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Enhancing Service Requirements of Technical Product-Service Systems

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Abstract

Due to the integration of product and services as a new business model, product reliability and strategies for cost reduction at the early design stage have become important factors for many manufacturing firms. It is, therefore, critical at this phase to analyse the risk involved with Service Requirements noncompliance in order to help designers make informed decisions; as these decisions have a large impact on the Product Life Cycle (PLC).

An investigation has been performed into how Service Requirements are analysed in a service orientated business to achieve reduced Life Cycle Cost (LCC) and improvements of existing Service Requirements. Weibull distribution and Monte Carlo principle have been proposed to do so; as they are considered as the most widely used in product reliability studies in the industry sector. A generic methodology for risk evaluation of failure to deliver a new product against Service Requirements is presented in this paper. This is part of the ongoing research project which aims to, apart from comparing current and targeted Service Requirements, it also facilitates an optimisation of them at the minimum risk of nonconformity.

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Keywords: PSS, Service Requirements, Weibull Distributions, Risk, Decision-Making

1. Overview of Product Service Systems

Worldwide, a change towards more service-oriented thinking has recently been taking place. This goes along with a structural change from a product-centric to a service-centric society, which affects private life as well as industry. The reason for this approach is related to three main triggers. The first, there are economic arguments; as services in general have higher margins than products and provide more stable source of revenue. Secondly, customers are demanding more services with higher specialisation and flexibility and with lower and more predictable operating costs. This is directly linked with prolonged life-cycles with continuous product updates, resource efficiency and contribution to environmental sustainability that the service orientated approach provides [1]. Finally, there is a competitive argument as services are more difficult to imitate, obtaining premium and unique products and differentiating them from the ones created in product markets [2].

Companies in mechanical engineering and plant manufacturing have recognised the great potential which lies in the paradigm shift of providing customer value instead of selling products. This is the case of Rolls-Royce which was originally set up as a product seller to become now one of the most high value businesses worldwide providing their customers with services. The company is using the Design for Service approach as a procedure to first design the service and then, the product that supports it. With this, there is a strong focus on two main aspects: to minimise the cost of providing the service by the reduction of the LCC and to increase the customer value of the service provided.

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For all this, the delivery of services has become more difficult to understand and analyse than the traditional model; mainly for the complete responsibility of service providers to extend the PLC through services and so, reduce the overall cost avoiding the cost of redesign [3]. Here is where this research takes relevance; as it aims to assess the main challenges of PSS and the existing alternatives used in companies to manage the complexity at the preliminary design stage and therefore, obtain a generic methodology to integrate and analyse Service Requirements with design concepts to make better choices.

Nomenclature

PSS	Product Service Systems
WLC	Whole Life Cost
LCC	Life Cycle Cost
PLC	Product Life Cycle
CDF	Cumulative Distribution Function

2. Challenges of Product Service Systems

The change in the business model towards a more service orientated one has increased the necessity of reconsidering new areas of investigation. Moreover, the trend to agree fixed price contracts in PSS has post even higher risk for the solution provider who has to carefully select adequate measures to reduce cost and control service delivery.

This section summarised the main challenges that companies face at the conceptual stage when a service wants to be delivered.

2.1. Uncertainty

One of the subjects whose interest has drastically increased in recent years is uncertainty. It can be defined as "A random behaviour of any physical phenomenon that causes the indefiniteness of outcomes" [4]. Figure 1 summarised the main sources of uncertainty in PSS:

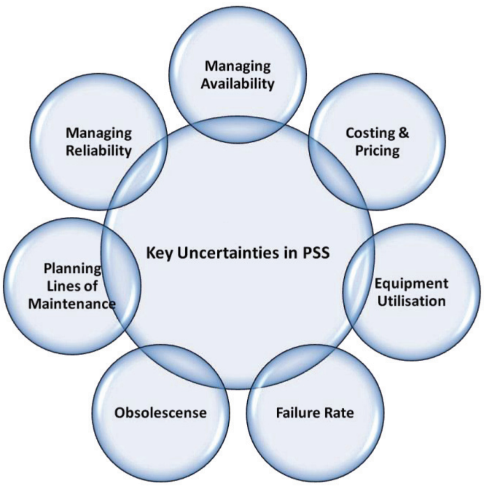

Fig. 1. Key Uncertainties in PSS [4].

