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Towards a comprehensive service business management environment for equipment manufacturers

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Abstract Transformation of equipment manufacturers to become providers of industrial services is a trend that involves deep transformation of companies. Equipment manufactures can potentially provide services significantly more efficiently and effectively by utilizing information about their installed base. We aim to recognise decision support functionality and required information contents for a system that supports service business in context of services like "full service", lease of maintained equipment, extended warranties, and operations and maintenance. A further supported function is product and service development. 8 cases from Finnish machine building and telecommunications industries provide a basis for our view of business needs in decision support of operational and tactical levels of service business management. We present a vision of a decision making tool for service business of equipment manufacturers – the Service Business Management Environment (SBME) and identify decision making situations ("use cases") of SBME. SBME integrates ideas and information content from Engineering Asset Management, Condition Based Maintenance, standards to represent and exchange life-cycle, reliability and maintenance data, and e-maintenance. If successful, SBME can support transformation of equipment manufacturers to service business. This takes place by aggregating information from whole installed base, which enables better accuracy in health assessment, prognostics, cost estimation, awareness of service contract status in terms of defined KPIs, and analysis of profitability of service offerings. Furthermore, SBME supports product development by providing information on field reliability, maintainability, recognition of epidemics and other inputs.

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1 Introduction

1.1 Background and motivation

Services are an increasingly significant part of the global economy. In this context, transformation of equipment manufacturing companies (*suppliers* for brevity) to become providers of industrial services is an important trend that involves deep transformation of companies, see e.g. [1].

The *installed base (IB)* of a supplier is formed by the set of delivered product individuals that are still in use [2]. Many companies offer services such as maintenance to product individuals manufactured by competitors or suppliers of complementary products. Therefore we call this extended set of product individuals in scope of service activities *Service Base (SB)*.

Primary activities towards the SB include provision of spare parts, repairs and maintenance, operation, upgrade and replacement. These primary activities, their management and support, ownership and financing can be allocated in different proportions to the customer, supplier or third parties. Different service propositions may be created that divide responsibilities and risk between the related parties. In order to gain a larger share of customer's business the service provider must be able to produce services with a better combination of cost and quality than the customer as self-service or through other partners can achieve.

Many of the activities towards SB can be performed with rudimentary information about the SB, but more extensive and better quality information –when applied effectively – can improve quality and cost of service provisioning. Simultaneously, advances in availability and price of telecommunications, and digital control and embedded intelligence of products make it increasingly feasible to collect and maintain up-to-date product individual level information about the SB. Product manufacturers have a significant, unleashed key benefit of *fleet view* to installed base, which can give a remarkable benefit over its customers or third parties. Combined with superior knowledge of products designed by the company, more comprehensive, accurate and accessible information creates potential to provide services more efficiently and effectively compared to customers themselves or third parties. For example, a customer may have 30 similar valves in a factory, and can compare their condition or maintenance records. However, the supplier can compare those 30 valves with the whole IB of that type of valves, e.g. several thousand individuals being used in various environments and in different points of their life cycles. This gives a competitive edge because the supplier is able to predict more accurately and reliably the maintenance needs.

1.2 Goals, Material and Methods

Our research in context of 8 cases from Finnish machine building and telecommunications industries shows that the state-of-the-practice of management of information about SB has significant potential for improvement. We aim to recognise decision support functionality and required information contents for a system that supports service business of suppliers in context of such services as "full service", facilitator contracts (e.g. lease of maintained equipment), extended warranties, and operations and maintenance. This support requires adequate information about the SB – both in terms of scope and quality. Product and service development benefits from the same information.

We present a vision of a decision making tool for service business of suppliers – the *Service Business Management Environment (SBME)*. We identify decision making situations ("use cases") of SBME in service business and product development. Our vision of business needs (and challenges) for SBME has been constructed based on both literature and ideas inspired by the 8 cases.

In order to support decision making in service business, we include decision support methods and required data contents from previous work. We take into account literature on Engineering Asset Management (especially data warehousing approach, e.g. [3]), Condition Based Maintenance (e.g. [4]), ways to represent and exchange life-cycle, and reliability and maintenance data ([5], [6], [7]). We take the point of view of a company that manufactures equipment and offers services to its installed base, possibly offering services also to product individuals manufactured by competitors.

This paper is structured as follows. Section 2 is an overview of SBME, Section 3 outlines 'use cases': service offerings and activities where SBME provides decision support. We continue in Section 4 by outlining main information contents of SBME. Finally, Section 5 provides discussion – brief comparison with previous work, challenges awaiting implementation, future work, and conclusions.

