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Management of factory and maintenance information for multiple production and product life-cycle phases

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ABSTRACT

Maintenance is crucial for future manufacturing systems. An extended local knowledge is essential to increase precision and efficiency, but also for improvements of the maintained object itself. Approaches exist that closes the loop from end-user to vendor, but intra loops are not so well developed.

This article discusses ways to interconnect and manage data and knowledge flow between work processes in user and vendor life-cycles. It aims to inspire improvements in existing approaches, closer connections between producer and customer, between users, and improved quality of maintenance work via factory-, company-, or group-wide data and knowledge about similar types of equipment

Keywords: Maintenance improvement; product improvement; machine builders; vendors of factory systems; knowledge and data loops; life-cycle; maintenance optimization; product population

1. Introduction

Maintenance is a targeted activity area in industry today. In the pursuit of increased profits, the area is under constant cost pressure. The process of maintenance ensures that infrastructures, plants, systems, and components can be used for their intended purpose during the course of their life-length by upholding asset properties such as function and performance. As such, maintenance is an important contributor to sustainability and business economy; and for manufacturing companies in particular it supports repeatable processes that can produce products within specified quality parameters.

The classical role of maintenance is clear – fix something when it is broken, or prevent it becoming broken when it is not. In the search for improvement of the activity in itself, companies try to rectify their purchasing and equipment acquisition processes in order to ensure that their initial requirements will also be realized on the factory floor with sufficient functionality and performance to carry out the specified production tasks at the estimated cost levels and required life-lengths. During production, they try to learn from events and faults, dig up root causes, and use this knowledge to implement preventive measures. Experience, feedback data, and decision logic are thus used locally to systematically select the maintenance tasks.[1] In pursuit of even higher precision in the maintenance work, various condition-based techniques are implemented in order to totally avoid faults on selected equipment. Today, most of this work is performed by the local maintenance organizations themselves, with little or no contribution from other parts of the company-wide organization and the vendors of factory machines and systems used.

However, even if the numbers of faults and errors tend to decrease and the times between failures to increase due to use of modern equipment with better quality, existing maintenance activities fail to reach sufficient precision and preventiveness. The manufacturing of tomorrow will require disturbance-free operation of the chosen equipment, more precise knowledge of when and where to intervene in order to prevent disturbances, and machining processes involving stricter quality spans, higher speeds, and the ability to sustain higher forces due to the use of newer materials with greater surface hardness. Vendors and users need to increase their knowledge sharing and transfer in order to be able to cope with manufacturing, product, and business requirements.

As today´s maintenance organizations become more and more decentralized, organizations aiming to support small areas or operation groups on the factory floor must be given an overview and reference based on a knowledge space as large as possible. Using data and information about the same or similar machines and equipment drawn from the whole factory, the company group, or even parts of or the whole product population[2] will improve analysis and decisions. Hence, users of modern equipment can be given deeper, broader, and more immediate knowledge about the deviations, events, disturbances, and faults that have occurred within the learning space available.

Going from the present situation to the one described above must involve collection of and access to data from machines and equipment inside and outside the factory. Natural hubs would be vendors of the equipment or user collaboration networks. By implementing a closed loop from vendors to the users of their products, data and information are fed back to product development and improvement. Improved maintenance plans and optimization of spare parts should also be included. Partial examples can already be found in products used in the medical and health industry,[3,4] the aerospace industry,[5] the automotive industry,[6] and applications where the manufacturer produces and delivers more complex products.[7]

Servitization is a new approach in which a manufacturer adds services to its existing products. Going through such a shift can have severe implications for the business model itself,[8] as producers also become service providers[9] and use or implement product service systems.[10] All these seemingly include the loop from user to vendor, but it is unclear how these approaches embrace user experience with disturbances and faults, improve local users' maintenance activities, or support vendors acquiring knowledge about the use of their products and forwarding that knowledge back to their product users. Examples also include terminology such as "spare-parts provider" or "after market activities", as well as pointing out obstacles to be overcome in order to get vendors to increase their service offering to customers.[11] Most of the approaches include only sparse descriptions of the interplay between vendors and users. They do not explicitly deal with the maintenance activities as such, and they do not address the achievable opportunities, such as being able to give the end users better maintenance plans, improved preventive techniques, or directives on how availability can be increased based on experiences from a bigger population of the same or similar products (or components). However, the area is being addressed in some business and technology development projects.[12,13]

An improved situation would of course include the optimization of spare parts and the provisioning of these to end users based on actual needs in predicted and preventive activities. Any other need should be estimated based on the most complete population experience possible, and could be provided as a shared service offer freeing the end user from expensive spare parts storage.

