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Quality Assessment of technical Product-Service Systems in the Machine Tool Industry

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Abstract

A stand-alone technical product in many cases is not sufficient to fulfill customers' requirements. Machine tool manufacturers have already reacted to this fact by offering combinations of products and services, commonly known as technical Product-Service Systems (PSS). Today, nearly every machine tool manufacturer offers PSS. In order to stay competitive, quality leadership of PSS is a promising competitive strategy for machine tool manufacturers. Thus, it is necessary to develop a PSS specific quality management. However, key performance indicators and criteria for assessing the quality of PSS in the machine tool industry are currently missing.

The aim of this paper is to present a customer-oriented approach for assessing the quality of PSS in the machine tool industry. This serves to ensure and continuously improve a long-term business relationship between a PSS provider and its customers. Use cases from the machine tool industry build the basis for this paper. To begin with, existing quality criteria of products and services in the machine tool industry are analyzed. These criteria are gathered by interviews with machine tool manufacturers, customer surveys and literature research. Next, interdependencies between product and service quality are identified. Then PSS-specific quality criteria are developed, which consider product and service quality criteria as well as their interdependencies. Finally, key performance indicators are presented in order to assess and benchmark the quality of PSS.

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Keywords: Quality, Product-Service System, Machine Tool

1. Introduction

Technical Product-Service Systems (PSS) refer to a technical product, which is completed and extended over its entire life cycle through various product-related services [1, 2, 3]. The aim of PSS is to improve a company's sustainability performance [4]. German machine tool manufacturers have recognized for some time that the offering of PSS is an essential element for the success of the company [5]. An extension of technology leadership in machine tools to quality leadership in PSS is considered as a promising competitive strategy [6]. To realize that intention, the first challenge is to make quality of PSS measureable and assessable. Currently, suitable quality assessment methods for PSS exist neither in science nor in industry. The integrated view of physical product and service has the effect that existing approaches for measuring and assessing quality are only conditionally suitable. They either refer to a technical product or a service [6]. Researchers advise for a high customer satisfaction a high service quality [7] which is as important as product quality [8]. Therefore, to ensure the customer satisfaction both parts are necessary for a quality assessment of PSS. According to [9] a third aspect, the price fairness, has to be considered for achieving customer satisfaction as well. In our paper, we focus on product and service quality. The aim of this paper is to make a contribution to overcome the separate quality assessment of physical and service products. For this purpose, a customer-oriented quality assessment for the life cycle of PSS is presented.

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2. Quality assessment of technical Product-Service Systems

2.1. *Quality assessment of machine tools*

In many cases the quality assessment of machine tools aims at technical aspects. Therefore, objective quality criteria already exist, e.g. working accuracy, performance, machine capability and environmental behavior of a machine tool [10]. Research has shown that aside from technical requirements, subjective factors (such as design, user benefit and quality perception) also contribute to the judgment of quality from the customer's perspective [11, 12].

To measure objective quality criteria, reliability analysis, maintenance analysis and availability analysis are suitable methods because they can be evaluated with parameters. The subjective quality requirements are determined by customer surveys or usability studies.

2.2. *Quality assessment of service products*

The quality assessment of service products differs from the quality assessment of machine tools. Service-specific properties are “integrativity” and “immateriality” [13]. According to Parasuraman et al., service quality can be assessed with quality criteria like physical environment, reliability, obligingness, sovereignty and empathy [14]. But as these quality criteria were developed in studies within the financial sector, they are only partially suitable for the quality assessment of machine tools. For the diversity of services in this sector (e.g. retrofit or spare parts support), they must be specified and expanded.

To assess PSS quality along the entire life-cycle of a PSS, it is necessary to use customer-oriented quality criteria. These can be grouped into feature-oriented or event-oriented criteria [15]. Only through a combination of the two quality assessments can the advantages of both be used for a better assessment. Beyond this, the assessment of service products can be done with service-specific parameter systems. Often these are based on a balanced scorecard and further adapted to the specific properties of service [16, 17]. However, pure quality key performance indicator (KPI) systems for services have only been sporadically considered so far [18].

2.3. *Quality assessment of technical Product-Service Systems*

The quality assessment of PSS must include an integrated view of physical products and services. Especially, the interactions between physical products and service products, and their influence on the overall PSS quality, must be considered. A new point of interest for quality assessment is to look at the processes of a PSS delivery from the customer's view [6]. This results from the customer-oriented understanding of quality in PSS. The quality assessment refers to any point of contact between a customer and the PSS provider (this could be contact between customer and PSS provider during a Telephone-service, or just the use of a machine tool by the customer). To fulfill customer requirements, the added value network must be regarded. It includes the service partners, branch offices and salesmen on the one hand, and the different suppliers of the PSS provider on the other [19].