2. SBME Overview

SBME aims to facilitate decision making to enable more efficient and effective service operations by optimizing the costs and value of service operations. Informed decision making is based on collecting and analysing a wide range of information about SB. We call this information *Service Base Information (SBI.)* SBI includes both technical and commercial information on each product individual, see Section 4. SBME processes SBI into a form that delivers the right information, to the right person in the right place and time, in the right way – an application of the informatics approach.

Product individuals communicate regularly with the SBME to keep the corresponding information in SBME up-to-date, alleviating challenges of manual data collection. Furthermore, product individuals should be adequately instrumented and empowered by the intelligence and communication capabilities necessary for collecting and transmitting the relevant usage, environment and condition data. From the data and information management point of view, essential SBME activities would cover the following:

- Acquire data from product individuals of SB.
- Acquire data from customers, their value production processes and customer satisfaction.
- Process data (diagnostics, prognostics, decision support).
- Provide decision support for service business management purposes.

A major functionality of SBME is to support services towards products manufactured by competitors. An extreme example from our case companies showed a maintenance site where all product individuals under maintenance were manufactured by a competitor. In another case of hundreds of thousands of product individuals in SB, about 1/3 are ‘own’ manufacture, 1/3 are manufactured by acquired competitors, and 1/3 manufactured by current competitors. Therefore rapid modeling of competitor products is essential.

SBME is to support different personnel groups by generating actionable information (recommendations), and by providing analysis tools that make accessing relevant information straightforward. As outlined in [6], recommendations may include prioritized operational and maintenance actions, capability forecast assessments, and changes in operations e.g. to allow a production run to complete. Some recommendations are to be acted on immediately such as notification of operators of an alert and recommended corrective actions. Other recommendations are longer term such as a warning production planning function about the high risk of failure of a production line due to a soon-to-fail critical product individual. Capability forecast assessments provide likelihood of accomplishing a specific goal, e.g. for deciding whether or not to accept certain orders or where to assign the work.

Some analyses to be supported by SBME take place on product individual level, e.g. optimization of operation or maintenance activities in case of a foreseeable failure. Other analyses concern the whole installed base or a subset of it, e.g. warranty cost prediction or detection of patterns of usage, environment, early symptoms, etc. that may provide an early warning of a foreseeable failure.

3. Use cases: service offerings and activities supported by SBME

Equipment is used in customer’s processes to provide some function(s). How optimally these functions are achieved depends on how the equipment is used and on its condition that may limit availability, quality of output, or even safety. As a whole, operation is a highly complex domain and relevant decisions, constraints on decision variables, and optimization criteria depend on the context.

Sales of many service contracts depend on reliable estimated costs of service provisioning and risks. Among key information is estimated equipment reliability, maintainability, estimated spare part consumption and preventive and corrective maintenance required. All these should be determined in context of estimated usage and environmental conditions.

After a service contract has been established, service delivery needs to be managed and SBME should support related decision making and reporting both towards customer and for internal purposes. Financial performance monitoring of contracts, products and services is required [2].

Table 1 summarizes the main use cases for service provisioning, some of their key performance indicators, main decisions and potential support from SBME.

Spare parts management. Based on SBI (actual usage and conditions, preventive maintenance programs for each product individual, new and expiring contracts, location information), spare part consumption can be estimated more accurately than based on historical demand. Similarly, SBI can provide inputs to strategic design of the spare part network, and tactical decisions such as determining spare part inventory levels [8]. A functionality of SBME is to identify compatible spare parts. This is seemingly easy, but complexity arises from product changes, product individual level differences in structure caused by configuration and engineer-to-order mode of operations, discontinuation or substitution of component types, and modifications and upgrades of a product individuals.

Basic maintenance contracts provide adequately skilled resources for the customer so that they perform corrective and preventive maintenance as planned and ordered by customer. The service provider is responsible for the availability and competence of workforce. Skills management and assignment of sites to regions are of central importance. Key decisions of *corrective maintenance* include allocating service jobs to field engineers and identifying necessary spare parts. Service can be expedited by informing the engineers on access requirements and by providing information to identify equipment [2].

