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Measuring service outcomes for adaptive preventive maintenance

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ABSTRACT

Services account for an increasing share of economic activity in the western world. As part of this, preventive maintenance (PM) service volumes are constantly growing as a result of a growing (and aging) asset population and maintenance outsourcing. While the pursuit of improved service productivity is in the interest of both firms and nations, the challenges of measuring service performance, and more specifically service outcomes, persist. This paper presents an outcome-based measure for fleet PM, which has far-reaching implications considering service productivity and performance measurement.

We develop a *statistical process control* based measure that utilizes data typically available in PM. The measure is grounded in reliability theory, which enables generalization of the measure within PM services but also outlines the limitations of its application. Finally we apply the measure in a PM field service process of a servitized equipment manufacturer. Based on actual maintenance records we show that the service provider could reduce their service output by at least 5–10% without significantly affecting the aggregate service outcome.

The developed measure and control process form the basis for *adaptive preventive maintenance*, which is expected to facilitate the transition towards outcome-based contracts through complementing *condition-based maintenance*. One of the key benefits of the approach is that it provides a cost-effective way of revealing the scarcely studied phenomenon of service overproduction. Based on our case, we conclude that there are significant productivity gains in making sure that you meet required standards for service output but do not exceed them.

1. Introduction

The global engineering assets base is growing and aging in an era where the pursuit of economic efficiency is driving both firms and governments to outsource their maintenance functions. This is creating a constantly growing demand for comprehensive maintenance services. In answering to this demand, the maintenance service provider is paid to restore and sustain engineering asset availability through corrective maintenance and preventive maintenance (PM). The nature of PM services implies long-term contracts, with a relationship-based business logic (Brax, 2005; Johnsen et al., 2009; Oliva and Kallenberg, 2003). Further, as the decisions and actions of the maintenance service provider have a direct effect on asset availability, the service provider is bound to accept liability, at least to some extent. This introduces outcome-based elements to contracting (Eisenhardt, 1989a), which may ultimately lead to business logics where the maintenance service supplier is paid for equipment availability (Baines et al., 2009; Hypko et al., 2010a; Ng et al., 2009; Oliva and Kallenberg, 2003). As service provider income is then tied to the service outcome, service operations management becomes more challenging. In effect, the pursuit for productivity is complemented by the pursuit for effectiveness (Djellal and Gallouj, 2013), which consequently raises the bar for operational performance measurement. This challenge, recognized by academics and practitioners alike (Oliva and Sterman, 2001; Selviaridis and Norrman, 2014; Viitamo and Toivonen, 2013), is what we address in this paper.

When moving towards more outcome-based contracts, the cost of quality (cf. Schiffauerova and Thomson, 2006) is reallocated from the customer to the service provider. This is the case for both below optimal quality (under-service), where the service supplier incurs penalty costs or loses performance bonuses, and above optimal quality (over-service), where the service supplier would have achieved the same outcome with less resources or inputs. The latter is exceptionally challenging in PM, where the created customer value equates to sustained equipment availability. In other words, the customer does not experience the value of the service as the service action is performed but rather it is

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experienced between the performed service actions. For the customer the actual service delivery can be a nuisance as the equipment may be unavailable during service delivery. This implies that mitigating over-service in the case of PM translates to postponing service actions as much as reasonable, while avoiding equipment failure resulting from under-service. In other words, it is a balancing act along the thin line between under- and over-service. The service operations challenge thus becomes one of optimal service timing, with respect to deployed resources and created value.

Currently the challenge of optimal service timing in PM is tackled in two principally different ways. In what could be characterized as *design-based preventive maintenance* (DPM) the manufacturer of the equipment estimates the proper service timing based on reliability estimates, calculations and simulations (Murthy et al., 2008). While this is a cost-effective way of determining service timing, it cannot account for the full spectrum of operational environments that the equipment may be subjected to, implying a likely bias toward over-maintenance. On the other hand, in *condition-based maintenance* (CBM), PM timing is based on the monitoring and prediction of equipment deterioration. While this method typically enables optimal service timing, it is not applicable for all maintainable technologies. Further, considering older equipment, the required sensors and other infrastructure typically need to be retrofitted. The question is whether something could exist between these two extremes which is more accurate and optimal than DPM while allowing wider implementation and less costs and effort than CBM. We seek to provide such an alternative through measuring and consequently learning from service outcomes, represented by equipment availability in the context of PM.