Perhaps the most widely used approach is Product Lifetime Management. However, this still lacks the content that connects existing knowledge with proposed new product development issues, taking care of the full knowledge potential from a more complete product population.

Finally, customers with the possibility to affect vendor behaviour have begun to develop stricter criteria describing a life-cycle including feedback loops from end users to vendors.[14]

The methods applied to increase availability, reliability, and robustness are thus in most cases applied and conducted by the local end user maintenance organization, together with a vendor community which still sees the aftermarket as consisting solely of deliveries of spare parts. This must come to an end!

The objective of this article is to describe a framework that could complement existing approaches by dealing with knowledge about the use of the physical products – machines and manufacturing systems – that are installed and used in a production facility. Starting with the issues facing a local maintenance organization and then successively building up a scenario where the local organization can be supported by the knowledge gathered from all data from the knowledge space around each product as well as from a larger population of the same or similar products, they could increase the precision of their maintenance work, obtain data and knowledge about faults and disturbances that have not yet occurred at their site, and thus increase both their efficiency and the value of their work. The full potential will arise when data and knowledge can be accessed from an even more complete product population than the one available internally, to achieve the best maintenance results possible. If the vendor is included and uses this knowledge, the best products possible could be developed by using data from users as well as information about the modifications and improvements they have implemented.

This article is based on analysis of a number of manufacturing companies, their present working manner in the machine and systems acquisition phase, their working manner and use of technical support systems for operation of their production facilities, and their maintenance and engineering processes.

The framework encompasses a vendor and the suppliers the vendor use, and a user of the vendor's product using the product for manufacturing of own products, including the multiple life-cycles involved. Hence, it could be used not only for improvement work, but also for development of vendor-customer cooperation, business models, and technical solutions.

The article is structured in the following way. It begins by addressing the life-cycles at users and vendors of machines and manufacturing equipment, and outlining the different work processes involved in various parts of the life-cycles. This is complemented with the data and knowledge that these processes produce or may consume if they are interlinked with each other. In order to implement and make use of these processes, data handling and structuring must be improved. The article ends with a short description of possible business areas that are being developed or could be developed using the flow of data and information between users and vendors of a product.

2. Life-cycle processes of concern

This section describes how users and vendors interact today, and how this interaction could develop in a natural way. The need for a new view of maintenance and its role in life-cycle management is now an established truth.[15,16] Historically, maintenance was equivalent to repair work. Today, we know that maintenance preserves the condition of a product so that it can fulfil its required functions at specified performance levels throughout its life. In addition, analysis of early product features and design solutions allows us to influence the reliability and maintainability of a product, and thereby its robustness. These inherent characteristics may of course also be dependent on deliberate business decisions.

Assuming that vendors are satisfied if their customers are, it is peculiar that most of the work deployed by users is so unsupported by the vendor community. Each user tries to create the best possible prerequisites by requiring, purchasing, and implementing their manufacturing systems with their engineering work procedures. In use, the system requires care, service, and maintenance to function. Even these work areas often start from scratch at each end user's site.

The view today (Figure 1) is that product design improvements (loop 3) connect to knowledge about failures and their effects (loop 2). This could in turn be used to define and improve what maintenance should be done (loop 1). So the concept exists – but it still lacks what it really requires in terms of how users and vendors could connect in practice.

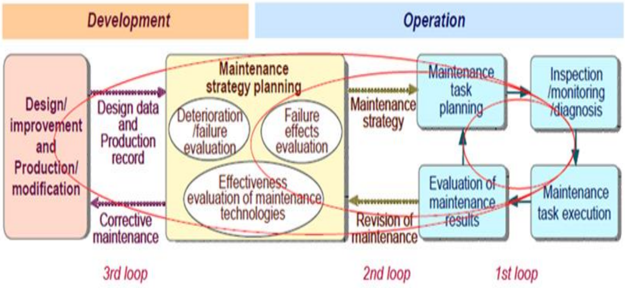

Figure 1 – Life-cycle maintenance[15]

2.1. User life-cycle

Today, users typically initiate and perform three types of life-cycles; their products, their physical processes (that produce the products), and the work processes needed (Figure 2).