Planning of maintenance. Planning of preventive maintenance (PM) activities is a major area of decision making to be supported by SBME. For example, it is possible to *optimize preventive maintenance intervals* based on globally aggregated relationship of usage, environment and field reliability of components or subssystems. In addition, field engineer traveling routes optimization is possible based on equipment locations. Effectiveness and efficiency of maintenance and maintenance programs can be evaluated based on KPIs that are based on failure and maintenance data. Example KPIs provided in [7] include field reliability and availability of equipment, failure rate and hazard rate, maintainability and repair rate, adherence to preventive maintenance programs, and cost of maintenance. *Remote monitoring* enables experts of the supplier to support the customer's value production processes. For example, troubleshooting, optimization of operation, and support of evaluation of equipment condition may be provided. An example is *(predictive) maintenance planning contract*, where the service provider advices on timing of maintenance based on condition and individual preventive maintenance plans. Timing can be based on e.g. remaining useful lifetime (RUL), condition indicators, preventive maintenance program criteria, records of failures and alarms, and required or estimated usage of equipment. For example, remaining useful lifetime simulations with real options approach can be applied for decision making for timing of maintenance [9].

Table 1. Summary of use cases, their KPI's, decision and SBME support.

Service promise	Responsibility & KPIs of equipment manufacturer	Key decisions of equipment manufacturer & SBME outputs
A: I provide spare parts to you *No specific contract*	Quick delivery of correct spares parts	Spare part compatibility with product individuals, availability of spare parts, inventory levels and locations.
B: I maintain equipment for you *"Basic maintenance contract"*	Corrective and preventive maintenance planned and ordered by customer	Availability and competence of workforce. Skills management, assignment of sites to regions, assignment of jobs to engineers.
C: I plan maintenance for you "*(Predictive) maintenance planning contract*"	Correct advisory in maintenance planning	When to perform which maintenance activities. Remaining Useful Lifetime (RUL) of equipment. Optimization of product-individual specific PM schedules. Remote and condition monitoring. Fault and maintenance event recording and analysis.
D: I take the risk of equipment failures from you *"Extended warranty contract"*	Minimum failures of equipment	Managing risk of equipment failures. Is equipment used as agreed? Is equipment maintained as agreed?
E: I guarantee availability of your equipment by adequate maintenance "*Full maintenance contract"*	Short and infrequent failures → availability	Decisions of A, B, C and D. Availability. Cost of service provisioning (work, spare parts)
F: I operate and maintain equipment for you *"Operations & maintenance contract"*	Maximum economic throughput of equipment	Align equipment economic and technical performance with customer processes. What do when a product failure is foreseeable? Overall equipment effectiveness (OEE). See also A, B, C, D, and E.

Extended warranty (EW) is an agreement to extend a base warranty provided at time of purchase of the equipment. EW may include conditions, such as use of original spare parts or a maintenance contract between a customer and the manufacturer. In order to manage EW costs and profits the manufacturer needs to monitor product reliability and related usage.

Full service a.k.a. performance contracts. In a performance contract a supplier usually guarantees a certain availability of equipment owned by the client, and is responsible for the design of the maintenance concepts and the planning and control of the maintenance activities [10]. The contracts are complex to define and require significant trust and mutually agreed ways of measuring performance such as availability. Optimization of preventive maintenance intervals, optimization of spare part inventories, applying condition monitoring etc. are of interest to constrain costs. Experiences from and information on global installed base can increase accuracy of these decisions.

In a *facilitator contract* the client uses systems owned and maintained by the supplier. The customer pays for usage e.g. in terms of time or units of production. Lease contracts are a well-known example of facilitator contracts [10]. Different KPIs from full service may apply.

In *results-oriented product-service systems* [11] the key is selling a result or capability where the producer maintains ownership of used equipment and the customer pays only for the agreed results or capability. '*Operations and maintenance*' type service contracts differ from results-oriented product-service systems in that the customer retains ownership of the equipment. Supply of materials and other production inputs can be allocated to customer or the service provider. According to [12], some typical decisions include performing corrective maintenance, compensating equipment, executing an intervention ("a field operation"), and performing no service. Compensating the equipment involves modifying the operational settings or adjusting the degraded or faulty system, sub-system or component so that the equipment can continue operating safely but at reduced level of performance. An intervention could be to instruct an operator based on analysis that reveals an incorrect or sub-optimal control setting. Performing no service in the case of a degraded component implies running the equipment to failure, or may allow e.g. a production run to be completed before full failure. A key decision concerns *timing of maintenance activities that require shutdown or operation at reduced capacity* such as major overhauls or required inspections. Scheduling may take into account condition indicators, PM program criteria such as time, amount of usage, occurred stress, maintenance history, and records of failures and alarms. Another major input is required or estimated usage of equipment, for example to time operations to a period of low demand or to avoid critical periods. Further optimization is possible by allocation of additional individual preventive maintenance activities to these maintenance breaks by deferring or advancing them in an informed way. One more main decision is to *determine maintenance strategy* for types of equipment or even for product individuals – run-to-failure, preventive maintenance (and its interval), or condition-based maintenance. This decision depends, among others, on equipment criticality, effect of maintenance on reliability, cost of a failure, and cost & effectiveness of preventive maintenance, and cost, availability and effectiveness of condition based maintenance. For example, plotting and analyzing equipment reliability since repairs/maintenance might reveal that preventive maintenance does not increase reliability of specific equipment. Thus, change of strategy into run-to-failure might be appropriate [13].