As [5] states the role of reliability and availability have become the two most explored uncertainty drivers of all of them. They are considered as parameters that if properly estimated can guarantee more long-term contracts. All this has considerably increased the responsibility of the solution providers who have to take advanced consideration of availability and reliability of the equipment before signing any contract with the customer. Besides, service complexity and urgent delivery contribute even more to the increase of those uncertainties.

2.2. Cost reduction

Focusing in a manufacturing organisation, the estimation of the main uncertainty parameters is highly desirable at the early design stage; as it is considered the phase where almost the 70% of the production cost is determined [6]. Figure 2 illustrates this statement: when 8% of the total PLC cost is reached in the concept phase, 70% of the total PLC has been already fixed [7].

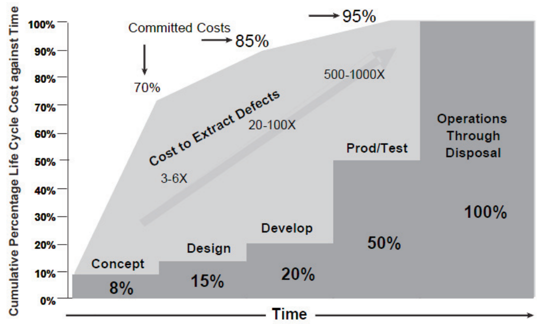

Fig. 2. Committed Life Cycle Cost against Time [6].

Figure 2 also proves that decisions regarding the costs and quality of the PLC at this conceptual design stage are crucial. Thus, the emerging challenge in uncertainty estimation is posting defiance in LCC prediction and reduction; as designers must scope the production solution and service solution concurrently [8].

Therefore, one of the main challenges for the PLC cost reduction is for designers, who have to understand and know the impact of their design decisions at the preliminary design stage in order to reduce cost in the life cycle.

2.3. Identification of Service Requirements

Another growing challenge experienced when delivering integrated product and service solutions is the identification of the top level Service Requirements that a customer is willing to pay for. The difficulty arises due to the variability of uncertainties over time and the unclear definition of the behaviour and performance of a new desired service. Moreover, due to the customised delivery of Service Requirements to the client, the challenge of relating those requirements with their associated uncertainties increases.

The accurate identification and analysis of Service Requirements is of high importance - it has a significant impact on a product PLC. Such step at the preliminary design will help companies to make informed design choices and will allow determining if customer-driven requirements are achievable, especially in terms of the overall cost of the service provision, including maintenance and support.

Section 3 focuses on alternative approaches used by industries to tackle the issue of Service Requirements analysis.

2.4. *Knowledge*

Another considerable aspect which complicates even more the management of this stage is the lack of information flow and knowledge. Consequently, designers are unable to visualise useful data and fix correlations between customised services and their associated uncertainties to assess customers' requests.

The lack of knowledge found at the early design stage is directly linked with the low maturity level of PSS in organisations; so it implies a need to research more about the capacity of companies to successfully adopt PSS methods. Moreover, in PSS designers require a broader range of knowledge to generate several design solution ideas. Indeed, in the transition towards a service orientated business, the ability of the customer to transfer data to designers and/or the ability of designers to make use of historical data is another important obstacle.

3. Service Requirements Analysis Methods for Service Provision

Previous section demonstrates the challenges designers face when identifying and analysing Service Requirements in the conceptual phase. As it is stated in [9], about 40-60% of all defects found in a project can be traced back to errors made during the requirements stage.

In this section the focus is on the study of two different methods for analysing and aligning the design concepts to the Service Requirements and thus, try to mitigate those challenges.

3.1. Weibull distribution

Weibull analysis is a very valuable approach for companies where understanding and predicting the failure risk and the reliability of a lifetime data become crucial [10]. It allows managing the life-cycle of a product more accurately, as it provides relevant information for facilitating the right decision-making; especially in the early design stage where decisions have a large impact in the reduction of the LCC.

