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Configuring use-oriented aero-engine overhaul service with multi-objective optimization for environmental sustainability

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A B S T R A C T

As a typical sustainable product-service system, the aero-engine overhaul service aims to recover the functionality to fulfil certain flight hours and thrust requirements. How to configure the overhaul service with various sub-services is a key issue in industry. In this paper, a use-oriented aero-engine overhaul service configuration approach is proposed with two methods: overhaul service configuration and part repair service configuration. The overhaul service configuration method decomposes the overhaul service into various sub-services and creates a hierarchical service tree model, taking the cost and energy consumption into consideration. Based on the sub-service filtering and selection rule, the bill of exchange service comes with the bill of discard service. The part repair service configuration method matches each part repair procedure service with a proper service provider. Some non-dominated bills of repair services are obtained by minimizing the repair service cost, finishing time deviation and energy consumption. Considering the multi-objective character of the overhaul service configuration problem, these two methods result in some Pareto solutions to fulfil the service requirements. Through implementing the approach as a prototype, a case study is shown to illustrate the use-oriented aero-engine overhaul service configuration approach and verify its feasibility. A bridge between the flight hours and thrust requirements and the overhaul service configuration results is built when the cost and energy consumption are minimized. The study contributes to the shift of aero-engine overhaul services from the add-on services to sustainable use-oriented product-service systems.

1. Introduction

At present, environmental issues are widely recognized as important throughout the world. Enterprises try to create more value by making most use of limited natural resources (Tukker, 2015). In addition, more and more enterprises are trying to increase their business areas over value chains and provide combination of products and services instead of providing physical products only (Mont et al., 2006; Meier et al., 2010). Under this circumstance, sustainable product-service systems (PSSs) attract industry as new ways of doing more sustainable business (Mont, 2002; Sakao and Shimomura, 2007). A sustainable PSS is defined as "a system of products, services, supporting networks and infrastructure designed to be competitive, satisfy customer needs and have lower environmental impact than traditional business models" (Mont, 2002). The sustainable PSSs are believed to reorient the current standards of consumption and production, and to enable a move towards a more sustainable society (UNEP, 2002; Tukker, 2015). Offering sustainable PSSs has positive potential for economic, social, and environmental effects as companies could improve resource utilization, competitiveness, sustainability, and eco-efficiency at the same time (Liu, 2013; Liu and Liang, 2015; Chou et al., 2015).

Different categories of PSSs exist in industry (Tukker and Tischner, 2006). According to Tukker (2004), PSSs are classified into product-oriented, use-oriented, and result-oriented ones.

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Product-oriented PSSs include supplying consumables to the provided products. Use-oriented PSSs include product leasing with the provider's responsibility to maintain the product functions, as well as product sharing/pooling (Mont and Tukker, 2006). Sharing/pooling utilizes less resources for a given need and thus benefits the environment (Byers et al., 2015), but is not a sub-category targeted in this paper. Comparing product-oriented PSSs and product leasing, which is the targeted sub-category of use-oriented PSSs in this paper, the latter improves the environmental performance more (Tukker, 2004). A main reason for this is that a provider of use-oriented PSSs often has responsibility to maintain the functionality and incentive to increase efficiency especially in the use phase.

Regarding the aero-engine sector, product- and use-oriented PSSs are provided (Smith, 2013). Under the use-oriented PSSs, the consumers purchase the aero-engines' flight hour services. The aero-engines owned by the service provider, are only service carriers. Among different service activities, overhaul is a significant issue in the maintenance, repair, and overhaul (MRO) chain (Zhu et al., 2012). The use-oriented aero-engine overhaul service aims to recover or rebuild the functionality to fulfil certain flight hour and thrust requirement in the following service cycle.

Although potential benefits of a use-oriented aero-engine overhaul service have been highlighted above, insights from literatures about PSS are often described in a generic level (Tukker, 2015) and thus insights for concrete ways to practice this service efficiently is limited (Vezzoli et al., 2015). In more details, the following barriers are faced.

