strategy to the urgency of the customer's needs (see Cohen et al. 2000). How the quality of these service delivery processes improves customer satisfaction and loyalty, has been discussed in depth by many researchers (see e.g. Berry et al. 1988, Grönroos, 2000, Kasper and Lemmink, 1989, Parasuraman et al. 1985). A distinction between services supporting the products, and services that support the customer's actions in relation to products is essential for developing an optimal maintenance and product support strategy (Mathieu 2001). The main goal of a service intended to support a product, is to ensure the expected function and/or to facilitate the client's access to its function. Services intended to support the customer, are related to improving the customer's accessibility to product function, efficient and effective use of it, and retrieval of performance attributes. Implementation of effective and efficient service strategies requires a thorough understanding of product characteristics, product application, etc. during use. However, the kind of services delivered by manufacturers of industrial products, which are closely connected to the product reliability and performance characteristics, have not been researched extensively (Goffin, 1998, Goffin and New, 2001).

## **2 CASE STUDY OBSERVATIONS AND ANALYSIS**

The company studied is a part of a larger industrial group of companies with regional offices located all over the world. It produces various types of customized integrated and advanced production systems. More formally, the regional offices purchase required systems from the manufacturer and integrate it into the customer's production system. The company has observed an increased trend in product support needs. It is not clear if this is caused by more products being sold, increased product complexity, reduced product reliability compared to earlier model, by changed or

more intensive product use, or by changed customer needs and conditions. The product will be more attractive if it is designed for low Life Cycle Costs (LCC), minimal required support, and optimal support delivery.

The study can be characterized as an action research methodology where the researcher participates in the processes and operations (see e.g. Westbrooke, 1995). Various forms of data and information were collected through employee surveys, interviews and conversations, study of company literature, participation in meetings and projects, and analysis of work processes. SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis methodology was used to organize and systematize the observations and information.

### *2.1 Recommended Maintenance Practices, Predicted LCC and Performance*

Customers are increasingly focused on reliability and cost. For the company to stay competitive it is necessary to deliver products with documented and predictable quality, reliability, supportability, and maintainability. The customers are also demanding an estimate for life cycle costs. The company has developed a software tool to assist in making sure that RAMS issues are considered throughout the product design, manufacturing, and delivery phases. The tool is based on FMECA (Failure Mode Effects and Criticality Analysis) methodology and is integrated in product development project management. An LCC analysis is dependent on good reliability and maintainability data input. Much of this data can be estimated using experience, service reports, spare and warranty parts data, comparison with similar products, product databases, etc. However, quantitative input from product owners and users would be valuable to reduce uncertainty in these estimates (see Markeset and Kumar, 2003a). The design tool developed in the company will provide a basis for recommended maintenance strategies (including preventive maintenance), training, documentation, spare part logistics, product support, etc.

### *2.2 Documentation*

Product documentation has gone through a tremendous development during the last five-six years and is now considered to be excellent, employing the latest software developments to make it more accessible and easy to use. For complex products, there is a problem to make the available information accessible and understandable to the user. Documentation also usually ends up being quite extensive. Excellent documentation can be of immense use in dimensioning of product support during the design phase, as well as in maintenance, service, diagnostics, and repairs/restorations after failure. Furthermore, documentation is important for the company in

respect to warranty and support. Recent developments in information technology make it easier to make digital documentation.

### 2.3 *Spare Part and Warranty Issues*

The sale of spare parts is an important source of income for the company, but at the same time warranty costs are substantial. Corrective maintenance often involves warranty considerations during part of the product's service life. The company want the market to have the impression that they provide high quality products that are reliable, durable, dependable, and come with no negative surprises. As a result, they are continuously trying to improve their products and to remove the need for spare parts. However, it often proves impossible to design out maintenance, and as a result the products have to be designed for effective and efficient maintenance and support. Even if the product is designed for maintenance free life cycle, random and unforeseen failures can still occur. It is negative for both customers and manufacturer that warranty parts are needed. However, both warranty and service provision is a way of reducing the risk for customer.

### 2.4 *Training*

The company offers various training programs for their customers. However, there may be a need for the instructors to acquire hands-on experience from a customized product application as seen from the customers' viewpoint. Lack of user understanding of product capabilities, and a difficult user interface, reduces the user's capability to utilize the product fully. The result can be a very dissatisfied customer. Incorrect use can also lead to increased maintenance, faster degradation, tear and wear, increased warranty costs for the manufacturer. In the worst case, it can lead to accidents, reduced safety, and damage to health and environment. Training of users and operators improves their ability to correctly apply/use and maintain the products, and, not least, increase user satisfaction. The ability to take full advantage of product capabilities and capacities, and to obtain maximum product value, also increases.

### 2.5 *Customer Complaints Resolution Process: Online Service & Assistance*

The company uses many databases and information systems to manage customer feedback, complaints and product problem resolution, quality assurance and control, field service reporting, information provision to customer with respect to product problem solutions, etc. They also have in place telephone help-lines and online/Internet support for fast problem resolution.

We observed that employees were often disturbed in their planned regular work to resolve customer problems requiring expert assistance. This kind of product support work they call ‘fire fighting activities’ and often have high priority. This kind of ‘work process disturbances’ will exist as long as unplanned and unpredictable product failures can occur and the customers (or any intermediaries) do not have the required competence to resolve the problem themselves. A more ‘proactive’ approach would be to try to reduce the consequences of such disturbances for both the customer and manufacturer, by planning and accommodating for such activities (inserting contingencies in experts’ time schedules, implementing possibilities for remote product surveillance, improved communication, etc.). To remove the need for this kind of assistance may prove impossible as the failure has to be designed-out, but the consequences can be reduced by increasing diagnostic capabilities, improving documentation, diagnostic and corrective routines, etc.

Figure 1. depicts examples of different kinds of product support observed in this study.

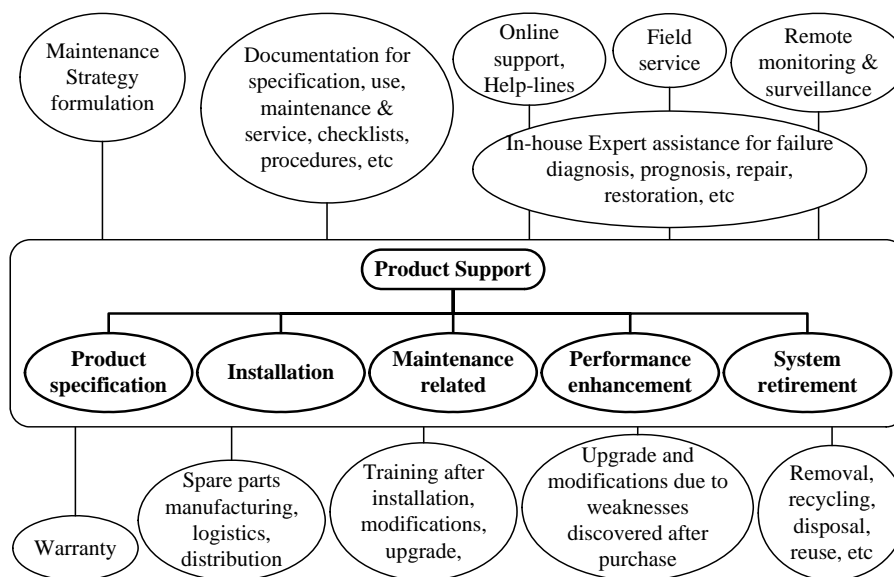


Figure 1: An overview of product support and service types observed in the company.

### **3 DEVELOPMENT OF PRODUCT SUPPORT AND MAINTENANCE CONCEPT: DIMENSIONING OF PRODUCT SUPPORT**

Based on the discussions in previous section, we find that product support and maintenance concept is decided and affected by issues both during the design and operation phase. We will now discuss design and development of product support during design phases of product development.

#### *3.1 Product Support and Service Delivery Strategy*

Product support needs are dependent upon product characteristics such as reliability and maintainability, the customer's skills and capabilities, and the environment in which the product is going to be used. Therefore product support specifications should be based on design specifications and conditions faced by the customer. The idea is to be proactive in the design phase, not reactive in the exploitation phase.

After-sales services are often in response to a customer problem, e.g. product failure restoration, problem diagnosis, expert assistance to resolve a problem, problem with using the product, etc. Therefore after-sales service is a recovery process that attempts to resolve a customer problem, which if not resolved, causes dissatisfaction and a less satisfied customer. The service function therefore attempts to recover the customer satisfaction to the level it was before the occurrences of problems (Grönroos, 2000). In the long-term, a manufacturer will benefit from supplying a product that needs as little maintenance as possible.

It is important to understand operators' requirements, performance targets, system attributes, and the competence level of operators and maintenance personnel before the design process is initiated. It is essential that customer needs and organization culture are integrated with system attributes and product support strategy. Companies developing products and services need to understand what consequences and benefits product attributes have on customer needs and values, and how they affect customer expectation and satisfaction. Product attributes related to customer satisfaction can be divided into 'must be' attributes (basic requirements), 'one-dimensional' attributes (performance requirements) and 'attractive' attributes (surprise and delight requirements) (Kano, 1984, Matzler and Hinterhuber, 1998, etc.). These are captured in the information pyramid depicted in Figure 2. The bi-directional arrows show two concepts, namely the concept of abstraction where concrete product and service attributes provide consequences and benefits which fulfill the customer's needs and values, and the concept of translation where information about customers needs and values are translated into concrete products and services (Johnson, 1998).

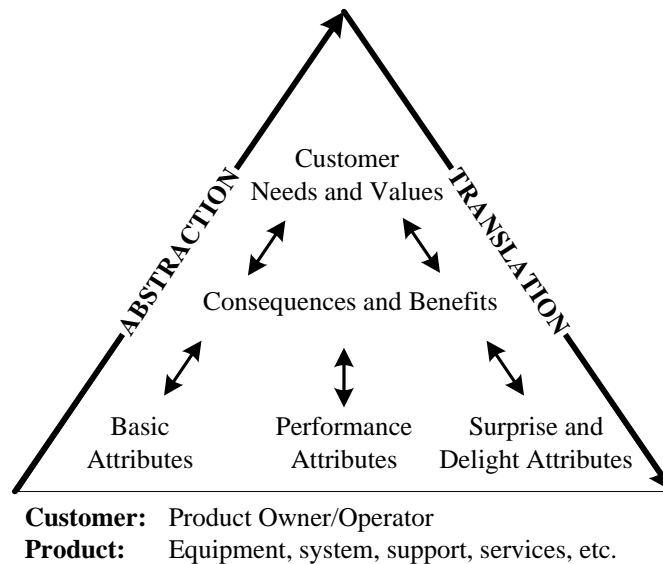


Figure 2: Integration of customer needs and product attributes (adapted from Johnson, 1998).