3.1.1. Weibull parameters

The Weibull Distribution used in this research is defined by two parameters. The first parameter, beta (β), is the slope parameter of the Weibull distribution and indicates the class of failure that describes the data. Moreover, this parameter classifies the failure mode and thus, gives a good indication of how the systems / subsystems may fail:

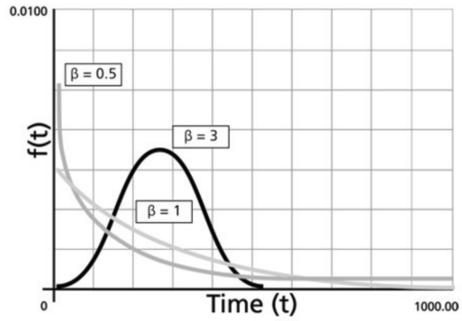

Fig. 3. Weibull Probability Density Function for different β [11].

- β<1 it indicates that the product has a decreasing failure rate;
- β=1 it refers to a constant failure rate;
- β>1 it indicates an increasing failure rate.

The second parameter, eta (η), is the characteristic life parameter which defines the value in time by which 63.2% of the failures will have occurred [12].

3.1.2. Analytical analysis

The Cumulative Distribution Function (CDF) of the two-parameter Weibull distribution used is expressed as:

$$F(t) = 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}} \quad (1)$$

where t represents time,
β the slope parameter,
η the characteristic life parameter.

In order to analyse a system and subsystem in-service performance, the probability plotting methodology is considered in this paper. This method is based on the linearity of the CDF or unreliability function of the Weibull distribution. The Equation 1 can be expressed in the linear form as follows [13]:

$$\ln\left(\ln\left(\frac{1}{1-F(t)}\right)\right) = \beta\ln(t) - \beta\ln(\eta) \quad (2)$$

If it is set y equal to the left side of the Equation 2 and $x = \ln(t)$, the CDF equation can now be rewritten as:

$$y = \beta x - \beta\ln(\eta) \quad (3)$$

This is now a linear equation, with a slope of β and an intercept of βln(η).

In order simplify the evaluation of the Weibull analysis outputs and ensure the right decisions at the preliminary design stage, the visualisation of the CDF and reliability at system level is proposed in this work. Among all the alternative methods to represent Weibull model system the Series Systems model was selected.

In a Series System, the system continues working as long as all its n components are working; this means that the system will fail whenever a component fails. This system model is represented in the Equation 4 [14].

$$Rs(t) = \Pr(X1 > t, X2 > t, \ldots, Xn > t) = \prod_{i=1}^{n} Ri(t) \qquad (4)$$

3.2. Monte Carlo principle

Monte Carlo simulation method is a technique used in combination with the Weibull distribution to analyse more accurately the uncertainties in the variables being used when a model is forecasted.

This uncertainty is related to the fact that at the early stage of the new product design detailed reliability data, i.e. Weibull parameters, is difficult to obtain or does not exist yet. Thus, those parameters are estimated based on historical service data and past experience. However, while this estimate is useful for developing an early model, since it is an estimate of an unknown value, it often contains some inherent uncertainty and risk.

Monte Carlo analysis method consists of a series of computational algorithms that work by repeated sampling of a range of possible values in calculating a series of probability distributions. It uses random numbers to sample from known probability distributions to determine a likely range of the model parameter values. Thus, by taking a random sample from the probability distribution associated with a model inputs, Monte Carlo method enables to obtain a single point estimate, which represents an overall system level output values [15].

4. Proposed methodology for Service Requirements improvement and risk analysis

Based on the work previously developed by [16] in order to improve the system design process of PSS, a generic methodology has been created to evaluate the risk of failure to deliver a new product against Service Requirements, Figure 4.

As inputs, this method considers two different branches:

- Historical data obtained from the companies' databases which store the already existing values of the Weibull's parameters together with other relevant data. This data allows to define and characterise the novelty of the new product design by the modification or removal of the already existing data or the aggregation of new one.