Product development. SBI can be utilized in product development at least in two ways. First, specifications and design details can be more precisely determined based on actual usage patterns, environmental factors, stress, and failure history of a current product generation. Field reliability and maintainability of existing systems and components can help to prioritize product changes. SBI makes it possible to identify and analyse needs of existing customers in context of a specific product, service, or application. SBI can also to support proactive customization of product and service offers and performance monitoring [2]. Second, identification of a developing 'epidemic' within a product type can be supported by SBME. In these cases, unexpected corrective maintenance is needed repeatedly among individuals of a product type. The company needs to determine why the product individuals fail and whether it is really an epidemic or just e.g. product abuse. The number of expected repairs can be estimated as well as possibly escalating warranty costs. If the product type is sold in large quantities or if it is used in critical processes, it is essential for the supplier to find out the root cause. SBME can support identifying the root-cause by enabling comparison of data of faulty product individuals to find out if the cause is the product itself, usage, specific environmental conditions or a quality problem of a specific component supplier, etc.

In addition, potential use cases of SBME stem from management of 'normal' warranties (e.g. fraud detection), HR activities (required skills development and sizing of field workforce), and sales (opportunity detection for new sales, upgrades and modernizations, spare parts, and analysis of needs).

4. Main information contents of SBME

Service Base Information (SBI) collected by SBME contains current, historical and also future (planned, predicted) information on product individuals that form the installed base. SBI contains technical (basic information, operational and resource data) and commercial (customer, service contracts, cost, and value) points of view. Main views of SBI are discussed below. In some of these alternative depths and level of detail are applicable, and some points of view are not always needed. Furthermore, some information may only be available in the context of a service contract. Metadata on information quality is required. Note that SBME needs and aggregates information on several levels ranging from product individuals through site or fleet level to global installed base level.

As usual, we distinguish between types and individuals, although the prototype model approach [14] may be adopted to add capabilities of modelling. Note that SBME models also product individuals made by competitors, including structure, usage and maintenance events to provide similar support than for 'own' products. Less detail e.g. in terms of structure may be available.

As-maintained compositional structure with *roles* reflects the current compositional structure of a product individual on the level of component individuals. Whenever a component individual is changed for any reason, this change is reflected in the as-maintained structure. A component individual in a product individual occupies a specific *role*. The concept of role is similar to (a low-level) *functional location* of SAP or *segment* of MIMOSA OSA/EAI [5], but roles are utilized also at a detailed level of product structure. For example, 'Intake_filter' of a compressor individual is a role. Originally, this role could have been occupied by individual C#123 of type INTKF791, then by an unknown component individual (e.g. unrecorded change), and currently from a specific point of time (say, T3) it is occupied by component individual C#936 of type INTKF795. Roles serve multiple purposes. The most fundamental of these is that the as-maintained structure can be represented as an association between a role of a whole component individual and a part component individual during a specific period of time. This time-based approach enables collecting information about useful lifetime and reliability of components. Additionally, a role may be used to associate information about component types that can occupy the role, i.e. eligible spares. This information can be carried over from type level, but changed locally as needed. Components in the as-maintained structure are individuals – each component individual has its own unique identity. This identity remains even if the component individual is removed from a product individual, possibly refurbished, and then installed to another product individual. Thus, it is possible to track the 'life-cycle story' of a component individual, e.g. number of refurbishments, successful and unsuccessful identification of faults, material or testing certificates, etc. In practice, it seldom makes sense to store the as-maintained structure as individuals down to the 'bolts and nuts' level. It is a common industrial practice that no 'machine readable' record is created when component individuals are replaced with spare parts. It is therefore impossible to determine field life of most component individuals and corresponding component types. We suggest to support time-stamped history of component individual changes – updating this is less tedious than information for serial number tracked component individuals. Furthermore, it should be possible to include indications of uncertainty – it should be possible to record a change with no clear indication of time or a rough estimate.Finally, many companies face competition from third-party spare parts. Information about competitive offerings can be associated on type level with roles.