2.4. *Quality criteria of technical Product-Service Systems*

To assess any quality, there is a need for criteria. These quality criteria must be identified and analyzed along PSS delivery from the customer's perspective. The criteria aim to not only assess quality of physical products and services, but also to take into account the interactions between the two. The third section of this paper shows how criteria are identified and what influences them.

3. Approach for quality assessment of technical Product-Service Systems

In this section a customer-oriented approach to assess the quality of PSS is presented. The approach consists of five phases, which are described in the following parts (figure 1). To ensure the approach usability for machine tool manufacturers, the whole approach is framed by a use case. Additionally, the use case demonstrates how to assess quality of PSS for a machine tool.

3.1. *Definition of considered project*

The aim of this section is to select and model PSS for the machine tool industry. Therefore, three different use cases are developed with machine tool manufacturers. Each of the use cases offers a product and different services. For every use case, all steps of PSS delivery are modelled from the view of a customer. For modelling the use cases, an object-oriented business process modeler called OMEGA was used. It is similar to the Process Root Cause Analysis approach (PRCA) because it offers the possibility to model goals and activities of a process [20]. The advantage of OMEGA compared to PRCA is that a generic quality model is not necessary. Furthermore, other modelers, e.g. Blueprints, UML do not present the opportunity to assign material and immaterial resources to every step in PSS delivery. Additionally, the executive organizational unit can be visualized. Therefore, it is possible to differentiate between processes which are conducted by the customer, by the added-value network, or by a combination of both. This is important to analyze the influence of a customer and its production environment on PSS quality.

To illustrate the PSS delivery, part of a use case which is modelled with OMEGA is presented in figure 2. The selected part of the use case refers to the “Telephone-service” of a machine tool manufacturer. In this example, the PSS delivery starts during the use phase. The customer gets a signal that his machine no longer works. This information is saved in the machine data. As a result of this failure, the machine cannot reach its agreed productivity. Therefore, the customer calls the service employee and describes the problem. Material objects of this process are the telephone system and the electronic data processing (EDP) system. The machine data, which is necessary for the service employee to identify the machine, is an IT object. To fulfill the customer requirements, the service