- Top level Service Requirements that the customer is willing to pay for once the service is working.

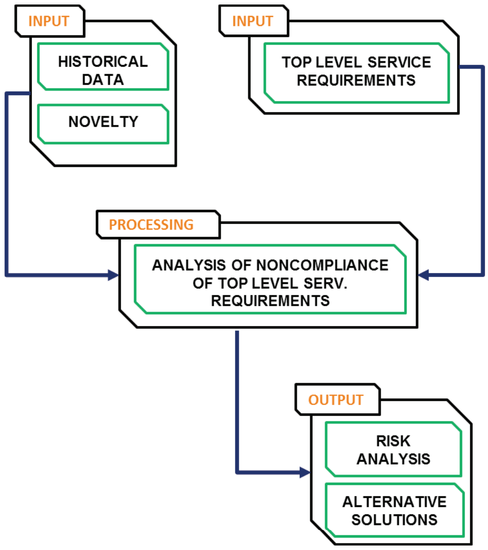

Fig. 4. Proposed methodology for risk analysis of noncompliance of a new product with Service Requirements.

These two branches are interconnected to analyse the risk of the new product design against the defined top level Service Requirements. The analysis begins with a detailed study of the unreliability of the given Weibull parameters based on the Equation (1) and (4) [17]. The second stage of the analysis is performed by the Monte Carlo method. The information obtained after running this simulation enables the comparison in an analytical and graphical way of the targeted and predicted Service Requirements. Both analysis shall provide as outputs the potential risk of not delivering the new design to the given set of requirements and facilitate the optimisation of them at the minimum risk of nonconformity.

In order to develop this generic methodology, the Rolls-Royce manufacturer three top level Service Requirements have been considered: average time between overhaul or Time on Wing (T.O.W), $/FH (cost per flying hour) and reliability of an aerospace engine [18]. These are the main business requirements assessed in the company for the development of new gas turbine engines.

This generic methodology has been implemented through a software tool where the Trent Engine Family has been used as the case study [19]. One of the mechanism used in the software tool is based on the analysis of the probability of failure of the new design through the Weibull distribution explained in Section 3.1. This allows the identification of the failure drivers on the new engine design and therefore, provides very valuable information for risk optimisation. The developed software tool makes use of a separate Rolls-Royce in-house tool to perform the core Monte Carlo simulations calculations and obtain as a result, the predicted values of Service Requirements [18]. Once those values are captured back in the tool, a targeted overhaul analysis is also performed. This analysis supports the determination of the optimal overhaul for the new design and thus, analyse the actual level of achievement of the targeted T.O.W and $/FH [19].

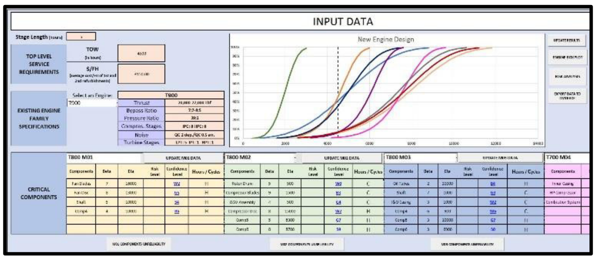

Fig. 5. Input screen of the software tool [19].

5. Conclusion and further work

In this paper the research work carried out towards the analysis of the Service Requirements has been described. The main focus is on the Weibull distribution and Monte Carlo simulation as the principle and most used techniques for life data analysis.

A generic methodology for Service Requirements improvement and risk analysis has also been presented. The innovative approach of integrating and analysing design and business aspects at the conceptual stage of a complex PSS shall contribute to a more precise determination of a new technical product feasibility and to a reduction of analysis lead-time through a better-decision framework. The improvements achieved in the design choices shall provide a better understanding of how services are influenced by business demand changes and therefore, help designer manage better the complex system design of services.

This methodology is part of an on-going research project with Rolls-Royce which aims to provide designers with the level of risk of noncompliance of Service Requirements. This methodology has been implemented in a software tool and validation of the results obtained will be accomplished in the near future.

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