Failure and maintenance data definitions of ISO 14224:2006 [7] can be applied as a basis for SBME:

- Failures are *associated with product individual and component that failed*. Actual failure data includes:
- *timestamps,*
- *failure impact,*
- *operating condition at failure* (e.g. running, start-up, testing, idle, standby).
- *Failure mode* is the effect by which a failure is observed on the failed item such as desired function is not obtained (e.g. failure to start). Applicable failure modes are specific to each type of equipment, but [7] defines 3 main failure modes and numerous sub-modes.

- *Failure mechanism* expresses the physical, chemical or other processes which have led to a failure. Again, 6 main modes and numerous sub-modes are specified.
- Sometimes also *failure cause* (root cause) is determined.
- Finally, 10 *failure detection methods* are coded, e.g. periodic maintenance, or production interference.

Maintenance data [7] is recorded both in case of preventive and corrective maintenance events. Each maintenance event includes

- *identification data* (e.g. equipment and items, related failure if any),
- *timestamps*,
- *maintenance category* (preventive (testing/inspection, condition monitoring, periodic), corrective),
- *maintenance activity category* (e.g. replace, repair, inspection),
- *impact of maintenance on operations* (zero, partial, total),
- *maintenance resources usage* includes maintenance man-hours per discipline, and utility resources applied;
- *maintenance times* include active maintenance time, down time, and issues that extended the time used.
- We agree with [2] – maintenance data should include person(s) who performed the activities to identify experts or colleagues that can provide support.

Operational, monitoring and environment data comes from digitised sources including sensors and instruments, the controller of equipment, laboratory equipment, and manual inputs [12]. Here *alarms and alerts*, *conditioning monitoring data*, and *usage data* are captured. Usage data includes how (control parameters, relevant process parameters) and how much the product has been used, including start-up, shutdown, and idle periods. Time series of relevant parameters are made available to SBME, either directly, as censored data, or as locally calculated features and statistics; some only on demand.

Failure logic information created with product development time techniques such as Cause-Consequence Trees and Failure Mode and Effect Analysis (FMEA) can provide support to life-cycle management in the SBME. Some failure modes are related to specific patterns of usage (e.g. extreme loads in specific conditions). Often these can be predicted only through experience such as occurred failures. Global management of SBI has the largely unexploited potential to reveal such patterns, and to enable prediction of potential failures in cases that match the pattern. This allows reacting in a pre-emptive manner before negative effects of a breakdown occur.

Service contracts are modelled to be aware of performance indicators in terms of promises made to customers (e.g. availability, response times), contract period, costs and other internal key performance indicators (KPIs). *Customer's value production process* is modelled sufficiently to understand the role of product individuals, their performance and availability in customer's value production. *Customer stakeholders and their roles* may be complex, and several customer stakeholders may be related to a product individual. Examples of stakeholder roles include owner and user. When these are organizations, responsibilities may be further allocated to several stakeholders. Decision making is often separated from users or maintenance technicians, and delegated to numerous stakeholders.

Site and location or fleet information describes physical, logical or geographical locations, and is associated with product individuals. Sites may be associated with an owner, operator, or other customer stakeholder roles. Physical location where a piece of equipment resides at a (fixed) site is often identified with a ‘tag number’, code of the physical location on a grid (e.g. B7) and/or functional location such as process ID (PID). Locations are independent of product individuals occupying them. When the installed base consists of moving equipment, such as ships, it may be challenging to know where each product individual is physically located, but membership in a fleet or association with customer (owner, operator) is normally maintainable. The customer may make e.g. the schedule of a vessel known to allow for planning of service events, such as repair in the next port. Access information is tied to location, including access procedures, safety procedures, and instructions for reaching the location.

Service tasks specify job contents (‘recipes’) in terms of amount and type of a human resources required (including adequate competences, such as technical qualifications and skills, experience and language). Furthermore, spare part needs and special resources are indicated. Performing a task triggers updates to the as-maintained structure and creates appropriate maintenance events.

5. Discussion

Related work. Our work differs from previous work that often takes the point of view of an asset owner (site, plant or fleet) owner. SBME’s main functionality relates to the three highest blocks of the architecture of ISO 13374 “Condition monitoring and diagnostics of machines. Data processing, Communication and presentation”, see [6]. These blocks combine monitoring technologies in order to assess the current health of the machine, predict future failures, and provide recommended action steps to operations and maintenance personnel.