System engineering is an effective approach to incorporate customer's specifications into the design process. It is a top-down approach to product development, viewing the system as a whole, focusing on customer's needs, wants, preferences, and requirements—starting with the functional requirements and the functional performance of the product. Figure 3. illustrates the relationship between product/system characteristics (reliability and maintainability), product exploitation (type of application), and product support. Designed product functional and RAMS characteristics influence how the product is operated and maintained, as well as what kind of, how much, and when support is needed. Furthermore, product use and maintenance, customer's skills and competencies, operational environment, etc., also influence what kind of product support needed. The continuous lines indicate primary influences, whereas broken lines indicate secondary influences. The box containing product characteristics and product support forms the functional product. To avoid blocking capital the customer can choose to buy only the function, and not the product (Markeset and Kumar, 2003a). Of late, this has become increasingly popular and a more attractive approach. With functional products, the user company focuses on core business processes (e.g. production) and need not worry about service/maintenance. In such an approach, both parties (supplier and customer) share the business risks.



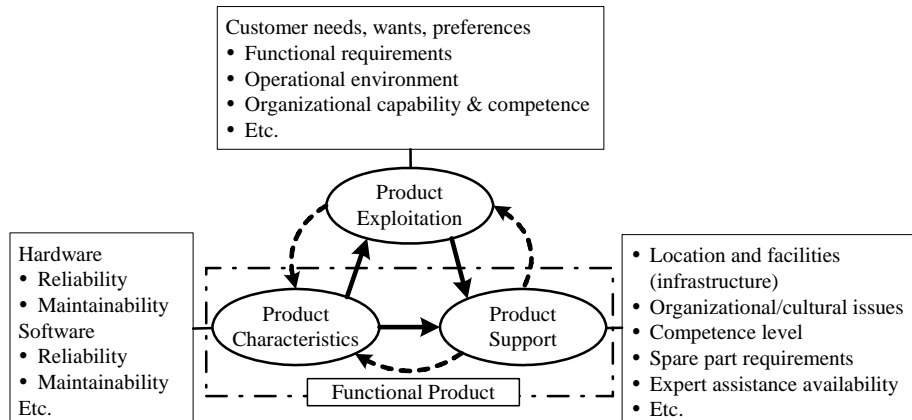


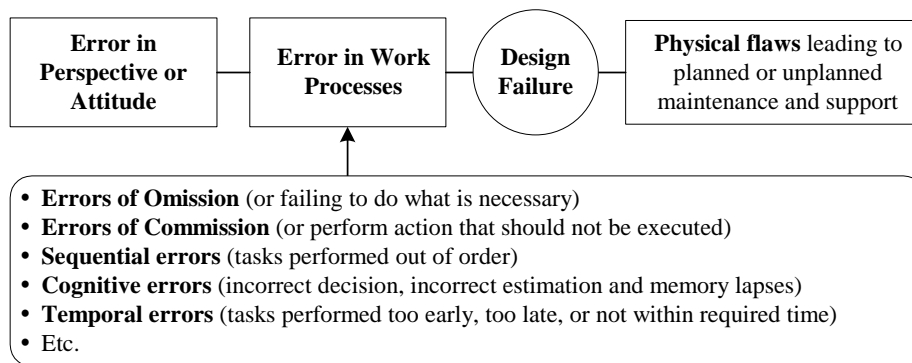
Figure 3: Relationships between 'Product Characteristics', 'Product Exploitation', and 'Product Support'.

### 3.2 Flaws and Errors: Root Causes of Product Support and Maintenance Requirements

As a product becomes increasingly complex, integrating advanced mechanical, electrical, software, and electronic subsystems and technical solutions, it becomes increasingly difficult to foresee all the possible ways that the final product can fail. As the components and sub-systems become more technically advanced and the number of components increases, the possibilities of failure also increase. Through exhaustive testing of prototypes before product release and use, many potential failures can be eliminated. In evolutionary design, there is the opportunity to improve the functional performance by designing-out weaknesses (physical, functional performance, etc.) found during exploitation. By adding something new or changing a standard product, by customizing it to fit a customer's demands, wants, and desires, one also introduces various new possibilities of product failure.

Product failures can be attributed to failure in the design and delivery processes, operational environment, or how the product is used. A design failure can be defined as an inability of an engineering solution to perform its intended function(s), while errors can be defined as the underlying cause for design failure (Volland, 1999). Both the specification process and the implementation processes of the product creation process contribute to design failures. The specification process is often a result of interaction between the manufacturer and the industrial customer, whilst the design specification implementation process is the responsibility of the manufacturer. The underlying causes of failures can be attributed to physical flaws (e.g. overload,

fatigue, corrosion, electrical hazards, etc.), error in work processes (design, analysis, manufacturing, assembly, maintenance, operation), and errors in user perspectives and attitudes as shown in Figure 4. Errors in work processes can cause physical flaws and typically include incorrect calculations, faulty assumptions, miscommunications, failure to follow established procedures and routines, performing tasks out of order, etc.



*Figure 4: Failures & errors leading to product support and maintenance requirement.*

Flaws in the perspective or attitude of the employees participating in a specific work process can lead to errors in work processes. Reason (1990) defines human error as “the failure of planned actions to achieve their desired ends – without the intervention of some unforeseeable event”. Typical examples are error in judgment, error in moral perspective, overconfidence, under confidence, indifference, arrogance, selfishness, and other forms of focusing upon oneself rather than upon others. Training and awareness creating activities are therefore necessary to avoid such errors. The manufacturer should therefore carefully design the work processes for design, manufacturing, assembly, etc. and, not least, for supporting product use, to avoid errors in use and reduced reliability and quality, and, finally, for better service delivery performance.

### 3.3 *Quality and Reliability Issues*

Customer satisfaction is related to both product characteristics and product support quality. Customer perception of product quality is affected by how well the product conforms to specification and fits to its intended use, and also by product reliability over time (Juran and Blanton, 1999). Customer satisfaction is also affected by product characteristics such as maintainability, supportability, and product support, as well as

by the processes involved in providing product support. Customer satisfaction is, in other words, not only decided by value and performance of hardware purchased, but by the total value received, and by the quality of the interaction and relationship experience throughout the service life of the product.

### 3.4 ‘Design out Maintenance’ and ‘Design for Maintenance’

While considering maintenance in design, there are generally two options: either one can try to design out maintenance (Figure 5.) or try to optimize the design with respect to maintenance issues (Figure 6.). After having identified maintenance characteristics one has the possibility to try to eliminate those characteristics that would cause maintenance costs. However, if maintenance is to be designed out, one has to consider the cost of reliability throughout the product’s life cycle.

Furthermore, one has to consider costs and available state of the art technology. There are also other considerations such as product capacity, design alternatives, and payback of development cost, etc., to evaluate. There will always be trade-offs between these considerations. LCC analysis can be used to compare design alternatives and its results have to be balanced against market needs, customer willingness to pay, customer preferences, etc.

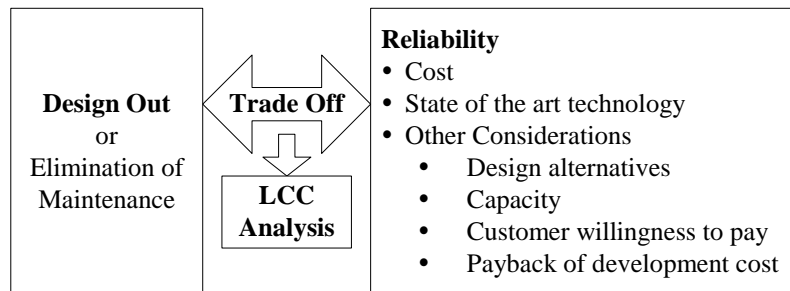


Figure 5: ‘Design out’ maintenance.

In designing out maintenance, one can use the RAMS tools like FMECA, FTA (Fault Tree Analysis), ETA (Event Tree Analysis), and risk analysis to arrive at the best LCC alternative. If the life cycle costs of the *design out maintenance* approach are higher compared to the alternative *design for maintenance*, one naturally prefers the latter. As long as the failure or degradation mechanism is known, one can design a compensating maintenance and support strategy to reduce risk, and to make the product easy to maintain and support. The presence of wear mechanisms causing maintenance does not mean that the system is unreliable – it may however become unreliable if the compensating mechanisms are unreliable or fail. If the reliability is

too low, maintainability issues such as accessibility to parts that need to be maintained, serviceability and interchangeability of parts and systems, use of modular design have to be considered (Blanchard et al. 1995, Dhillon 1999, Ericsson and Erixon, 1999, Thompson, 1999). Warranty and life span are also issues to be evaluated. The objective of such analysis is to reduce product maintenance time and cost, and to determine labor and other related costs by using maintainability data to estimate item availability.

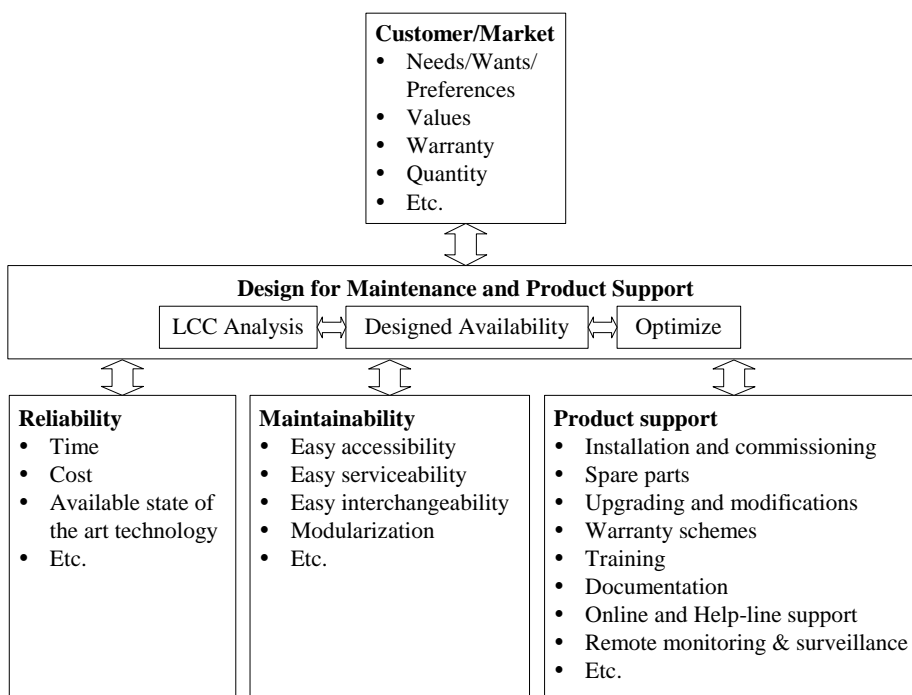


Figure 6: 'Design for' maintenance and product support.