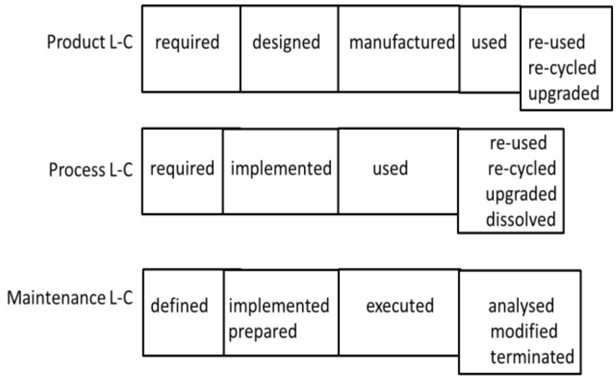

Figure 2 – Typical life-cycles performed by users.

Starting at the top of Figure 2, the product development process defines and specifies the equipment that is needed to manufacture the product. This equipment in turn must have the functions and performance needed to manufacture the specified product. At the end of the implementation phase, the equipment is installed, verified, and tested. After production, the result is the final product offered to the market and end users.

Throughout the use phase of the process, activities to uphold functions and performance must be carried out. These activities are first based on the knowledge gained and the deliberate choices made by vendors of machines and equipment, for example the physical solution and material choices made together with the first maintenance plan and its spare parts requirements. During commissioning and installation, the requirements set up (including maintainability) are checked and verified. The initial test production phase finally ensures that the initial requirements for function and performance are met. From the first test period onwards, every deviation from the requirements must be detected, corrected, and subsequently prevented by the user's maintenance organization.

2.2. Vendor life-cycle

The life-cycles on the vendor side are in principle the same. The vendor's products will be used in their users' factories. The product to be manufactured is specified in a process that starts with the early conceptual design, continues with functional design, and ends with the physical design using components and subsystems from sub-suppliers and manufacturing of parts using different materials. Parts to be manufactured using the vendor's production system constitute the basis for process requirements in the same manner as the above-described user process, including setup and use of different work processes (Figure 3).