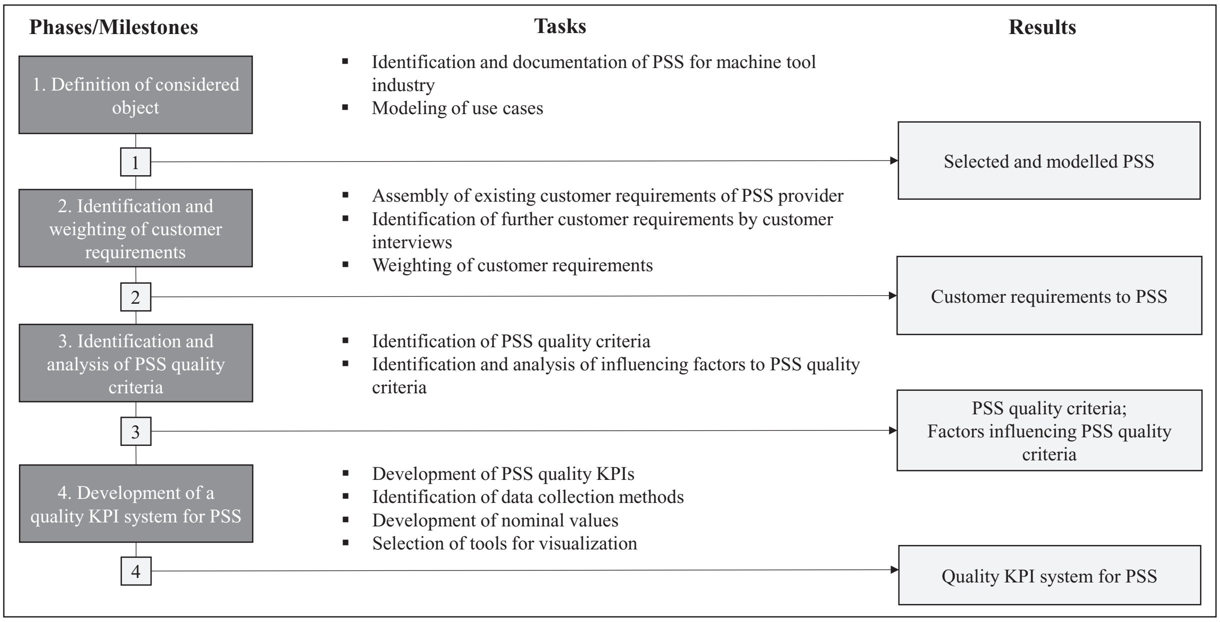

Figure 1: Overview of the approach for assessing the quality of PSS

employee should have technical and social qualifications. In the second step, the customer gets a ticket. The next step involves a help-desk employee who helps the customer to solve the problem. The resources needed in this step are the machine data, the telephone/EDP, the help-desk and remote access. After this call, the customer receives information that a new spare part or a service technician is necessary to resolve the problem, or that the help-desk employee has already identified and released the software problem. As in the second step, here it is also important that the help-desk employee has both technical and social qualifications. After the second call, the problem is solved. Of course, it may happen that there are further services to be considered, but for the purposes of this paper, the PSS is complete.

3.2. *Identification and weighting of customer requirements*

During the second phase of assessing quality of PSS, the customer requirements are identified and weighted for each use cases. The customer requirements are not based on a quality model as it is in the framework of [20]. The requirements are considered by customer interviews with lead users. The OMEGA model is taken as a tool to show the PSS delivery to the customers during the interview. The customers are asked to indicate requirements for every step as well as resources and results. Based on the Kano model a classification of customer requirements in basis, performance and enthusiasm requirements is possible [12]. During the interview, the basic requirements which are expected automatically and not mentioned by the customer are asked separately. The requirements of the customer are listed by process step. The comparison of pairs was used as a methodical support to

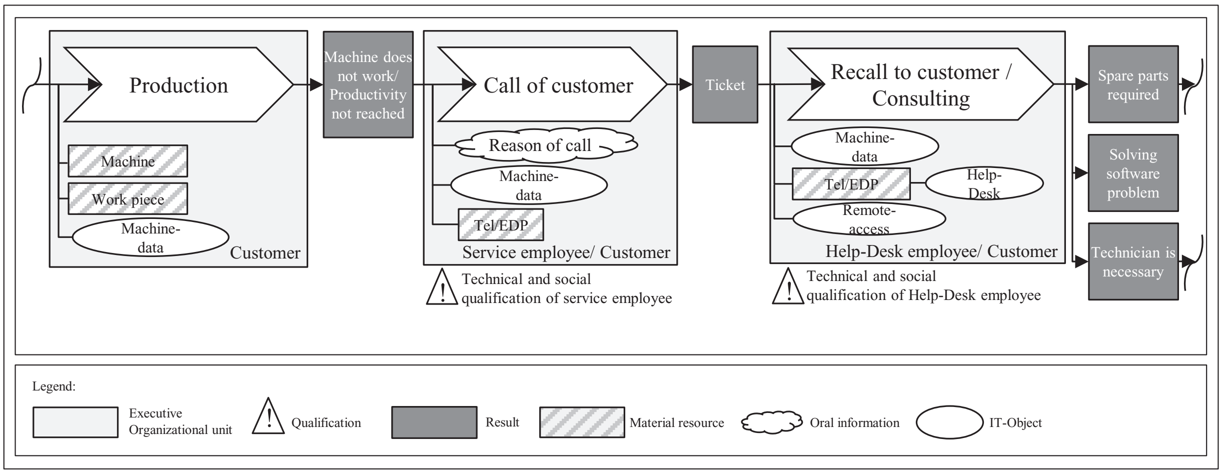

Figure 2: PSS delivery in customer environment

Process step	Customer requirements		Weighting									Weight
			1.	2.	3.	4.	5.	6.	7.	8.	∑	
Production	1.	Information about the error on the machine tool		3	6	6	6	6	6	6	39	20%
	2.	Availability of the machine	3		6	6	6	6	6	6	39	25%
Call of customer	3.	Availability of service employee	1	1		6	6	6	6	1	27	14%
	4.	Considering customer prioritization	1	1	1		1	1	1	1	7	4%
	5.	Knowledge about techn. terms of service employee	1	1	1	6		3	6	1	19	10%
	6.	Time of call	1	1	1	6	3		6	1	19	10%
Recall to customer / Consulting	7.	Waiting time till recall	1	1	1	6	1	1		1	12	6%
	8.	Fast problem solving	1	1	6	6	6	6	6		32	16%
…	9.	…	…	…	…	…	…	…	…	…		…
		Assessment factor: 1: less important 3: same importance 6: more important										

Figure 3: Comparison of pairs of customer requirements

contrast and weight these requirements (figure 3). It is a customer-oriented method and the results depend on the customer's individual weighting. Based on this, relevant process steps and requirements for PSS quality criteria are identified for each use case.