Other ways to reduce future maintenance needs, is to reduce capacity, to substitute/ eliminate the weak functions, or to replace weak components by ones that are more robust. If we allow the system/component to fail due to various limitations, then we need to have a provision for easy and quick repair/ replacement. Thus, when designing for maintenance, one will first have to examine the reliability characteristics, and thereafter decide the maintainability characteristics. Both reliability and maintainability are traded off to meet the design requirement. LCC analysis, in combination with risk analysis methods, could be a viable tool for evaluating these issues (Blanchard and Fabrycky, 1998, Moss, 1985). Furthermore,

the maintenance procedures need to be correct, precise, as well as easy to follow and technical methods need to be safe enough.

### 3.5 *Operating Environment*

Operating environment should be seriously considered while dimensioning product support and service delivery performance strategies. More often than not, the recommended maintenance program for systems and components are based on their age without any consideration of operating environment. This, in turn, leads to many unexpected system and components failures. This creates poor system performance and a higher LCC due to unplanned repairs and/or restoration as well as support. The environmental conditions in which the equipment is to be operated, such as temperature, humidity, dust, maintenance facilities, maintenance and operation personnel training, etc., often have considerable influence on the product reliability characteristics and thereby on the maintenance need and product support requirement (Kumar and Kumar, 1992, Kumar et al. 1992). Furthermore, the distance of user from manufacturer, distributor/supplier can bring additional influence.

### 3.6 *Design for Data Collection, Diagnostics, Prognostics, Internet Applications, etc.*

During operation phase, manufacturers can benefit from obtaining information about the product's technical health as well as conformance and deviations from the expected performance targets. The collected data can be effectively used for the development of new generation of products, but most importantly, it can be used for changing design to remove or reduce any critical weaknesses in design that lead to higher demands on service and maintenance. The data can also be used to make prognoses about future maintenance and support needs, and to predict when to upgrade, modify or replace the equipment. See Markeset and Kumar (2003b) for further discussion.

The designer's goal, in respect to design for diagnosability, is to create a process of determining the parameters that can signal product ill health. Automated sensor-based diagnostics systems have been the focus in work conducted towards diagnostics in mechanical systems (Paasch and Ruff, 1997).

Remote and real time assessment of performance, which often is a must for automated and complex systems, requires integration of various technologies such as sensory devices, reasoning agents, wireless communication, virtual integration and interface platforms. In the near future, Internet and advanced communication technology can be used to facilitate easier assessment of product performance, maintenance, and support system. Furthermore, advancements in information

technology provide a better interface and thus largely facilitate communications between users and the support system (Lee, 2001).

### *3.7 The Capabilities of Manufacturer's Service Organization and Customer's Maintenance Organization*

In general, manufacturers/suppliers beside being a manufacturer also need to maintain a service organization delivering services to their customers in the same way as any other service organizations such as a hotel, travel agency, bank, etc. Therefore most manufacturers usually have a service department responsible for delivering services such as assistance in fault finding, failure diagnostics, supplying expert assistance, spare part delivery, spare part storage, etc. However, many manufacturing companies are uncomfortable with the intense service expectations of their customers. The service department usually functions in a different way than other internal departments, since its relationship with the customers often is of a much longer duration. The service department needs to stay in contact with the customers for the rest of the product life span. While designing and dimensioning a product support and service delivery strategy, designers have to analyze the company's own service delivery capabilities and to align them with customer's needs. It is important to analyze owners' maintenance organization, location, level of competence, culture, etc., to arrive at the best service and maintenance alternative. If the supplier is delivering a total functional system (i.e. including operation, maintenance, and support), the customer's user environment, operation and maintenance goals and strategies, and so on, need to be understood to assure optimal and sustaining functional performance and customer satisfaction. This will help the designer to design an appropriate service delivery system that will satisfy the customer. As mentioned in the preceding section, this necessitates that manufacturing companies should analyze and understand its 'CUSTOMER' before adopting any strategy for service delivery. If not, the outcome can be poor product support and a dissatisfied customer. This is mainly due to work culture gaps, separating service environments from manufacturing environments.

### *3.8 Interactive Problem Resolution*

Some influential aspects of future product performance and failure are contended to be fundamentally unpredictable and unknowable at the design stage (Bea, 2001). When such problems occur in the exploitation phase, an interactive and improvised approach is often needed for fast, effective and cost efficient problem resolution. Furthermore, the manufacturer, distributors, customer, and suppliers should design in contingencies, risk reduction activities, active intervention training, etc., in product support for making the problem resolution process, for this kind of problem, as

painless and cost efficient as possible. By being proactive in the design stage, the consequences are less in the product exploitation stage for this kind of problem.

#### **4 DEVELOPMENT OF MAINTENANCE CONCEPT: OPERATION PHASE**

Once a system or product is commissioned for use, the maintenance concept is more or less fully governed by the type of maintenance strategy adopted by the user for the system. Establishing maintenance strategy requires understanding the technical characteristics of the product, and functions to be performed. Of course, one has to examine the types of resources (organization and level of competence) available. Often an interactive approach is needed to deal with maintenance problems in unpredictable environments such as mining, offshore oil exploration and production, etc.

Furthermore, measures need to be started for implementing world-class maintenance practices evolving from manufacturing and process industries, namely TPM (Total Productive Maintenance and RCM (Reliability Centered Maintenance). TPM (see Nakajima, 1986) was developed in Japan and has many successes in manufacturing sectors. On the other hand, RCM (see Moubrey, 1997) was developed in USA and is popular among aerospace and process industry for optimizing maintenance processes. In fact TPM and RCM have been major themes in the development of maintenance strategies for the last 10 years. Many companies have followed this route and have demonstrated considerable improvements in plant and process performance (Dawson, 1996). Many industrial companies are also adopting these philosophies and practices in their operations and maintenance strategies.

The type of maintenance strategy decided upon should be developed taking into account internal resources (facilities, tools, competence, knowledge and manpower, etc.) available to deal with maintenance and repair problems and issues. If there is a lack of competence or manpower to deal with maintenance/service work, one has to rely on external resources.

##### *4.1 The Use of External Resources and Outsourcing of Maintenance*

Contractors, distributors, and consultants who provide competence, knowledge or manpower to operations and are not directly employed by the product owners, are termed as external resources. Of late, many users companies are focusing on their core processes and competencies while outsourcing other areas. With the advent of this trend, outsourcing of maintenance is becoming a popular way to deal with maintenance and support requirements.

Recently many manufacturer and suppliers are offering total performance guarantee for their products or are supplying functional product as mentioned earlier. In such cases, the manufacturer and suppliers are taking the full responsibility for the operation, maintenance, and support of the system. The customers only pay the supplier for the function they provide. This has revolutionized the product support issues from the designers' point of view, forcing them to look for the best available solution that will lead to the lowest LCC. The past practice of making profit by the sale of spare parts and services to customers is no longer valid in case of functional products.

## **5 CONCLUDING REMARKS**

If a product is designed with due consideration for product support, factors influencing service delivery performance, and the competence and capability of users, it can be a major source of revenue for the manufacturer, distributors (agents) and users, and it can provide a sustainable competitive advantage in the market for all parties involved. Especially, in industries where operations are often located in remote areas, a good product support can play a key role in ensuring customer loyalty. The ultimate goal of the product, or service, is to facilitate or fulfill the customers' goals. These goals therefore need to be designed into the product or service. Furthermore, performance indicator system should be used to monitor the effectiveness and efficiency of the implemented operation, maintenance and support strategies. See Kumar and Ellingsen (2000) for further details.

In this paper we have discussed a general approach for the dimensioning of product support by taking into account product design characteristics, information technology applications, capability of service delivery organizations, client service needs and expectations, the manufacturer's delivery capabilities, etc. It is clear that maintenance is more or less dependent on the designer's perception of function to be performed, manufacturer's service delivery capability and user's competence, and capability of any third party involved. Products and services have to be designed from a holistic perspective benefiting and adding value for all participants. It is believed that if designed properly, product support and support strategy can be a major source of revenue and profit for the manufacturers, product owners, and intermediaries. Furthermore, during the operational phase of systems, a considerable amount of savings can be made from service and maintenance cost by establishing an effective and efficient service and maintenance strategy.



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# **PAPER V**

## **Study of Product Support Strategy: Conventional versus Functional Products**

Accepted for publication in Journal of Quality in Maintenance Engineering



# Study of Product Support Strategy: Conventional versus Functional Products

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## **ABSTRACT**

Most advanced durable industrial products need some kind of support to compensate for weaknesses in design or in product exploitation. Traditionally, the customer buys, operates, and maintains equipment used in production systems. Alternatively, the customer can buy the performance, instead of the physical product. In such cases, the manufacturer is responsible for operating, maintaining, and supporting the product in addition to designing and making it. Thus, the long-term profit for the process owner (customer) and the manufacturer alike will depend on the product's designed-in LCC (life cycle costs) – hence RAMS (reliability, availability, maintainability and supportability) characteristics – as well as the effectiveness and efficiency of the product exploitation and support processes. In general, product support is a source of income for the manufacturer. In a functional product scenario, the need for product support is a liability and a cost driver. Hence, delivery of performance requires a fundamentally different approach for product support strategy.

Based on a case study of a manufacturer of advanced durable industrial production systems, we examine different scenarios for product support. The case study shows that the company offers a large variation of services to support their conventional products throughout the life cycle. The company is gradually moving from offering products and traditional after-sales services, to offering services to support customer's product-related actions as well.

*Keywords:* Conventional products, Functional products, Functional Performance, Outsourcing, Life cycle cost, Life cycle profit, Total integrated performance, RAMS integration, Services to support product, Services to support customer, Product support strategy, Service delivery strategy, Service reception strategy

## 1 INTRODUCTION AND BACKGROUND

When a manufacturer delivers an advanced industrial product, the customer receives more than just a physical product/machine. Increasingly, traditional manufacturers find that both they and their customers depend on the services attached to the products. The services create additional long-term income and performance feedback for the manufacturer and improved utilization and maintenance performance for the customer. Levitt's (1972) contention "everybody is in the service business", seems to be becoming true.

Industrial customers demand increasingly better performance with respect to capability, capacity, quality, reliability, regularity, costs, as well as profits generated over time from their production systems. Even though many advanced<sup>1</sup> products/systems are steadily becoming more reliable, (*thus needing less corrective maintenance*), and easier to maintain (*thus resulting in reduced downtime*), they may need more advanced support services than before due to increasing complexity and integration of hardware, software, sensors, controls, information technology, etc. Often these services can only be provided by the manufacturer. Consequently, the customer and manufacturer may have a business-to-business relationship lasting throughout the product's service life. The relationship is based on the product's weaknesses, the manufacturer's and customer's capabilities and expertise, operation and maintenance strategies, infrastructure, etc. The relationship is as much based on intangible knowledge and expertise as on tangible physical components (such as spare parts, repair tools, documentation, etc.). Therefore, it can be characterized as a service process, where the service delivery strategy is dependent on a negotiated agreement (see Kumar et al, 2003, and Kumar and Kumar, 2003).