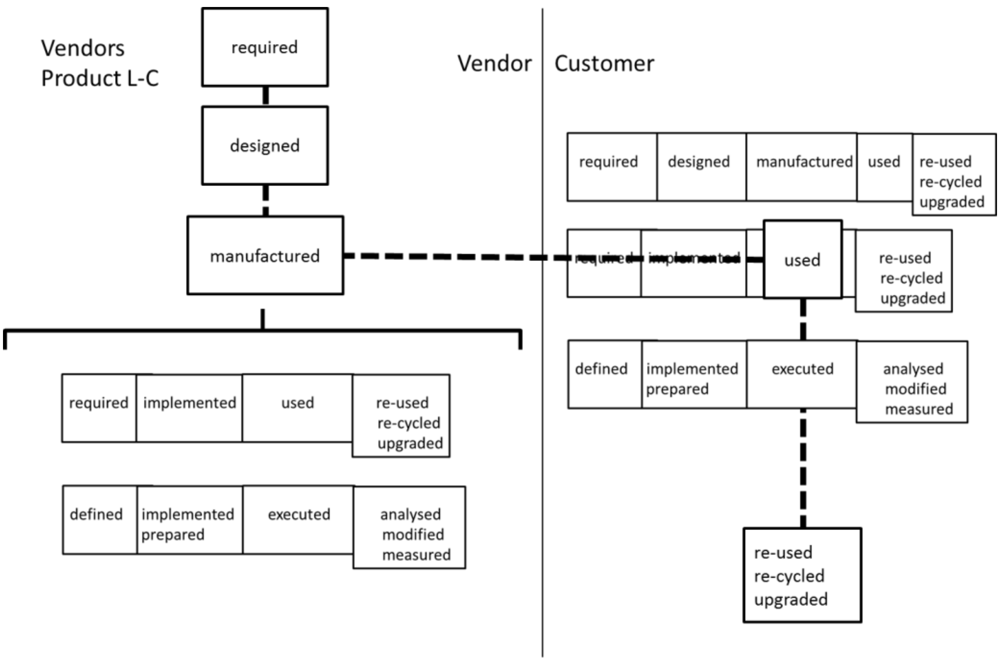

Figure 3 – Vendor life-cycle hooked to a user's life-cycle

3. Processes in life-cycles, and their activities that create data and knowledge

As indicated in the previous section, vendors today leave their users with more or less no support after their products have been chosen, installed, and paid for. Vendors also seem completely uninterested in their users' desires to specify, verify, and obtain prerequisites that are as good as possible at the commissioning phase in their early process life-cycle, and to gather knowledge about the use of the product they have bought. Even if users raise questions about badly-functioning parts of their products, the vendors have never heard of anything like that from other users of the same type of product.

By defining the knowledge different processes may produce and could consume in order to improve, a point of departure is established for integration of the different loops illustrated in Figure 1.

3.1. Vendor product development and equipment design

The product to be manufactured always starts with an early conceptual design followed by function design. Implementing functions in physical format includes trade-offs between using components from suppliers or developing and manufacturing them in-house. During the physical implementation of the functions, aspects of use must be considered, including life-length. Solutions including factors such as the possibility of wear must be evaluated, including the vendor's choice of whether or not the result should be maintainable. If maintenance is required, then physical access, modularization, and the spare-parts required and offered must be considered.

The knowledge established about weak parts, parts exposed to wear, system functions that need periodical service, and so on, constitutes the first maintenance plan. Together with the list of required spare parts, this part of the vendor process establishes the requirements for the setup and initiation of their users' production and maintenance work processes. As the product will be entering the market for the first time, no experience from users will yet exist.

3.2. The process of equipment implementation in the user life-cycle

A user must establish requirements on their own production process with its different systems based on their own products' requirements. This early process design phase is illustrated at the left of Figure 4. The vendor community, of course, also participates here during the tender phases with the possibility to learn the user requirements and test those against their own product specification. The user tries to include experience from earlier use of similar equipment as well as that gained from earlier process establishment projects.

Having chosen a vendor, the user needs to set up the process and the work processes. The physical installation of the vendor's product includes geometry issues of the equipment followed by the verification of functions and performance. Test series production results and final adjustments conclude the physical process implementation. The work processes include start-up of the maintenance activities from the first moment the equipment is set running. The vendor's initial maintenance plan is usually considered too generous and thus not trusted. The reworked vendor plan constitutes the first maintenance plan.

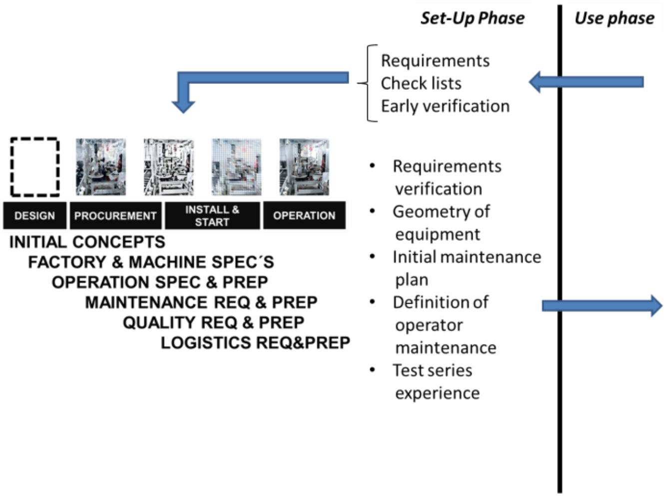

Figure 4 – Early phases of the user process life-cycle

3.3. User life-cycle and processes upholding properties

Starting with production, any events, deviations, disturbances, and faults are successively handled by the maintenance organization. Parts of the preventive work and fault corrections that are not too difficult are performed by the operators. The user gradually builds up knowledge from using the equipment, in various parts of the organization. Some knowledge is stored in computerized maintenance management systems (CMMS). There, the physical machines are depicted as logical tree structures with branches covering different subsystems. Information on the preventive and corrective work done to these subsystems is attached in the form of references and data describing what has been done and when.