- An aero-engine overhaul service is a complex activity (Zhu et al., 2012) and may benefit from introducing a hierarchical structure (Joore and Brezet, 2015). However, a concrete way to configure the overhaul service with variable sub-service options in an optimal manner on the context of sustainable PSS is not established.
- To practise an aero-engine overhaul service efficiently, selecting the best or better service and thus evaluating alternative services with multiple indexes is needed. Besides the flight hours and thrust requirements, cost and environmental impacts should be considered. However, a concrete evaluation method for this purpose is missing.

Therefore, to solve these problems, this paper aims to propose a use-oriented aero-engine overhaul service configuration approach. More specifically, a bridge between the requirements for the service and the configurations is built. The configuration process takes environmental impacts into account and adopts multi-objective evaluation and optimization algorithm. Two key issues, overhaul service configuration and part repair service configuration, are presented in detail.

The rest of this paper is organized as follows. Section 2 reviews literature related to service configuration and evaluation. Section 3 puts forward the use-oriented aero-engine overhaul service configuration and evaluation approach. In Sections 4 and 5, the overhaul service configuration method and the repair service configuration method are presented respectively. In Section 6, how to implement the approach as a prototype is presented. The case study is shown in Section 7, which is followed by concluding remarks in Section 8.

2. Literature review

With background of diversification of customer demands (Koren, 2010), efficient customization receives attention (Hu et al., 2011) – even in the environmental sustainability field (Sakao and Fargnoli, 2010). Combined with servitisation trend in industry (Neely, 2007; Meier et al., 2010), PSS customization is a relevant issue in industry (Zhang et al., 2016a). To customize PSSs, configuration of product and service modules in PSSs is an efficient approach (Song and Sakao, 2017).

To configure PSSs, several approaches have been proposed. Shen et al. (2012) proposed an ontology-based approach and a system for representing knowledge of configuring product extension services in servitisation. Long et al. (2013) proposed an approach in which functional needs and perception needs of customers were translated into specific PSS configurations through factor analysis and a sort of statistical learning theory. Some other approaches were based on a hierarchical systems optimization method (Cherubini et al., 2015). Among them, the embedded analytical target cascading (ATC) mechanism (Kim et al., 2000) is used optimal system design (Kim, 2001) and supply chain configuration (Qu et al., 2009). In addition, an extended ATC method was used to accommodate "OR" elements, in terms of working logic and mathematical formulation (Huang and Qu, 2008). The alternative selection of "OR" elements could be integrated into the target cascading process. An embedded ATC mechanism could coordinate all the related services to formulate the optimal solution (Qu et al., 2009; Huang et al., 2011). This hierarchical service configuration method was verified to be more efficient than a centralized one. Further, a PSS based on warehouse service was described as a tree structure by using ATC and an optimal resource configuration was obtained (Cao and Jiang, 2013).

When a service is configured, some quantifiable objectives regarding its performance may be determined (Aurich et al., 2009). This can be formalized as a service composition and optimal-selection problem (Tao et al., 2011). Different objectives should be selected according to the case in question, for example, cost and CO_2 emission. Some researchers argued that product and/or service degradation must simultaneously consider users' expectations and environmental aspects (Gaiardelli et al., 2014; Salazar et al., 2015). However, most of earlier researches adopted single-objective combinational optimization problem formulation. Some algorithms were designed to solve multi objective problems. Typical examples included the group leader algorithm with the idea of Pareto solution (Xiang et al., 2014), the quantum multi-agent evolutionary algorithm (Tao et al., 2014), the uncertainty and genetic algorithm-based (Huang et al., 2011), the chaos optimal algorithm (Huang et al., 2014), etc.

A product service could be hierarchically decomposed into some sub-services based on ATC method. Some objectives were considered to evaluate every solution. Most works aimed to decompose the top service into sub-services for target cascading or task disassembling (Qu et al., 2010; Huang and Qu, 2008). In fact, a use-oriented aero-engine overhaul service is expected to fulfil certain service requirements. The configuration process should decompose the overhaul service into various sub-services when both the service requirements and other factors are considered. A bridge between service requirements and service configurations is needed. Considering the trend of the environmental awareness, the ecological impacts should be considered as well.

3. The use-oriented aero-engine overhaul service configuration approach

3.1. Problem and assumptions

The overhaul service configuration aims to find out some optimized combinational service solutions by decomposing the use-oriented overhaul service into various sub-services. Assuming X is a solution, the problem can be formulated as follow.