In the following, the concept of delivery of performance as an alternative to a conventional product is examined. However, for many companies the delivery and support for conventional products is still the only alternative. Therefore, firstly the product support strategy for a conventional product is discussed. Thereafter, the improvement opportunities of conventional product performance based on a case study is discussed. At the end, the implications of delivering performance on the background of conventional products are presented.

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<sup>1</sup> In this paper, the notion 'advanced products/ systems' refers to industrial durable products where mechanical, electrical, electronics, components and sub-systems, cables, etc. are integrated into complex systems and (often) controlled by the use of sensors, electronics, and software. Several 'advanced systems' can be engineered and programmed to perform a holistic function together. See Stevens et al. (1998) for details.



### *1.1 Definition of Functional Product: Delivery of Performance*

As an alternative to selling and supporting a conventional product, the manufacturer can deliver the product performance. In this scenario, the plant owner outsources the whole function to the manufacturer and/or supplier. In other words, the customers do not buy the industrial products/ systems/ machine, but instead buy performance such as drilled meter per shift, volume per hour, etc. The manufacturer is responsible for the product performance based either on a pre-designed existing product, or on a new product. The focus thus is on the delivery of performance rather than the physical product and support services. In brief, product support strategies will be different for functional products as compared to conventional product.

There exists a large volume of literature discussing product support strategy for conventional products. However, we have not found literature that explicitly focuses on development of product support strategies for situations where the business process owner buys the performance of the products/ systems rather than the physical product itself. In an increasingly competitive global market, where the industry is looking for ways to reduce operation and maintenance costs and to increase performance of their production lines, the purchase of a functional product is becoming an interesting alternative.

## **2 PRODUCT SUPPORT STRATEGY FOR ‘CONVENTIONAL PRODUCTS’**

Most published literature on product support focuses on support from a traditional perspective where the customer buys and exploits the product and the manufacturer makes and supports it (see e.g. Blanchard, 1998, Dhillon, 1999, Fabrycky et al. 1991, Patton and Bleuel, 2000). In a conventional scenario, operations and maintenance processes are normally performed by the product owner. Expert assistance as well as original spare/ warranty parts may be required from the manufacturer and/or third party. The manufacturer interacts with the customer’s maintenance function to supply what in the literature is commonly called after-sales service, product support or just support. Advanced and repeated training may be needed to ensure effective and efficient operation and maintenance. Furthermore, many of the systems need to be modified and upgraded during its service life. In the end of the product’s service life the customer may need assistance from the manufacturer to dispose of/ recycle the product. Since advanced systems are seldom off-the-shelf products, most often the customer and manufacturer have to cooperate early in the design phase to specify the products. In design one wants to optimize values with respect to lowest cost related to function, economics, and HSE (health, safety, environmental) as shown in Figure 1. In the conventional product scenario the customer has to pay for the product, unavoidable services to compensate for product weaknesses, and possible

supplementary services to assist optimal product exploitation. Product operations and maintenance is an expense as well.

The objective of services accompanying physical products is to “ensure that the product delivers the promised level of performance” (Patton and Bleuel, 2000). One of the important characteristics of a service as compared to a physical product is that *services are processes, not things*. The product of a service is the process of providing the service. Relationship success and satisfaction therefore is also dependent on the quality of the process. The monetary worth of service products is dependent on the ‘functional worth’ to the customer (Michaels, 1996). Functional worth can be defined as the cost of the least expensive way to perform the intended function of a product. Functional worth may vary over time, but generally it is a function of what the product does (functionality, or a product’s form, fit and function relative to intended use), its availability when needed, and its costs. Since processes, and hence services, are more difficult to copy than a physical product’s characteristics, services can be used to differentiate products providing the same function, in a situation where product price and quality are equal (Grönroos, 2000). The supplier therefore needs intimate knowledge of the customer’s operations and how the product and attached services will fulfill this purpose.

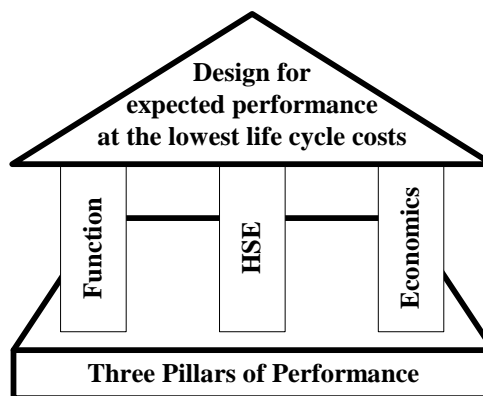


Figure 1: Design for expected performance at lowest costs

In this paper, a difference is made between services supporting the product (often called product support, after sales service), and services supporting the client actions related to the product (customer support) (see also Markeset and Kumar, 2003a, Mathieu, 2001). Product support is governed by the product’s functional weaknesses. It therefore includes support services such as maintenance, repairs, spare parts, expert advice, and so on. Customer support, we believe, is governed by both manufacturer’s

and customer's knowledge, expertise, and preferences. In addition, the manufacturer's capabilities, willingness to provide necessary support, geographical location, business strategies, and so on, influence this kind of support. The purpose of customer support, is to assist the customer to maximize all processes (including operations and maintenance), actions and strategies related to the product in order to optimize the product's profit making potential. Figure 2. illustrates the conventional relationship between a product's designed-in characteristics, its type of application/exploitation (including use environment), product support, and customer support. Also shown are some of the factors that influence performance of each. The continuous lines indicate primary influencing characteristics whereas broken lines indicate secondary influences. RAMS and functional product characteristics create the basis for exploitation as well as support services needed. However, to optimize product performance, these characteristics must be considered in the early design phases based on customer's requirements (see e.g. Markeset, 2002a, Blanchard, 1998, Dhillon, 1999, Østerås, 1998). This is often not done before late in the design process. Hence, technology and services to support the product is partially *pushed onto the customer*, instead of being *pulled by the customer* based on real needs, wants and preferences.

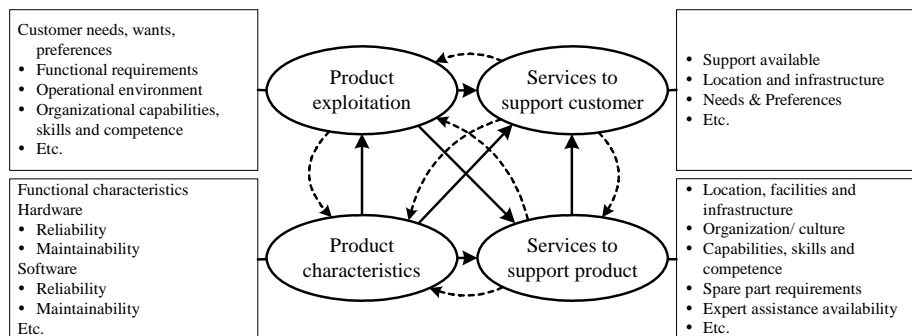


Figure 2: The conventional view of influences between product characteristics, product exploitation, services to support the product, and services to support the customer

Based on a case study of a manufacturer of advanced products, we will discuss how maintenance and services influence LCC and LCP (life cycle profit) for both manufacturer and customer. In the case study, we first map services offered to the customer. We will thereafter discuss how the company in a traditional approach has the potential to create services as separate products, based on expertise and a strong worldwide service network. Moreover, we will introduce the concept of 'Integrated System Performance', based on the concept shown in Figure 2, as a way of achieving

goals and additional value creation, and to create a lasting win-win situation for both parties.

### *2.1 Product Support Strategy for a Conventional Product: A Case Study*

The case study reported in this paper is part of a larger study of a manufacturer of advanced customized industrial products/systems (see Markeset and Kumar, 2003a, Markeset and Kumar, 2003b, Markeset and Kumar, 2003c). Information was collected through interviews, surveys, conversations, and through participation in meetings, and can be categorized as participatory action research. The manufacturer is a subsidiary of a large multinational firm with Regional Offices (ROs) worldwide. Since the firm offers (and partly manufacture) a wide range of products, mostly related to production line automation, the ROs have to supply a wide range of services. They function as technical support centers offering services such as onsite (field service), telephone, and online support. For online support, the customers get access to online 'problem solution banks' containing documented technical information and knowledge. Customers can download documentation, user manuals, video instructions, etc. They can also participate in technical forums and sign up for auto notification of technical updates and product releases. Some of the online support is free, whilst some is offered as 'premium' services. The ROs are the first contact point for the customers, whether it is in product inquiry or a support (service) inquiry. If the ROs are not able to assist the customers, the manufacturer is contacted.

It was found that the company and the ROs offer services for all life cycle phases (needs analysis, concept and design, design and delivery, etc.). Many of the services are directed at improving the use of the products (advanced training, upgrading and modifications, access to problem resolution and technical information databanks, etc.), rather than just supporting the product (spare parts, warranty parts, failure diagnostics, etc).

The various ROs also offer services such as: consulting services, design and delivery services, environmental services, financial services, maintenance services, migration services, optimization services, outsourcing services. It was observed that many of the services offered are not directly related to the products offered, but rather to the expertise/ knowledge available in the firm (e.g. financial services, productivity analysis, process analysis, etc.). However, it was further observed that the manufacturer on the other hand, mainly delivered services that supported the product, and that the service department was not very well integrated with the design and manufacturing environment/ disciplines. Information flow from the product users and service engineers back to the design environment was not well developed (see Markeset and Kumar, 2003c). The company clearly has the potential to create services as separate products based on expertise and a strong network. Such service

products can for example be support for competitors' products, support on similar products, services directed at enhanced product use, productivity analysis, process analysis, financial services, etc.

## 2.2 Additional Value Creation based on 'Conventional Product' Performance

As described in Figure 2, the system life cycle performance for a conventional product is dependent on the performance of the delivered product's characteristics, product support, as well as customer support. Figure 3. shows that the total integrated performance of a conventional product is dependent on product characteristics, characteristics of the customer (product exploitation), and characteristics of the compensating services. The system's designed-in characteristics, exploitation environment characteristics, and user characteristics decide how the product performs with respect to capability, capacity and quality. Even with excellent maintenance and operational strategies, the performance of the system cannot become better than 'built-in by design' without redesigning or modifying the product. Judgment of capability, capacity and quality performance can be used to assess the kinds of services needed for the individual customer. Product characteristics together with characteristics of the services intended to support the product, decide the maximum possible performance of the physical function. The performance of the function can be used to assess its exploitation performance (compare actual to possible performance) and the need for supplementary services to support the customer in exploiting the product function. Note that the kind of and amount of services needed may vary widely among customers. The total service performance is a function of the performance of all the services delivered.