The physical process, however, will produce different interlinked phenomena. Some of these will cause deviations from normal (setup or verified) production, such as quality deviations due to changes in environment parameters; others will cause disturbances and faults, for example deterioration of machine functions due to wear of tools (Figure 5).

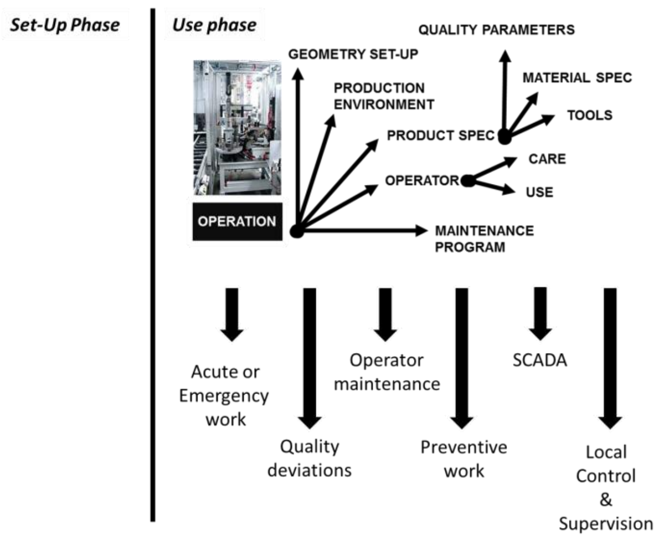

Figure 5 – The user life-cycle use phase and the context generating different activity data and knowledge

Today, the different data-generation activities (indicated by arrows in Figure 5) could be handled by many parts of the organization. Together with an ongoing decentralization of the organization on the factory floor, it is not difficult to comprehend that these local parts of the organization need the strength and insight given by a more global knowledge and data reference.

4. Exchange of data and knowledge between life-cycles of interest

By interconnecting the different life-cycle phases with their processes and activities, the amount of usable data and knowledge from different origins can be increased substantially for both vendor and user. To increase the data and knowledge content even more, some of the following connections can be applied. Figure 6 illustrates all alternatives except the fourth.

1) Between users of the same or similar equipment inside the total user organization, for example a business group of several companies.

2) Between users in different companies using the same or similar equipment.

3) Between a vendor and all users of a particular vendor product.

4) Between vendors using the same or similar components, sub-systems, or products in their respective products.

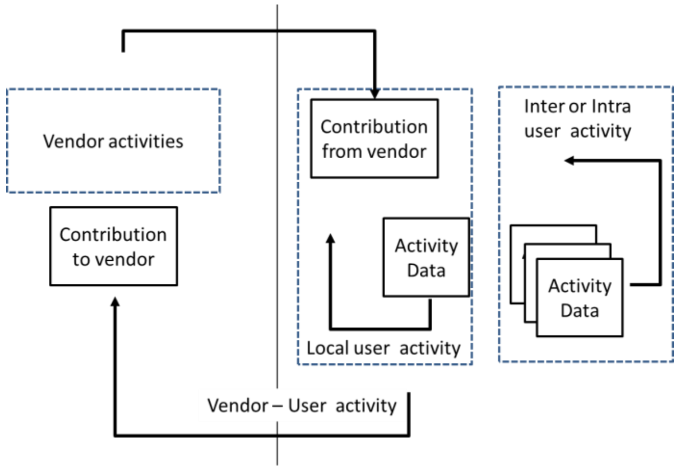

Figure 6 – Interconnection of data and knowledge between vendors and users.

By interconnecting the vendor-user loop, several types of data and knowledge could be exchanged, thereby successively improving the vendor's product and the user's use of the product (Table 1).

The data needed to achieve the user-vendor interexchange originates from the activities performed in the users' processes, (Table 2). The data descriptions given in Table 2 use the typical data found in CMMS systems. Data describing the consequence costs should also be added, to give even better possibilities to estimate the value and results of maintenance activities.

Moving on to the central and local data collection and control units, the typical data collected and stored are given in Table 3. It is assumed that data could be retrieved from proprietary local control units in the products (machines and systems) delivered by different vendors. Central systems such as supervisory control and data acquisition (SCADA) systems are often installed by users, and the databases are typically easy to access.

