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# Root Cause Analysis of Product Service Failures in Design -A Closed-loop Lifecycle Modelling Approach

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**Abstract**

A number of industries including aerospace, telecom and automotive incur warranty and product return costs due to product malfunctions in service, which can also negatively impact customer satisfaction and loyalty. Product failures, which occur in service, are often caused by root causes at design or at manufacturing phases. Therefore a novel inter-loop modelling framework is needed which takes information from different phases to determine root causes and corrective actions. This goes beyond current intra-loop methods such as design optimization, statistical process control etc., which uses information from a single phase to address failures in the same phase. However, inter-loop modelling poses the challenge of integrating heterogeneous data from different phases of lifecycle with product and process models to determine failure root causes and corrective actions. To deal with failures in service, this paper proposes Closed-loop Lifecycle Modelling approach, specifically integrating information from service and design. Related work on fault diagnosis and corrections is also reviewed in the context of intra and inter loops of product lifecycle.

The proposed methodology addresses root cause analysis (RCA) of service failures caused due to dimensional variations of product features. RCA identifies critical geometric features of internal components, which affects dimensional variations of product features. This is done by integrating warranty data from service to design models such as CAD, Geometric Dimensioning & Tolerancing (GD&T) etc. Steps of the methodology include: (i) identification of faulty product features from the Ishikawa diagram of the failure reported in warranty; (ii) variation simulation analysis of geometric features of internal components; (iii) determination of critical geometric features affecting faulty product feature via surrogate modelling of dimensional variations; and (iv) analyzing sensitivity of faulty product features on critical geometric features. The proposed Design-Service inter loop is demonstrated by an industrial case study of automotive ignition switch and *'Sticky Key'* service failure. RCA of *'Sticky Key'* issue identifies critical geometric features and their sensitivity in affecting the faulty product features, which cause the failure.



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*Keywords:* Product service failures; Product Lifecycle; Root Cause Analysis; Functional Requirements; Design Paramters; Variation Simulation; Surrogate modelling; Sensitivity analysis

## 1. Introduction

Product failures in service such as warranty and No-Fault-Found (NFF) failures result in significant costs of warranty and product returns in industries such as automotive, aerospace, mobile phones etc. [1][2]. NFF-related problems negatively affect customer satisfaction in terms of product safety and reliability, and contribute to increased product life-cycle cost [1]. Therefore, root cause analysis (RCA) and corrective actions (CA) of product failures in service is important.

In the service phase, unexpected product malfunctions whose root cause cannot be diagnosed after service checks are categorized as No-Fault-Found (NFF) failures. Service failures are often caused by root causes at design or at manufacturing phases. For example, erroneous characterization of customer attributes during early product development increases the risk of unexplored interactions during the design phase [2]. Such interactions may go


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unnoticed by designers and increase the risk of failure regions inside defined design tolerances (*in-tolerance* failures). In the manufacturing phase, one of the reasons, why unexpected challenges might arise is due to process capability being commonly not taken into consideration concurrently with product and process design. Thus, the impact that process variations have on final product quality may cause a product's non-conformance. The lack of concurrency demands the need to move from just part and product tolerancing (driven by seminal concept of part interchangeability) to simultaneous parts/product and process tolerancing (process-oriented tolerancing) [3].

Root causes of service failures are often in design and manufacturing. Therefore, to address root causes of service failures, it is necessary to develop analytical methods based on inter-loop modelling which integrates heterogeneous data from different phases of lifecycle with product and process models. This research proposes a Closed-loop Lifecycle Modelling approach to deal with service failures by specifically integrating warranty data with design models. The remainder of the paper is organized as follows: Section 2 describes the framework Closed-loop Lifecycle Modelling. Related work on fault diagnosis and adjustments are reviewed in the context of the proposed framework. Section 3 presents root cause analysis of service failures specifically linking warranty data with design models. This is followed by an industrial case study in Section 4. The paper ends with remarks on future work in Section 5.

## 2. Closed-loop Lifecycle Modelling

The loops of self-resilient production system are classified as intra-loop and inter-loop based on availability of data from same or different phases of PLM respectively. Fig. 1 shows the closed-loop framework. The intra loop refers to integration of data with product and process models from same phase of PLM such as SPC which uses manufacturing data for monitoring purposes. The inter-loop refers to integration of data with product or process models obtained from more than one phase of PLM such as addressing service failures using the approach proposed by Mannar et al. [2], which uses data from manufacturing and service phase of PLM.

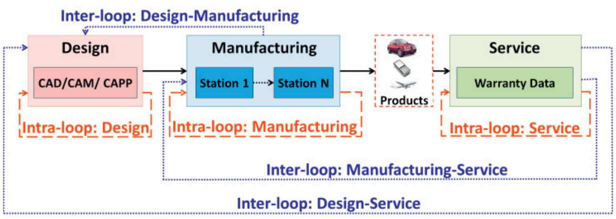


Fig. 1. Framework for Closed-loop Lifecycle Modelling

### *2.1. Intra loops in PLM*

In design phase, product simulation generates data on design parameters (DPs) satisfying pre-defined functional requirements (FRs). Methodologies have been developed to enable design changes and optimization by modelling the relationship between critical DPs to FRs and critical process variables (PVs) to DPs [4,5].

In manufacturing phase, the intra-loop consists of continuous data of DPs and PVs obtained using in-line and/or off-line measurements of products and processes during production. The intra-loop in manufacturing is used to addresses out-of-tolerance 6-sigma failures using SPC techniques [6,7]. The monitoring capability can be further integrated with process models to enhance the intra-loop capability of the production systems for fault diagnosis and adjustments [8].

Intra-loop in service consists of warranty data and failures data which are analyzed to send feedback to OEMs for setting economic warranty reimbursements to customers, estimating field reliability of products and changing design to address service failures [9]. Warranty data is also used to improve performance of service centres by generating pre-alerting rules to diagnose product failures from customer complaints [10].

### *2.2. Inter loops in PLM*

The Design-Manufacturing inter-loop integrates information from manufacturing with design to evaluate and improve diagnosability and adjustability of products thus reducing test time of failures in case of uncertain faults [11].

In Manufacturing-Service inter-loop, the Functional Region Localization (FRL) methodology [2] integrates manufacturing and service information to identify and isolate in-tolerance fault regions in DPs. Prakash et al. [12] determine the necessary process adjustment to reduce number of products falling in NFF fault region.

For Design-Service inter-loop, there is need for analytical method to identify root causes of service failures by integrating warranty failures with design models. Shrouti et al. [13] maps service failures in mechanical assemblies with faulty FRs such as gaps or contacts between internal components. Simulation of geometric DPs is done to model variation in FRs. The current research extends this work by (i) demonstrating the use of fault trees to identify faulty FRs for a given service failures; and (ii) identifying critical DPs related to faulty FRs; and (iii) developing analytical surrogate model linking faulty FRs as a response of critical DPs. Corrective actions via design adjustments such as mean shift and tolerance reduction of DPs will significantly benefit from the information on critical DPs and analytical surrogate model of faulty FRs. Section 3 describes a methodology of root cause analysis (RCA) of service failures by integrating customer complaints and parts replaced information from warranty with design models such as Ishikawa diagram, CAD, GD&T and variation simulation analysis. RCA identifies critical geometric DPs whose dimensional variations results faulty FRs. Sensitivity of faulty FRs on critical DPs is also determined. Fault Corrective action by tolerance re-allocation depends on identification of critical DPs and sensitivity analysis to minimize dimensional variations in faulty FRs.