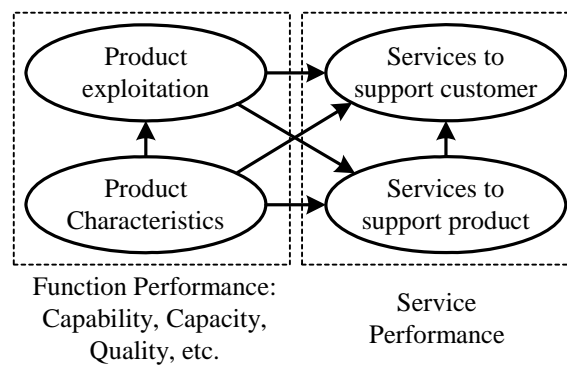


Figure 3: Conventional product performance

In a conventional product scenario, it may be difficult to see how a win-win situation between manufacturer/ supplier and customer easily can be achieved. There are many areas for possible conflicts – especially with respect to sharing of generated profit and costs, as well as with respect to performance measurement and evaluation. The manufacturer can make money in selling the product as well as in offering services. In the worst case, the manufacturer can sell the product with a loss only to earn money on offering unavoidable after sales services.

Actually many manufacturers have problems in seeing incentives as to what there is to gain from making the product more reliable and easier to maintain as long as they are not worse than competitors' products. The predominant belief is that it will cost more and take more time to design a product for high reliability and low maintenance costs as shown in Figure 4. (see also Markeset and Kumar, 2001, van Baaren and Smit, 2000). The benefits of designing the product for reduced LCC through improved RAMS and functional characteristics, are reduced operational and maintenance costs and extended service life. However, the reduced losses mainly benefit the product owner. Actually, the manufacturer will sell less spare parts and generally will earn less money on making the product better and reducing life cycle cost. The focus in the LCC concept is on ownership costs, not on LCP generated by the product for the manufacturer. However, for a product owner there are opportunities for improving the product performance in collaboration with the manufacturer for mutual benefit.

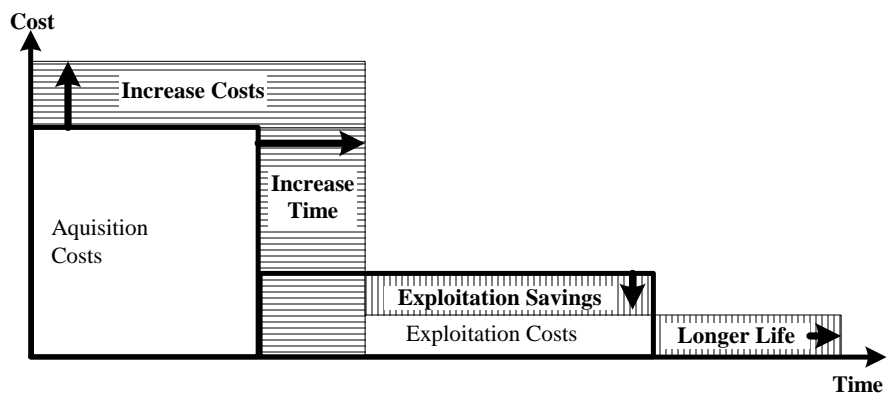


Figure 4: Conventional Product – Effect of Design for Performance (Adapted from van Baaren and Smit, 1998)

### 2.3 Conventional Product Performance Improvement Opportunities

Unplanned stoppages are generally the most common cause for low performance (Jonsson, 1999). Ericsson (1997) reports from 10 field studies that industrial machines were functioning satisfactorily only 59% of planned production time. The remaining time was spent on maintenance, machine setting up, and on materials. Plant owners want to maximize the LCP generated by the production facilities (Ahlmann, 1984). In Figure 5, Life cycle benefits and costs are shown in a time perspective. LCP can be improved by reducing the costs, by improving ownership effectiveness and efficiency related to operations and maintenance, and by improving support. However, one needs to keep in mind that minimizing the costs does not necessarily result in maximized profit. Production equipment operation, maintenance, and support planning need to be based on market dynamics. Opportunities for profit may be lost because of unavailability caused by badly planned preventive maintenance, unplanned corrective maintenance, as well as ineffectiveness in operations and maintenance strategy.

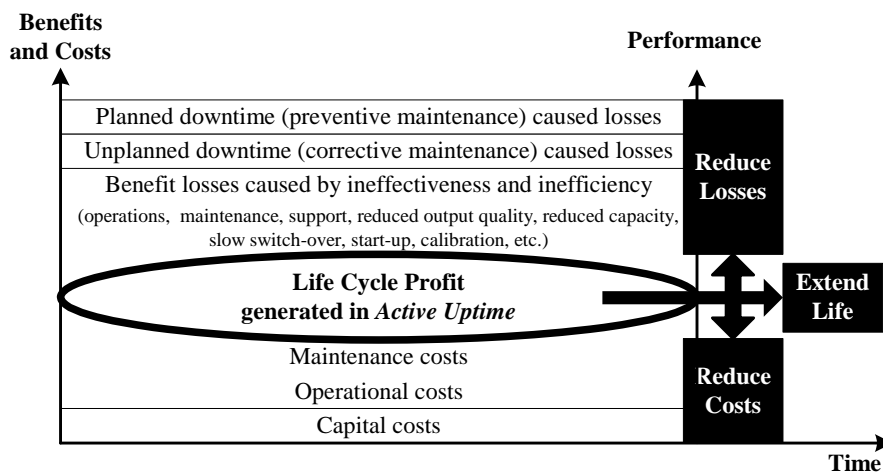


Figure 5: Enhancement of a product's life cycle benefits (adapted from Ahlmann, 1984)

Normally LCC and LCP analyses are performed with respect to cost and the amount of profit the product will generate for the owner (see e.g. Blanchard, 1998, Dhillon, 1999, Fabrycky and Blanchard, 1991). However, the same analysis can be performed with the product manufacturer in mind. To create a win-win situation for manufacturer and customer the focus has to be on how to optimize the value chain for maximum competitive impact, and on how to create additional value for the end-

customer. To do this, cost drivers and performance killers associated with production equipment, work processes, and organization, need to be mapped and controlled.

#### *Mapping of Performance 'Cost Drivers' and 'Performance Killers'*

The goal of mapping cost drivers and performance killers is to reduce unnecessary losses in technology and processes and to take advantage of opportunities for profit in a dynamic market by optimizing maintenance and plant availability. Examples of cost drivers are unplanned maintenance, process bottlenecks, equipment with high energy requirements, potential liability issues, operational and/or maintenance costs, training costs, facility costs, disposal costs, etc. Performance killers are factors that reduce performance without being strong enough to stop the process. Examples of performance killers includes equipment that is critical with respect to uptime/ health/ safety/ environment, bottlenecks in capacity/administration/inventory, incompetence, lack of proper tools and facilities, faulty procedures/ checklists, inadequate information and communication flow and system, etc. Performance is furthermore, heavily influenced by personnel motivation and attitudes.

#### *Alignment of Service Delivery Strategies and Service Reception Strategies for Enhanced Performance*

Since industrial product owners will need various kinds of services and support for the various products in use in their product lines throughout their service life, they have to have in place an overview and control of services to be received and a strategy for how to receive them. Each owner therefore needs to develop a service reception strategy. This reception strategy has to be closely linked to the operations and maintenance strategy employed in the company. The reception strategy will further be dependent on the type of equipment, competence, criticality, etc. It therefore has to be closely linked towards the various service delivery strategies of the manufacturers providing the support as shown in Figure 6. If the manufacturer's service delivery strategy is not closely aligned with the product owner's service reception strategy, there are inevitably going to be gaps between them. These performance gaps will lead to dissatisfaction for all parties involved. The consequence could be a less than optimal relationship between the parties involved and a reduced possibility for creating a win-win situation.

Furthermore, since the manufacturer's customers have various support needs, the manufacturer needs to have a general strategy in place directed at all the customers, and a special strategy that fits the needs, demands, and requirements of individual customers. The product owner needs to have a general and specific strategy in place dependent on the kind of products the strategy encompasses. Some products are more



critical and complex and therefore need more maintenance and support. For such products, a specific strategy has to be developed.

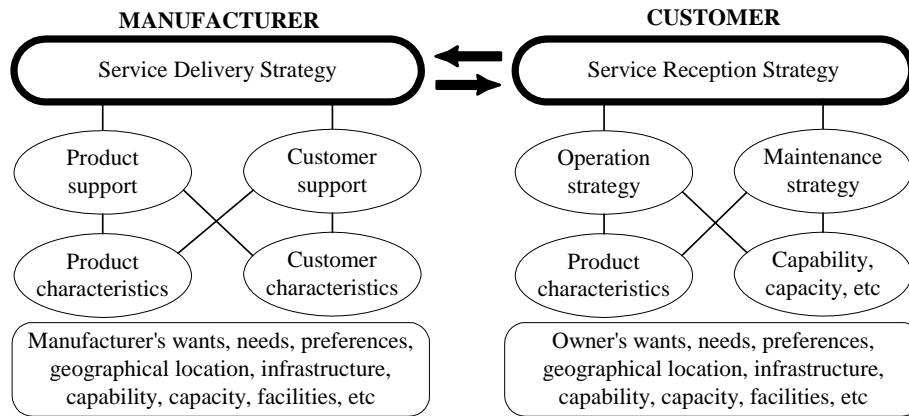


Figure 6: Some factors influencing Service Delivery Strategy and Service Reception Strategy

#### *Outsourcing of Functions*

Often the companies neither have, nor want to have, the competence and resources necessary to perform maintenance on advanced systems. They therefore often resort to outsourcing maintenance to manufacturers, to specialist intermediaries, or to a combination of both. Lately, increased focus on core activities has as well resulted in more outsourcing of non-central functions. In the Shreeveport study (Gay and Essinger, 2000) the most common motivating factors for outsourcing were found to be service cost reduction, headcount reduction, focus on core business, competitive strategy, access to expertise, improved service delivery, and improved quality. However, outsourcing is not without risk – it may result in loss of control, competence, operational flexibility, etc. but, on the other side, it can be a way to mitigate business risk and enhance business performance as well. Outsourcing is often a matter of trust and cooperation between the parties involved. See Bragg (1998), Kakabadse and Kakabadse (2002) for further discussion.

Moreover, due to the fast development in technology and increasing focus on core activities, in the recent past a new trend is noticed where customers are not willing to invest capital in buying advanced complex industrial systems. They are showing preference for purchasing the function, or to be exact, the performance from the product function, such as tons per hour, meters per shift, etc.