For the presented use case, the customer requirements are admitted and listed according to process step in figure 3. For the first step, the customer wants to get information about the error on the machine tool so that he can clearly explain the problem to the service employee. The customer weighted this requirement with the assessment factor 6 compared to the other requirements from 2 till 8. This means that the information about the error is more important for the customer than the availability of the service employee or any of the other listed requirements. The percentage weight of this requirement is 20 %. The second step is the customer call. Here, the customer expects the availability of the service employee, and that the service employee prioritizes the customers according to the severity of the problem. The customer wants a working knowledge of technical terms used by the service employee to avoid misunderstandings when explaining a problem. The duration of the call is also relevant for the customer.

When the service employee calls the customer back, it is expected that the waiting time is as short as possible. Fast problem solving is also a requirement of the customer.

3.3. *Identification and analysis of PSS quality criteria*

PSS quality criteria are related to the entire PSS and represent the quality of products and services as well as their interdependencies. The customer requirements are identified and reproduced in a top-down representation of quality criteria (figure 4). Similar quality criteria are aggregated to PSS quality criteria. For example, one PSS quality criterion is the

Use case „Telephone service“				
Process step	**Customer requirements**	**Quality criteria**	**Quality KPI**	**Influencing factors**
Production	▪ Information about the error on the machine tool ▪ Availability of machine	▪ Transparency of errors ▪ Availability of machine	▪ Machine capability ▪ Mean time between failure (MTBF)	▪ Error diagnostics on the machine tool
Call of customer	▪ Availability of service employee ▪ Considering customer prioritization ▪ Knowledge about technical terms of service employee ▪ Time of call	▪ Availability of service employee ▪ Time ▪ Technical knowledge	▪ Average time till employee answers ▪ Customer surveys	▪ Amount of service employees ▪ Employee training seminars ▪ Customer requirements
Recall to customer / Consulting	▪ Waiting time till recall ▪ Fast problem solving ▪ Technical knowledge of service employee ▪ Duration of availability of service employee ▪ Good remote connection	▪ Time ▪ Technical knowledge ▪ Availability of service employee ▪ Reliability of remote connection	▪ Target time for recall ▪ Average time for solving problem ▪ Amount of annual connection problems	▪ Prioritization of customers' errors ▪ Amount of service employees ▪ Difficulty and scope of problem ▪ Data transmission rate
…	…	…	…	…

Figure 4: Identification of influencing factors for quality criteria

availability of a service process (e.g. availability of a telephone hotline, availability of spare parts). This criterion results from each service process, from the machine tool in the customer environment and from the interaction between these as well [6]. In this example, the customer requirements which are related to the availability of any single process in PSS delivery are summarized. To assess each quality criterion, Key Performance Indicators (KPIs) related to the requirements have to be analyzed. In this example it is the mean time between failures (MTBF). A possible influence factor for the MTBF are the error diagnostics on the machine tool. With error diagnostics, it is possible to forecast and to react to the next failure at an early stage so that the machine operator can maintain his machine preventively. As a result of a preventive maintenance, the MTBF can be reduced and the availability of the machine can rise. This example underlines the interdependencies between product and service. It explains how the product error diagnostics can influence the service and the maintenance of the machine tool positively by giving fast and detailed information about the error. Thereby, timely and high-quality maintenance can be ensured.

For the presented use case, the availability of service employee, which is required in steps 2 and 3, is hereafter just one quality criterion. The availability of service employee depends on the amount of employees, the amount of customer problems and the complexity of those problems. The company's amount of customers is also a factor. In figure 4, an excerpt of influencing factors is shown.

3.4. *Development of a quality KPI system*

The aim of the fourth phase is to assess the overall quality of a PSS as one quality indicator. Therefore, it is important to develop a quality KPI system. The quality criteria describe the degree of performance of customer requirements which were defined in the first stage of the use cases. Along the entire PSS life-cycle, the quality criteria are influenced by many factors. The OMEGA model is used to identify the influencing factors. These can be divided into the categories "product", "services" and "customer". To determine the influencing factors, parameters connected to quality criteria are necessary. For the determination of quality KPIs, data acquisition is very important. Data acquisition includes different processes in the customer environment, so that the customer is a significant precondition to identifying the parameters. The chosen data acquisition method depends on the data characteristics and their usage. The last step is the documentation of all data. Information about the developed quality KPIs is documented in a parameter description. To combine product and service related parameters, similar KPIs have to be summarized. Finally, parameters of the product and service are connected to construct a quality KPI system.