We aim to model SBI on a well-founded conceptualization that takes into account existing standards. In view of [2], central pieces of SBI are records on items, customer locations, and service events. Mimosa OSA-EAI [5] presents a broader technical view that implements ISO 13374-2 [6]. OSA-EAI is represents e.g. measurement data, concrete maintenance plans, diagnosis results, and equipment identification. It does not provide means to perform analysis, and the business view to SBI is absent. Asset Management literature includes the business view; [3] presents one of the most comprehensive conceptualizations, but is limited in terms of presentation of the technical view.

Challenges. Manual collection of data about installed base is challenging. For example, a current industrial challenge is maintaining as-maintained structures up-to date, because component changes are often not registered, and their visibility to supplier is poor. Even if personnel of the supplier perform these activities, a 'computer-understandable' coded event is usually not created. Similarly, maintenance and failure events are not registered or are registered in a way that leaves many aspects unclear. For example in some of our cases it is common that about half of failure classification codes are ('other' or 'miscellaneous'). In our experience, currently the utilization of SBI is hampered by scattered availability, insufficient quality and lacking comprehensiveness.

Future work. Implementation of SBME is a major undertaking, and stepwise implementation of the vision is required. The large scope of information causes challenges, and issues of 'big data' become relevant due to the potentially huge amount of SBI. Currently SBME-related information may be scattered in several (e.g. 5 - 10) systems, and some of it is not available at all. SBME will not replace these systems. There are numerous challenging aspects of integration.

Conclusions. We presented a vision of Service Business Management Environment (SBME) – a comprehensive decision making tool to be developed from the point of view of service business of equipment manufacturers. The requirements originate from experiences from 8 cases, and the vision utilizes a wide range of information to provide decision making support using state-of-the art methods. The SBME vision promises significant gains on efficiency and effectiveness of service operations of equipment manufacturers gained through better utilization of fleet view of the service base. Realization of the SBME concept requires significant future work.

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References

[1] Oliva R, Kallenberg R (2003) Managing the transition from products to services. International Journal of Service Industry Management 14(2):160-72.

[2] Ala-Risku T (2009) Installed Base Information: Ensuring Customer Value and Profitability after the Sale, doctoral dissertation, Industrial Engineering and Management, Helsinki University of Technology

[3] Mathew AD (2008) Asset management data warehouse data modelling, doctoral dissertation, Queensland University of Technology

[4] Jardine AKS, Lin D, Banjevic D (2006) A review on machinery diagnostics and prognostics implementing condition-based maintenance. Mechanical systems and signal processing 20(7):1483-510.

[5] Mimosa (2007) MIMOSA's Open System Architecture for Enterprise Application Integration (OSA-EAI) Version 3.2 Technical Architecture Summary

[6] ISO (2007) ISO 13374-2:2007 Condition monitoring and diagnostics of machines -- Data processing, communication and presentation -- Part 2: Data processing

[7] ISO (2006) ISO 14224:2006(E) Petroleum, petrochemical and natural gas industries -- Collection and exchange of reliability and maintenance data for equipment

[8] Dekker R, Pinçe Ç, Zuidwijk R, Jalil MN (2011). On the use of installed base information for spare parts logistics: A review of ideas and industry practice. Int J Prod Econ (In press, accepted 2011).

[9] Haddad G, Sandborn PA, Pecht MG (2012) An Options Approach for Decision Support of Systems With Prognostic Capabilities. IEEE Transactions on reliability 61(4):872.

[10] Martin HH (1997) Contracting out maintenance and a plan for future research. Journal of Quality in Maintenance engineering 3(2):81-90.

[11] Baines T, Lightfoot H, Evans S, Neely A, Greenough R, Peppard J, et al. (2007) State-of-the-art in product-service systems. Proc.Inst.Mech.Eng.Pt.B: J.Eng.Manuf. 221(10):1543-52.

[12] Dausch M, Hsu C. (2006) Engineering service products: The case of mass-customising service agreements for heavy equipment industry. International Journal of Services Technology and Management 7(1):32-51.

[13] Moseley S. Asset Management Basics (2012) Maintworld 4(1):6-8.

[14] Peltonen H, Männistö T, Alho K, Sulonen R (1994) Product Configurations-An Application for Prototype Object Approach. In Tokoro M, Pareschi R (eds) Proceedings of Object-Oriented Programming. 8th European Conference, ECOOP '94, Bologna, Italy 4–8 July, 1994