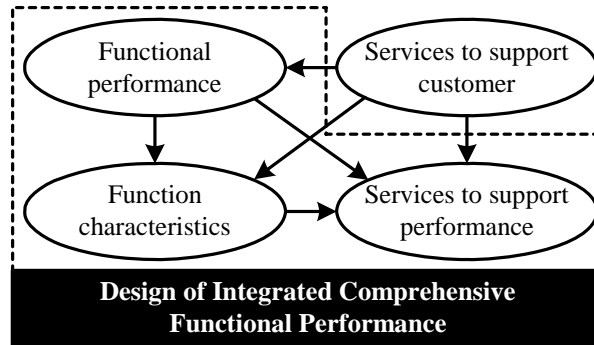
### 3 'DELIVERY OF PERFORMANCE' SCENARIO

In the conventional product scenario the plant owner purchases the product, operates and maintains it, as well as disposes of it. Since the customer is primarily interested in obtaining the benefits of the function (i.e. the customer is interested in the hole the drill makes, not the drill, to use Levitt's (1969) well known metaphor), a scenario can be described where the plant owner chooses to *outsource the total function* to for example the manufacturer of the product/machine. This is an advanced form of outsourcing, which is becoming increasingly attractive to companies as they attempt to focus on core activities. In this scenario, the manufacturer is responsible for the continuous performance of the function. Thus, services to support the product or to support the customer have to be an integrated part of the function to be delivered. Actually, *the process of continuously delivering the function according to some agreed upon performance criteria is the service*. However, this service will depend heavily on the performance of the physical product function. If performance is too low, the manufacturer needs to do what is necessary to improve it and to deliver the agreed upon performance level. In this scenario, the manufacturer will not profit from after sales support services. Rather *product support will become a cost and a liability* for the manufacturer.

In the following, two sub-scenarios of performance delivery will be considered. In the first case, the manufacturer bases the delivery of continuous functional performance on a new design, whilst in the second case a pre-designed product is the basis for the functional performance.

#### 3.1 *Delivery of Performance based on a New Product*

If a manufacturer is to be responsible for delivering 'total functional performance' instead of just delivering and supporting a physical product performing a function, the physical function needs to be designed for maximum performance effectiveness and efficiency at minimum LCC and maximum LCP. This means that the operational and maintenance costs needs to be as low as possible. Product weaknesses causing the need for services to support product (see Figure 1.) must be designed out, if possible. If not, the product needs to be designed for cost effective reliability, and thereafter for easy maintenance and support at lowest cost. Services and maintenance, directed at enhancing product exploitation, need to be attempted and minimized by incorporating them into the training of operation and maintenance personnel, or designed out through improved product RAMS and usability characteristics, improved documentation, and so on, as shown in Figure 7. The less required of the 'conventional product services', or the more that can be designed into the product or incorporated in operators and maintainers training and experience, the better the performance will be. The manufacturer will not make any profit in speculating in maintenance and support.



*Figure 7: Product designed for integrated comprehensive functional performance at lowest life cycle costs.*

In this scenario, the manufacturer would like to optimize all RAMS and functional characteristics, as well as product support. The manufacturer would benefit from designing the product for lowest possible capital, maintenance, and operational costs, and to do it in less time as shown in Figure 8. After all, as a supplier of a function, the manufacturer would benefit from reduced operational costs and extended life. In addition, if, for example, the delivery of the performance were tied up to performance bonuses and/or penalties, it would pay to reduce losses in the operation phase and to make the performance as effective and efficient as possible. If the manufacturer and customer both focus on creating the best possible value for the end-customer, in the end, they would both benefit from best possible performance by having production line equipment that had high uptime and produced best possible quality output. Thus, the product support strategy can be designed on exploitation performance premises. Actually, in this scenario, there is much less a conflict compared to the delivery of a conventional product scenario.

### *3.2 Delivery of Performance based on an Existing Product*

In the second case, the manufacturer delivers performance based on an existing designed product. This case is similar to case 1, except now the manufacturer has less possibility to influence performance through product design. Since many products are developed through an evolutionary improvement process based on improved knowledge and experiences, technological development, as well as market inputs, they have reached a technological level at which it neither is possible nor cost efficient to improve the functional and/or RAMS characteristics further. Moreover, since the manufacturer owns the physical function, and hence has to live with the weaknesses, there will be no profit from 'conventional services' to support the

product or customer. In other words, improved profit must come from improved operational, maintenance and product support strategies. Reliability is influenced by how the product is used, by the use environment, load, and so on. Availability also can be influenced by improving the preventive maintenance strategy and product support strategy. Consequentially, training of operation, maintenance, and support personnel will be important to ensure effective and efficient function performance.

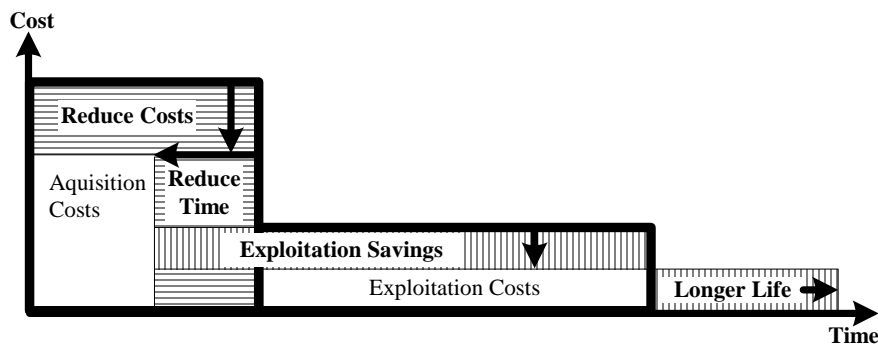


Figure 8: Functional Product – Effect of Design for Performance

#### 4 ADDITIONAL VALUE CREATION: FUNCTIONAL PRODUCT VERSUS CONVENTIONAL PRODUCT

To generate maximum profit, industrial customers are interested in products that will produce quality output at minimum costs at the rate and time the market wants. In the conventional product scenario, the manufacturer potentially can profit from selling the product, from selling services to support the product, as well as from selling services to support the customer. Hence, to generate maximum profit through reduced costs, the manufacturer will have to focus on optimizing the performance of each of the related processes. The customer will have to optimize the performance of the operation and maintenance processes, as well as reduce costs related to external services, which for the manufacturer is a profit.

In the case of functional products, the manufacturer will have to focus on optimizing the same processes that the customer is interested in optimizing. The manufacturer would be responsible for total costs, and the total, comprehensive, and integrated performance. It is an opportunity to gain knowledge about the operational and maintenance performance of the system under varying conditions. In product design and development, there exists a window of opportunity during the early life cycle phases, to reduce life cycle costs where the ‘risk avoidance opportunity’ is

greater than the costs of risk avoidance (Michaels, 1996). By taking advantage of the information and knowledge now readily available, both products and processes can be improved. The knowledge can be helpful for developing new products as well. Furthermore, the knowledge would be valuable for developing and/or improving services for customers who choose to purchase the product in the conventional way.

In the conventional product scenario, the customer's internal interface is between the production process and maintenance process. The manufacturer interacts with the customer's maintenance organization to supply spare parts and expert assistance. In the functional product scenario, the customer receives a performance as a product. The interface and coordination is now between the manufacturer and the production process owner (customer's production department), and in some cases, maybe between the manufacturer and the customer's marketing department. If performance of the function is too low, or costs too much, it would be in the manufacturer's interest to do what is necessary to deliver the agreed upon performance and cost level. This leaves maintenance and support in a new perspective where design for high performance at the lowest cost becomes the sole goal.

Furthermore, if a supplier/manufacturer offers functional products to several customers, conflicts may arise where priority of resources (expertise, spare parts, etc) may be critical. One of the challenges will be to be able to meet multiple needs for several customers and to make the best necessary trade-offs to satisfy all the customers simultaneously. Moreover, if a business owner purchases functional products from several manufacturers, problem may arise with respect to coordination and cooperation, as well as effectiveness and efficiency.

Table 1. summarizes some of the basic differences between a conventional product and a performance delivery scenario.

*Table 1: Comparison of conventional and functional products from a manufacturer's perspective*

<b>Product Support Strategy Specifics</b>	<b>Conventional Product</b>	<b>Functional Product</b>
Ownership of physical product	Customer.	Manufacturer.
Support	Support generates revenue for manufacturer but is a cost for customer.	Support is a cost driver and liability for manufacturer.
Functional and RAMS Characteristics	Manufacturer focuses on selling a competitive function in the form of a physical product. Manufacturer profits from support and therefore may be reluctant to optimize RAMS characteristics.	Best possible product RAMS characteristics results in lowest operational and maintenance costs.
Interface in exploitation phase	Service delivery department and maintenance department.	Manufacturer and customer's process owner.
Process optimization with respect to effectiveness and efficiency	Manufacturer and customer will focus on optimizing own processes with respect to cost and profit generation. Customer will focus on balancing operational, maintenance, support costs and product performance.	Manufacturer and customer are interested in optimizing the performance of the function and all related processes to generate maximum profit at lowest cost.
Profit generation	Manufacturer profits from sale of physical product, and any support services delivered. Customer profits from the output generated by the product.	Both parties profits from the output generated by the product performance.
Price	Customer wants highest function performance for lowest cost. Manufacturer wants maximum profit from product and supporting services at lowest cost.	Both parties are interested in the performance of the product. The product and all related processes must generate maximum profit at the lowest life cycle costs.
Negotiation of services	Focus on trade-offs between product price, performance and costs. Operations and maintenance processes are controlled by the customer.	Focus on performance at the lowest costs. Operational, maintenance, and support costs are all in the hands of the manufacturer/supplier.

## 5 CONCLUDING REMARKS

In this paper, the focus has been on product support strategies for enhancing the performance of industrial products. Industrial customers are interested in the total integrated long-term value offered, not only the product performance. Increasingly, this integrated value includes the performance of services in addition to the

performance of the products. A conventional product scenario is studied and compared to a scenario where the customer only buys the performance.

In the conventional product scenario the performance of the product can be enhanced by improving the service delivery strategies for supporting the product as well as supporting the client in using the product. In this scenario, the manufacturer potentially can benefit from delivering the product as well as the supporting services. Therefore, few incentives exist to improve the product more than necessary competitively. Furthermore, the customer needs to have in place a service reception strategy especially fit for the product. To achieve customer satisfaction, this strategy has to be aligned with the manufacturer's service delivery strategy.

In the case of functional product, the customer buys the performance, not the product and the related services. The manufacturer actually provides a service. In this perspective, there is little to gain for the manufacturer from traditional product support. Actually, the need for product support becomes a cost driver and a liability for the manufacturer. Thus, if possible, product performance should be improved through improving the RAMS and other characteristics. Furthermore, operation, maintenance and product support strategies need to be developed with cost reduction, effectiveness, and efficiency in mind. Consequently, for functional products the product strategy will be fundamentally different as compared to conventional products.