While equipment availability as such is fairly easy to measure, the performance measurement challenge lies in measuring availability in a way that supports service action timing. While it is fairly easy to measure how efficiently maintenance actions are performed (e.g. the time it takes a technician to perform a maintenance action), PM effectiveness is a more challenging concept. This is because the service provider will know neither how much the PM action will postpone the inevitable failure nor when the next PM action should be performed. Postponing failure is essentially the service outcome and it determines the equipment availability. Thus we answer the question: *How can PM service performance be measured in a way that facilitates control of service outcomes?*

We answer this question by designing (Van Aken, 2004; Holmström et al., 2009) a statistical process control (SPC) based measure, building on principles derived from reliability theory. This measure, untypically for SPC, essentially measures the customer process instead of the service supplier's process, making it an indirect measure of value-in-use. Hence, the developed measure could also be seen as a manifestation of *service-dominant logic*, where it is not the service supplier process but the customer process which is the basis for performance measurement (Ng et al., 2009; Vargo and Lusch, 2004; Vargo et al., 2008). Further, due to the customer focus of the measure, we can also measure distributed service production with a conceptual service process (implying multiple concurrent process instances), whereas traditional SPC applications have been limited to centralized (service) production with a single, continuous concrete process.

Due to the statistical basis of the measure, its applicability lies mainly in the PM of groups or fleets of similar equipment. Consequently, the control of service outcomes is also exerted on a fleet level. In other words, the design complements the service operations management of single pieces of equipment with managing fleets of equipment, introducing a systems perspective to service provision, as proposed by Ng et al. (2009). Further, the developed measure, along with the outlined method for the control of service outcomes that we call *adaptive preventive maintenance* (APM), provides the sought "middle ground" alternative to DPM and CBM. Through being more optimal than DPM, while involving less implementation costs and effort than CBM, APM also lowers the bar for the transition towards outcome-based contracts through a cost-efficient reduction and quantification of outcome uncertainty (Eisenhardt, 1989a). Thus this work aims at contributing to a more productive society by maximizing service effectiveness rather than efficiency.

This introduction is followed by a review of previous research into the role of outcomes in performance measurement and how this is related to SPC application in service operations. In Section 3 we describe the design methodology employed by the research along with a description of the case company. In Section 4 we describe the development of the measure and related control process, including the measure's foundation in reliability theory. In Section 5 we demonstrate and evaluate the measure in the case context (consisting of three embedded cases). Finally, in Sections 6 and 7 we discuss the implications for theory and practice, and outline the limitations of the research, ending with concluding remarks.

2. Measuring service outcomes

The customer perspective has had a legitimate role in performance measurement since the influential article by Kaplan and Norton (1992). However, few works have outlined *how* the customer perspective should be included, let alone *what* should be measured (Neely et al., 2000). The customer perspective is also central regarding preventive maintenance (PM), because performance measurement has to focus on the customer process, as PM is performed to sustain equipment availability. Customer satisfaction typically figures in frameworks and practice, in some situations even to the extent that it is presented as the only measurable outcome (cf. Brown, 1996). However, regarding PM, measuring only customer satisfaction is problematic because it does not solve the underlying problem of the attributability of outcomes to service actions as it is dependent on the customer appreciating the technical consequences of the delivered service (Woodruff, 1997). An alternative outcome measure frequently appearing in different frameworks is customer value. The problem with customer value as a measure is that it is hard to define precisely (Parasuraman, 1997) and while being an antecedent to customer satisfaction (Woodruff, 1997) it also suffers from the same dilemma of service outcome attributability.

A possible avenue to overcoming the challenges regarding different measures of customer perspective is to measure quality. The customer perspective is also, at least to some extent, captured by the concept of quality (Neely et al., 1995). Despite this, the relationship between customer satisfaction, quality and value is somewhat ambiguous (Reeves and Bednar, 1994). However, quality can more easily be translated into concrete measures (Parasuraman et al., 1985). Service quality has also been tied to service co-creation by Lillrank and Liukko (2004), who note that variance in quality depends on the heterogeneity of the processes which produce the service. Grönroos (2000) defines service quality as a construct with two different components valued by the customer: the functional quality, which addresses *how the service was delivered,* and the technical quality, which addresses *what was delivered.* Within these components, the customer-perceived quality is determined by the difference between expected and experienced quality (Parasuraman et al., 1985). Related to this, we should also consider Reeves and Bednar's (1994) dual definition of quality as both *conformance to*