Table 1

Contribution to vendor	Contribution from vendor
Activity types occured Types, frequencies, consequences	Updated maintenance plan
System or component shortcomings	Inspections required Improvements req. Modifications req.
Customer value loss estimation	Product updates/releases
Realizeable vendor value	Value improvement potentials
Performed: - Improvements - Modifications - Redesign	

Table 2

Acute Emergency Work	Preventive work
Equipment Id Structure reference Time stamp off and on Used Spare Parts Work time Total Cost for activity Free text	Equipment Id Structure reference Planned work time Actual work time Time stamp off and on Used Spare Parts Total Cost for activity Free text

Quality Deviation	Operator Maintenance
Equipment Id Structure reference Time stamp off and on Work time Total Cost for activity Scrap products Free text	Equipment Id Structure reference Time stamp off and on Used Spare Parts Total Cost for activity Scrap products Free text

Table 3

SCADA	Local control and supervision
Equipment Id Structure reference Time stamp Signal reference Value Unit Stored values with time stamps	Equipment Id Structure reference Time stamp Signal reference Value Unit Stored values with time stamp

Finally, there are loops that do not involve the vendor; the inter- and intra-user linkages that can be developed will create possibilities beyond those existing in local user surroundings. Table 4 illustrates the advantages that could be achieved by exchanging data and knowledge between users.

Table 4

Inter or intra user contribution
Activities occured*
Performed: - Improvements* - Modifications* - Redesign*
After analysis: System or component shortcomings* Value loss estimation* Value improvement potentials*
* With time stamp

5. Process improvements needed in the vendor and user life-cycles

In order to retrieve, store, and use the data and knowledge described in the previous section, it is necessary to address some features connected to the improvements needed in the present situation. Starting at the customer or user side, examples will be given that establish basic necessities. First, the data representing the various life-cycle events need to be structured in a better way. Today, these events are not separated from each other. Second, the life-cycle events themselves need to be strictly specified, and each data set belonging to an event needs to be defined.

5.1. Handling of the root version and its properties

The first data set created represents the first version of the implemented physical process – the root version. Data and knowledge describing the activities of the set-up phase form a point of departure – the first finger print, and the first data (Figure 7). Using the production process also means introducing life-cycle events such as:

- changes introduced from vendor updates
- changes introduced from the product
- changes introduced from production processes

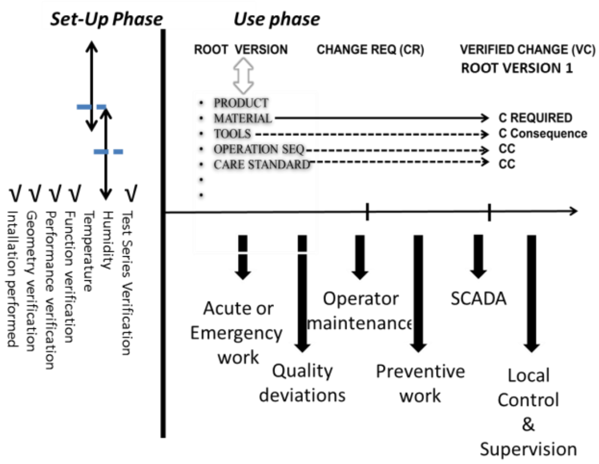

Figure 7 – Establishment of root version, and activities defining the first root version

All these life-cycle events will affect the root version properties once set up and established. Hence, each such change needs a separate analysis of the adjustments of the root version properties necessary in order to meet requirements, and verification that these requirements are met. Subsequent data generated from each new root version create a unique data set which is connected to the root version only. As time proceeds, the upcoming life-cycle events and their interrelated linkages lead to a successive build-up of new knowledge areas and their associated data.

5.2. Acquiring data from users

Vendors could of course claim that it is impossible to collect data from users due to variation in format, storage, and so on. However, it would be possible to provide standard data formats or to translate data from existing formats in the users' CMMS. Vendors do need a system for handling data from users, and examples of such systems already exist.[17,18] The total volume of data in each individual company increases tremendously each year. The data itself is completely unstructured, unless it is given the structure demanded by, for example, a CMMS, and even here there is no guarantee that such a structure will be applied throughout the company group for exactly the same machines or pieces of equipment.