## ACKNOWLEDGEMENTS

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# **PAPER VI**

## **Negotiation of Product Support and Service Delivery Agreements in a Multinational Environment**

Submitted for publication



# Negotiation of Product Support and Service Delivery Agreements in a Multinational Environment

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## ABSTRACT

As industrial durable products are becoming progressively more advanced and complex, the role of services delivered by the manufacturer to support the product as well as to support the customer in exploiting the product's function to an agreeable performance, is becoming increasingly important. Thus, the process of negotiating delivery of such services is becoming critical. Aspects such as who is to deliver the services, how to deliver them, how to receive them, and at which performance level, and so on, need to be considered by both the provider and client. The goal of an effective negotiation is to achieve a win-win situation for both the service provider and the client. Such a negotiation process must consider all influencing factors (customer's requirements, geographical location, cultural influences, etc.) that affect the outcome from the process/approach.

This paper discusses the role of the negotiation process in developing an effective, efficient, and competitive service delivery strategies in a multinational environment. We emphasize that to achieve a win-win situation for both parties, 'transparency' and 'trust' is essential. Often, the negotiation works as lubricant between supplier and customer relationship.

*Keywords:* Industrial products, Service delivery strategy, Service delivery agreement negotiation, Customer satisfaction

## 1 INTRODUCTION AND BACKGROUND

Most of the advanced and complex products cannot be made maintenance free. Maintenance therefore will be needed to retain or restore the product to an acceptable operating state. Spare and warranty parts, expert assistance, field service, therefore

will be necessary throughout a product's service life. Most firms engaged in manufacturing of durable industrial products provide services to support their products as well as the customers. Services to support the product are provided to overcome product weaknesses, which are impossible to design out because of various design constraints such as cost and state of the art technology. As industrial products become increasingly advanced and complex, the customers may also need assistance to optimize operational and maintenance strategies to reduce costs and to enhance the performance of the product purchased. Often manufacturers provide services related to product delivery and exploitation throughout the product's service life. Typical examples includes:

- Assisting the customer in defining the product specifications, so that they really reflect what is needed, required, wanted or preferred.
- Assisting the customer during the installation and commissioning phase of the product/system to install, adjust and prime the product, and to operate it correctly for the first time.
- Assisting in defining the operational strategy, which best fits-in with the rest of the plant, where the product is to be used.
- Providing advanced training and assisting in performance evaluation.
- Undertaking utilization analysis and application assistance.
- Providing remote diagnostics.
- Making available help-desks, online help, telephone support for fast and efficient problem resolution.
- Assisting in optimizing logistics support.
- Evaluating and assisting in retiring/disposing the product at the end of life
- Etc.

These services are not all rooted in product weaknesses, but may as well relate to weaknesses in customer's resources and capabilities, geographical location and infrastructure, customer's core business focus, etc., as well as the customer's preferences. We observe that the total product received by the customer is more than the physical, tangible product, spare parts, documentation, and maintenance tools. It includes services intended to support the product as well as services intended to support the customer in utilizing the product (see Mathieu, 2001 and Markeset and Kumar, 2003 for further discussion). Goffin (1999) asserts that, after-sales service and product support is important for manufacturers because it can be a major source of revenue as well as essential for achieving customer satisfaction. It can provide a competitive advantage, and can play an important role in increasing the success rate of the new product.

However, service offering has to be based on customers' real needs and wants, whether realized by the customers or not. Moreover, the process of offering and delivering the services may be influenced by social or business culture. To deliver services to ensure satisfaction and long-term loyalty, negotiation of the service

delivery agreement plays an important role in dealing with the customer and the customer's organization. The process of negotiation includes ascertaining the needs and requirements of the customer as well as of the service provider, and defining the ways to achieve goals of the negotiated agreement. Figure 1. depicts some of the wanted and unwanted inputs and outputs in the service negotiation process.

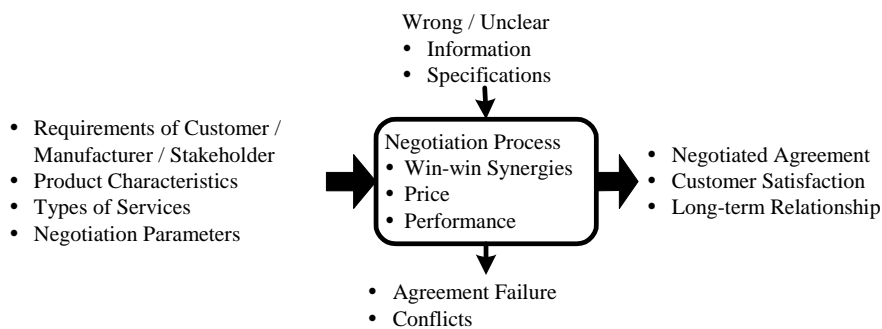


Figure 1: Negotiation Process's Wanted and Unwanted Inputs and Outputs.

The wanted inputs include ascertaining customers and suppliers requirements that are discussed and clarified during the negotiation process. Products characteristics as well as negotiation parameters such as geographical location, cultural influences, etc. will influence the service delivery process. The types of services to be delivered needs to be included in the agreement to ensure long-term relationship based on customer satisfaction, so that both parties benefits from the product throughout the service life. If the negotiated agreement contains confusing and/or wrong specifications and information about what services to be delivered and how they are to be delivered, the negotiation process results in service delivery failure and conflicts. Therefore, the negotiation agreement should include descriptions of product performance, service delivery performance, as well as contingencies to handle unplanned and unpredictable situations. The agreement should be written to avoid misunderstanding and misinterpretations.

On this basis, in this explanatory paper we will discuss the basis for delivering services to support industrial products and the users. Furthermore, we will attempt to map and discuss factors that will influence the service delivery and service reception process in a multinational environment. These factors need to be considered while negotiating service delivery agreement. This agreement is to functions as a foundation for the service delivery strategy as well as a service reception strategy.

## **2 KEY CONTENT OF A SERVICE DELIVERY AGREEMENT**

Services to support product are founded in product weaknesses, and hence RAMS characteristics. Failure rates of components, therefore, play an important role for this kind of support. If the failure is instantaneous, spare parts are required to be kept ready for use to reduce downtime. If failures develop gradually, more time is available to order parts and for planning of maintenance. For the manufacturer, the services related to product failures can generate profits if the product is not under warranty. Normally the manufacturer provides a recommended preventive maintenance plan with the product. Based on this plan a LCC estimate can be prepared and used for selecting among alternatives similar in function and price. Sometimes this maintenance plan is locked as long as the product is under warranty. However, the maintenance strategy is based on predictable failures influenced by operations. The service agreement, therefore, should focus on approaches such as condition monitoring for making the failure mechanisms predictable. However, not all failures can be observed using monitoring techniques. Some failures must be planned for through the use of statistical prediction based on subjective assessments, experience, and historical data.

If the failures are not predictable, the result will be corrective maintenance. If corrective maintenance happens in the warranty period it imposes losses for both parties. If it happens outside the warranty period, the manufacturer will profit from selling spare parts on short notice, whilst the customer will have maintenance cost as well as production losses. Services to support the product therefore can be divided into planned, unplanned, and warranty, depending on failure predictability.

Furthermore, services to support the customer is related to product exploitation, capabilities of operational and maintenance personnel, production capacities, etc. As a specialist on own products the manufacturer can offer support through advice to optimize product operation and maintenance performance. However, the need for this kind of support will vary among customers. Many of the services to support the customer's actions in relation to the product can be planned. However, in a fast changing market it would be impossible to plan for all possible scenarios. Therefore, both parties must be prepared to deal with situations, which are fundamentally unpredictable and unknown. This brings in the negotiation of contingencies into the negotiation process.

Based on the above, some of the key content of a service delivery agreement is discussed.



### 2.1 *Planned Services*

Planned service is performed according to a scheduled plan often based on manufacturer's recommended preventive maintenance strategy. It refers to activities, which aim to prevent breakdowns and increase the availability of the system. A planned service/ preventive maintenance policy reduces the number of failures, the cost of the planned service may not get offset by the reduction in unplanned service / corrective maintenance costs (Löfsten, 1999). Planned services involve all activities to avoid unexpected failure (e.g., repair, replacement, adjustments, lubrication, health monitoring, spare part logistics, maintenance tools and facilities, training, and so on). It provides a critical service function without which major business interruptions could take place (Mirghani, 2001). Furthermore, planned services include possible product upgradation and/or modifications, supplementary services such as product exploitation, efficiency, advanced training of operation and maintenance personnel, as well as evaluation of operations and maintenance strategies. The service delivery agreement should specify; what, when, how, where, and to which performance level planned services are to be delivered. Furthermore, the responsibilities for achieving these objectives should be specified.

### 2.2 *Unplanned Services*

For unpredictable product failures, there has to be a plan and contingency for dealing with unplanned event. This means that, if a product fails suddenly, we should be ready to resolve the problem, effectively, efficiently and at a minimum cost and loss of profit. A plan for dealing with unplanned situations should be discussed at the time of negotiations to avoid conflicts with the customers.

Furthermore, at the time of negotiation of service delivery agreement, issues beyond anybody's control, i.e. "Acts of God", (e.g. earthquake, fire, flood, etc.), need to be considered. It is essential, to outline clear-cut responsibilities and to create plans in the agreement to reduce conflicts and to ensure a long and healthy relationship with the customers. However, negotiation can affect the final price and support costs. Some service providers offer fixed service costs, not only dependent on price, but also on the service provided (e.g. telephone support by hourly rate or fixed annual price) (Kuo, and Wilson, 2001).

### 2.3 *Warranty Services*

To reassure product availability, the manufacturer/service provider often provides a product warranty. Generally, two types of warranties exist, expressed and implied. Implied warranties are not part of the agreement, but exist in governmental legislation and regulations. Expressed warranties are those that are agreed upon by the both parties and put up in writing as part of the contract. Once all aspects of service

requirements are agreed upon, price has to be considered. In order to decide about the price, the service provider needs to know something about the customer's budget (Kuo and Wilson, 2001).

## 2.4 Price

Marketers of industrial services focus on costs, as the sole objective to gain profit. Therefore, competitive conditions are evaluated only to ensure that the organization's price is not too low or high compared to competitors. In pricing methods, negotiation prices are considered as mark-up prices and target return prices, both of which are cost-based. Industrial product prices depend on the budget or the economic condition of the customer's organization. *Different rates can be charged for the products depending on the buyers, quantity, time, place, type of maintenance/ service and duration* (Morris, 1989). Pricing not only serve as a promotional purpose, but also contribute to efficient use of service capacity. Prices are a variable component of the organization's overall marketing strategy.

Once the key content of the service delivery agreement is defined, both parties need to be aware of parameters/ factors that may lead to conflicts and hinder the successful outcome of a service delivery negotiation process.

## 3 PARAMETERS INFLUENCING SERVICE DELIVERY

Before starting negotiation of prolonged service delivery process to accompany a physical product, various aspects of the customer and the product need to be identified and understood. These aspects, also known as negotiation parameters, may influence both the negotiation process and the delivery of the services. The negotiation parameters can be divided into internal and external. Internal parameters are related to the particular customer and product, whilst the external parameters are related to the location of customers. The following parameters will be discussed:

- Customer's requirements
- Geographical location
- Cultural influences
- Customer's level of competence
- Service delivery interface

### 3.1 Customer's Requirements

The global marketplace requires the development of a manufacturing system that begins with customer requirements (Richard and Pearson, 2001). Often requirements only include the needs of customer and not the needs of the service delivery process.