The context between the influencing factors, the quality criteria and a PSS quality criterion is presented in figure 5. It shows an example to identify a PSS quality KPI, or a PSS quality criterion. The chosen KPIs of the quality criterion "availability of service employee" for this paper (see figure 5) are the time to answer customer calls, the average time for solving problems and the time for callbacks. The common element for these three KPIs is the amount of service employees. The more employees an enterprise has, the faster they are able to answer customer calls. The average time for solving a problem likewise decreases with more employees. As more employees work in the service department, more time is available to help a customer. If there are enough service employees, it is possible to organize service employees specialized after several initial letters of customers. In this case the service employees may better know their customers and their machines. Therefore, faster problem solving could be guaranteed.

The chosen KPIs for the quality criterion "availability of machine" for this paper are the mean time between failures (MTBF) and the machine capability. These two factors influence the "availability of machine". For example, the MTBF depends on the number of error diagnostics opportunities. The more sensors that are available for locating an error quickly, the less time is needed to solve the problem. So, a high number of error diagnostics opportunities influences the quality criterion positively. The machine capability is also an influencing factor. If the capability is not reached, then the

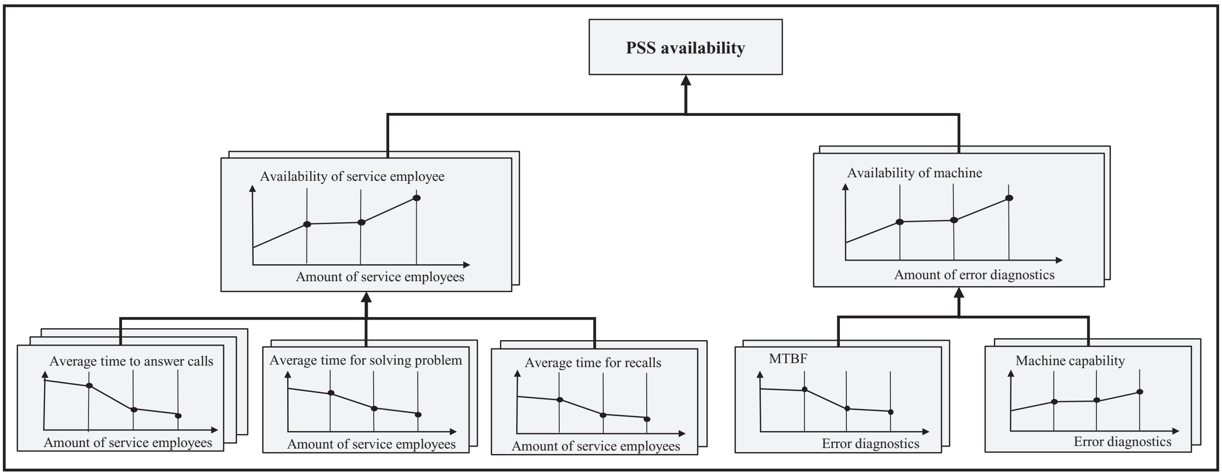

Figure 5: From influencing factors to PSS quality criterion

availability of the machine cannot be fulfilled because the machine produces parts which are beyond tolerance limits. These deviations can be detected with error diagnostic tools. For a quick detection, a high number of error diagnostics opportunities is essential.

These two quality criteria are combined to the PSS quality criterion “PSS availability”. This criterion refers to the entire PSS. Only by combining the quality criteria from different elements of a PSS can a quality criterion for the whole PSS be found. In this paper, one PSS criterion of a use case is presented. Further PSS criteria have to be determined by other projects to develop generic PSS criteria for the machine tool industry.

The PSS quality criteria give the provider of a PSS the information of whether its PSS works, and whether tolerance limits are met. For this purpose, target figures must also be defined.

4. Conclusion and outlook

This paper has presented a new, customer-oriented approach for assessing quality of technical Product-Service Systems. The approach is illustrated with a use case from a machine tool manufacturer, demonstrating how customer requirements for a PSS are identified and how they can be transferred to different quality criteria. Next, the quality criteria are aggregated to one PSS quality criterion. The identified PSS quality criterion considers the influencing factors from machine tools as well as from services. In this paper, the process for identifying a PSS quality criterion is shown for the PSS availability.

Future research should include collection of further customer requirements for developing more PSS quality criteria. After that, the quality KPI system can be devised and transferred into a user-friendly software demonstrator. This tool can help machine tool manufacturers to assess the quality of PSS and to consolidate and develop their quality leadership.

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