By using pre-defined formats, an active vendor not only sets the scene for their own improvement work, but also allows a better contribution to individual users, who could benefit from a better predictive maintenance based on the whole population of a vendor's clients.[19,20]

5.3. Closing the product loop; by the vendor or through inter- or intra-user collaboration

By adding successive data and knowledge from life-cycle activities, more precise maintenance could be achieved through analysing faults that have occurred, checking status and condition, and introducing preventive measures that are not motivate solely by one's own experience. Vendors could issue regular maintenance plan updates or work order requests to users that could prevent disturbances and faults from occurring. If the vendor is uninterested, users in the user community could unite and transfer raw or processed data between each other to increase machine/product availability, thus obtaining a better result than would be possible for a single user or a single product installation alone.

Including the vendor makes it possible to continuously improve the vendor's product features, functions, performance, and value at users installations. The vendor could issue periodic hardware and/or software updates of their products, together with updated subsystems or components. Following different root version changes (a priori knowledge!), a proactive vendor could initiate actions to better suit the new working conditions at a user site.

5.4. Optimization of spare parts

Today, the handling of spare parts creates large costs for users. Based on the criticality of, for example, a machine, users themselves need to introduce short logistic chains in order to achieve the maximum possible availability. However, the need for parts based on known or estimated preventive measures must be handled more efficiently in the future. Certainly, vendors could provide for the parts needed at users storage shelves and ship the parts necessary for each preventive measure.

6. Business development

In general, the area of maintenance suffers from a lack of economic models including and embracing the consequences and risks of not performing maintenance. The existing economic system, with its periodic calculation of results and balance, does not support long-term or preventive activities. Our ability to initiate and perform activities in order to avoid consequences could therefore benefit from the broadest possible knowledge in order to convince decision makers to accept actions and investments focused on maintenance. The fact that it is difficult to address this area has been identified in many reports.[21] Below are some examples of the business possibilities and the development needed.

Røstad et al.[12] reported that closing the product life-cycle information loops will create a shift in business practices. Manufacturing companies that do not close the loop will experience reduced competitive power.

Hanski et al.[22] discussed the general benefits of getting information and ideas from better customer contacts. By observing the user and analysing the observations made, ideas could be found that could be brought back to the vendor.

Ahonen et al.[23] pointed out that knowledge about the customer is needed for any transition towards customer-centric services. There is a lack of frameworks for gathering useful information and converting this into useful knowledge. The possibility to offer maintenance services has been discussed, but with no connection to the loop of maintenance knowledge between vendor and user.

The fact that experience and knowledge about the use of a product could improve product development is an area of great interest. However, the coupling to maintenance is not always clear; instead, commenters simply note that information about weak points and improvement actions could "be used by other divisions of the company".[24,25] There is a lack of reports assessing a longer life-cycle of a product and analysing whether investments in maintenance do actually lead to improvements. Perhaps there is too much to lose in revealing what the situation really looks like? It is likely that exceptional data exist from entire lives of products, but vendors and users seem to consider these data too confidential or inconvenient to publish. Long et al.[26] found by analysing US military systems that vendor investment in reliability improvement increased the reliability of their products by as much as 674% in one system. Examples are also given where support costs decreased followed investments in product reliability. Mikler[27] found that when performing life cycle cost calculations, the cost of consequences such as lost production was the largest life-cycle cost associated with using that particular equipment. Assuming the same would occur in many situations, there is a clear potential to shift costs and expenses among vendors and users. A large consequence cost could act as payment for investments made by the supplier in order to increase reliability.

7. Conclusion

Using information and data from identical or similar knowledge areas or domains – inside or outside the company – will be an important resource for users and vendors to improve the use of systems and products supplied by vendors. Data and information could be accessed and used (for example) to build better and more complete maintenance plans, improve decisions or the decision base, introduce new preventive measures, or indicate parts or functions of the product that need to be improved.

The local sub-optimization that currently exists in local maintenance organizations is coming to an end. The available local knowledge spaces will be combined with a more complete knowledge base from inter-user and intra-user use of the same or similar products, or from the whole product population as offered and supplied by the vendor, thus forming the best knowledge base possible for each product, machine, and system.

Acknowledgments

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