The problem of service delivery strategy content versus strategy implementation has to be considered. Customer's requirements must state, **WHAT**, is needed. Thereafter the service provider can determine, **HOW**, this can be solved to satisfy the customer (Harwell, et al., 1993). Therefore, the starting point for negotiating the delivery of services must be the service provider's general service delivery strategy outlined to accompany a physical product, and the customer's general service reception strategy (see Figure 2.). However, the general service delivery strategy will have to be refined in the negotiations to fit the customer's special needs, wants and preferences. The customer's general reception strategy will also have to be refined to fit the special needs of the product as well as the wants, needs, and preferences of the service provider. The successful long-term delivery services will depend on these considerations that are assessed in the service negotiations and defined in the service agreement.

Dependent on the type of relationship the service provider want to have with the customer, requirements have to be defined in the negotiation. Without considering customer's wants, needs, and preferences, the negotiation may not be effective. Those manufacturers, who are able to meet the needs and expectations of their customers, will have a competitive advantage. Furthermore, the customer must focus the processes on fulfilling the end-customer's requirements. To create good reputation and goodwill in the market, focus on end-customers is needed while negotiating. Knowledge and understanding of detailed market inputs and competitors of the markets would be an advantage.

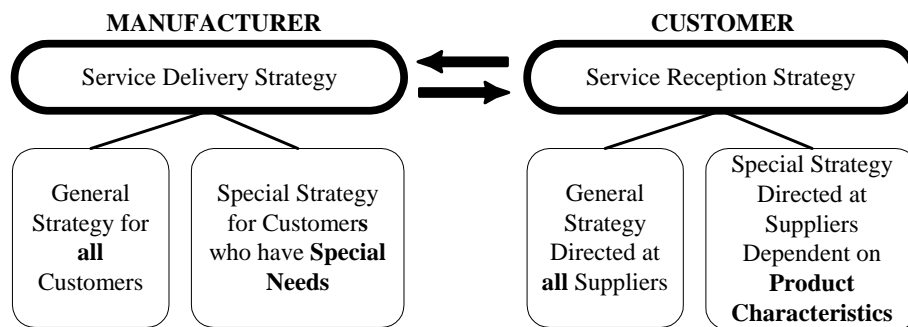


Figure 2: Service Delivery Strategy versus Service Reception Strategy

Furthermore, the location where the product is to be used will influence not only the products technical characteristics, but the delivery of attached services as well.

### *3.2 Geographical Location/ Infrastructure*

The geographical location plays an important role from product usage and maintenance aspects, through the operating environmental issues such as temperature, humidity, corrosiveness, dust, etc. These aspects will influence wear, tear, and deterioration, and hence, the type of support needed.

If the manufacturer and customers are located in different part of the world or in remote areas, extra resources need to be provided to achieve the same level of support as compared to those located closer to the provider, or where the infrastructure allows for faster and more convenient distribution, delivery, communication, etc. Apart from infrastructure issues, local legislation, rules and regulations, political issues, culture, and so on, influence the service delivery strategy as well.

Furthermore, customer characteristics vary for different countries and regions of the world. These characteristics are influenced by living standard, educational level, etc. They therefore, influence how the product is operated, maintained, and therefore what kind of services are needed – both with respect to services to support the product as well as services to support the customers. Global market's customers can be divided into two categories/ types considering standard of living: a) Customers from developed countries, b) customers from developing countries (Malhotra et. al., 1994).

### *3.3 Customer's Level of Competence*

In developed countries, service customers are buying products according to the performance and appropriateness of the technology. In such countries, services can be provided through electronic media, but in developing countries, customers are buying product as per the past performance of the product. In developed countries, direct contact with customers hardly exists. However, in developing country personal relationship is important. For example, if service is required to be delivered in Sweden, service provider can keep in contact with customers through net, telephone, fax, etc but with same product/system in India, service provider has to visit the customer time to time and see the performance of the products/system. Customer expectations are very high in the developed countries and they have a lower tolerance to low quality of product. Customers of developing countries due to lack of quality awareness and low purchasing capacity are at times compromising with lower quality products. The wide gap of quality creates a wider range of tolerance of customers to be considered by the service provider. Besides standard of living, capabilities and resources at the place of operation, business core focus, plant and product requirements, availability (uptime) and demands for product output quality, and so on, also need to be considered. Furthermore, customers from different locations may have total different demands to product documentation, instructions, and specifications.

Whilst, in some countries detail procedures are needed, other countries demand fewer details.

In developed countries, the customers want to interact face-to-face with the service provider in order to understand the behaviour pattern and strategy of the service provider. This will help to minimize the risks of buying products of poor quality. It is also useful for service provider, as it would evaluate the strength of the customer's organization and their reception strategy.

The strategy for delivering services to local customers need to be adapted to their special needs. These needs have to be considered in the service negotiation process. One also needs to be aware of local characteristics that may influence the process of negotiation.

Furthermore, service delivery is heavily influenced by cultural aspect of the region where the product is to be used.

### *3.4 Cultural Influences*

Cultural differences impacts on the behavior towards and understanding of the customer and interactions between the customer and the service provider. It may cause people to view or value the social interactions inherent in the service delivery process as well as the negotiation process. Different culture systems could produce divergent negotiating styles, shaped by a culture, language, geographical location, history, and political system. When delivering services across the cultures, many of the rules used in one country may not apply elsewhere. The value of being transparent may help to reach a quick agreement, but this may not be acceptable in a different culture. To achieve success, firms must be fully prepared, and therefore must improve their knowledge about customer, understand their culture, and must be ready to devote time and efforts to the service delivery process. To succeed internationally an organization has to develop and practice a successful and cross-cultural service delivery skill. In cross cultural context, two business partners could be separated from each other by a totally different language and culturally-based business etiquette, and also by a different way of perceiving the world, of defining business goals, of expressing feelings, and of showing or hiding motivation and interests (Gulbro and Herbig, 1999). For further details see Herbig and Kramer, 1992; Gulbro and Herbig, 1995; Martin and Herbig, 1997; Zarkada and Fraser, 2001.

Often, due to geographical location and distance, services to support an advanced industrial product are outsourced to a third party related to the manufacturer (e.g. regional office), or an independent supplier chosen by the customer as shown in Figure 3. The interface between the service process partners therefore needs to be considered in the negotiation process.

### 3.5 Service Delivery Interfaces

The practical aspects of delivering services influence the quality of the service. Zeithaml et al (1990) assures that service delivery is a process. Hence, the quality of the process is dependent on the interfaces between the parties involved. Therefore, the service delivery interface, serving as a basis for the relationship between the service provider and receiver, needs to be considered when negotiating the service delivery agreement.

Presently, companies use outsourcing as a way to focus on core business and thereby minimize business risk and to increase competitiveness. In a scenario where the manufacturer and the customers are located in different countries or at great geographical distance, the manufacturer need to know the customer's cultures, organizational goals, etc. An alternative would be to contract out/ outsource to a regional service provider who knows the product well and can work as the manufacturer's extended arm. In this case, it would be easy to dimension product support and to develop a service delivery strategy for the product. In third case, the customer chooses to outsource the service to an independent service provider not related to manufacturer. The independent service provider would still have to obtain spare parts for the product as well as expert assistance from the manufacturer. This will reduce business risk for the manufacturer, but may as well increase the risk for the customer if the independent provider does not know the product, customer, or manufacturer well. If the independent service provider chooses to acquire spare parts, expert advice, etc. elsewhere, the risk of product failure may increase. This may reflect back on the manufacturer in reduced goodwill and dissatisfaction. Hence, the outcome and the result from the performed service should be clearly defined during the negotiation process.

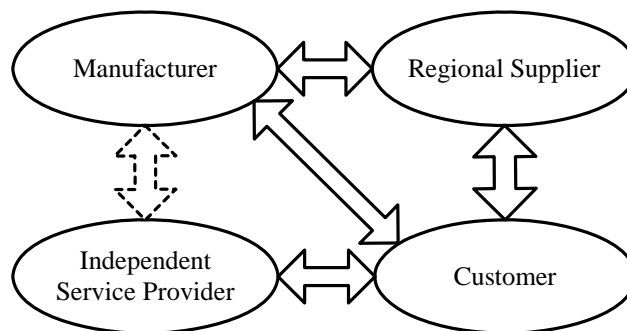


Figure 3: Service Delivery Interfaces

#### **4 SERVICE DELIVERY AGREEMENT & FOLLOW-UP**

After finalization of the agreement, to achieve customer satisfaction, the services must be provided as per mutually agreed terms. Based on the agreement, a modified service delivery strategy is developed to fulfill the 'special' demands discussed in the negotiation and specified in the contract. Similarly, the customer needs to adopt a service reception strategy that will make it easier to fulfill the negotiated agreement. If the customer is satisfied with the service provided, initial inhibition is replaced with customer delight, which may translate to customer loyalty. Customer satisfaction, measures the firm's responsiveness, its technology (capabilities and products) and product quality/reliability (Ellis and Curtis, 1995). Moreover, it creates in the market a good reputation, goodwill, and image status for the organization.

To be able to achieve a win-win situation for the service supplier as well as for the receiver, the parties have to agree upon the parameters for assessing the performance of the product as well as of the service. The service delivery process needs to be monitored, to assess the goals of the strategy and its specified quality. Depending on the feedback received, suitable amendment/ modifications/ adjustments according to the negotiated contract can be taken.

The goal of the negotiation process is to arrive at an agreement in which both parties are satisfied with. However, the service delivery process will need to continue as long as the product is in operation. As during the service delivery negotiation, it is impossible to predict all future situations and conflict, both parties need to be prepared to renegotiate the agreement in detail. Potential conflicts caused by changes in the market may result in new capacity, capability, or quality demands. This may require modifications of the product and the delivery of services to support the product as well as to support the customer's use of the product. As the product and service performance is the basis for the relationship, both parties need to be open in dealing with new opportunities and to seek a win-win solution to reduce business risk and avoid conflicts.

#### **5 CONCLUDING REMARKS**

In the process of negotiation, both the service provider and the customer, attempts to know each other and to understand each other's needs, wants and preferences. A long-term and healthy relationship depends on that additional values are created for both parties. While safeguarding individuals' interest, it is equally important to assure transparency and clarification of key content of the negotiating process to avoid misunderstanding and conflicts. A successful negotiation process is a function of service delivery strategy content as well as limiting parameters. The negotiated

agreement should clarify key content, responsibilities, as well as performance level. Ultimately, quality of the delivered service will decide the success or failure.

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