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On Knowledge-based Development: How Documentation Practice represents a strategy for Closing Tolerance Engineering Loops

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Abstract

Knowledge from multiple sources is required for defining tolerances in new product development (NPD). Successful outcomes in product development (PD) depend on the collective ability to integrate this knowledge into the product. Assessing variability and tolerance capabilities are essential parts of PD-knowledge as they represent limits of specifications with wide-ranging impact. Reducing the engineers time spend on (re)defining tolerances and searching for the right information can prevent substandard NPD performance in terms of quality, lead time, cost and product innovation. Hence, two topics of significant importance for achieving leanness (i.e., effectiveness *and* efficiency) in PD are towering tolerance knowledge and associated documentation practices. This paper presents the results of a survey among engineering professionals of two industrial companies made to study documentation and tolerance practices in different industrial environments. The results reveal similarities between the challenges that the companies face, including implementation of effective documentation (e.g. Knowledge-Briefs, A3 reports), visualization of physical relationship between product performance attributes and design parameters (e.g. trade-off curves) and the transfer of knowledge between projects for organizational learning. This paper makes a contribution to the body of knowledge related to (lean) NPD by documenting current industrial challenges and practices in achieving viable internal tolerance engineering routines and processes, along with the needs for documentation tools.

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1. Introduction

Tolerances are often referred to as the omnipresent backbone of engineering [1]. Successful tolerancing practice in product engineering enables efficient manufacturing and high-quality products in the market place [2]. This requires processes for defining, checking, documenting, storing, and retrieving tolerance information along with knowledge of (inter)relationships between parameters [3], as well as experience and know-how of products and production capabilities. When performed correctly, towering tolerancing knowledge improves effectiveness and reduces uncertainties in NPD [4]. Additionally, tolerancing processes within internal business-quality system are sometimes taken for granted, considered to be tedious or lacking explicit focus [6]. The reason may be that companies are suffering unknowingly at a system level from their shortcomings at a detail level in the tolerance engineering (TE) practice [5]. Furthermore, the lack of adequate processes for communicating and documenting (re)useable tolerance knowledge may cause repeated problem solving, vagueness of own capabilities, etc. The overall outcome is typically substandard NPD performance, where resources are used on reactive problem-solving and firefighting instead of creating customer value [7]. An additional factor for lack of value is design engineers spending significant time searching for and organizing

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information [8]. TE activities may fall under the category of NPD practices commonly referred to as 'knowledge-based development' (KBD), aiming to (re)use and improve existing product and manufacturing knowledge. Knowledge needs to be created, captured, standardized, stored, and reused in an effective manner [9]; e.g., by linking it to the product architecture [10]. Hence, practices and tools for good communication, collaboration and documentation are essential. For lean NPD execution, a framework for KBD can serve as a tool for linking several sources of generalized product information directly to a new product design and relate it to associated tolerances.

The aim of this research is to investigate how existing knowledge on tolerance capabilities is captured and reused within product development (PD), and how it can support the definition of more viable tolerance limits. This paper presents the results of a survey conducted among engineers in two Norwegian case companies. The following research questions are posted: RQ1: How do KBD professionals perform (lean) documentation practice? RQ2: How interlinked is documentation and Tolerance Engineering practice among KBD professionals?

2. Documentation and tolerances within KBD

The primary objective of Lean Product Development (LPD) is to create value to the customer [11, 12] by minimizing waste, improving quality (innovation), reducing time-to-market and product(ion) cost. Two important components of the lean philosophy are organizational learning and continuous improvement [13]. One central tool in this regard is the PDCA (Plan-Do-Check-Act) cycle [7], in which improvements and iterations are done continuously in small steps, aiming to reach the ultimate goal of a perfection through a learning-spiral with each cycle closer to the target than the previous one. Knowledge is one of the few permanent sources for competitiveness as reuse saves time and prevents repeated problem-solving and unnecessary design loops and may mitigate risks [14], providing a company with more resources, to spend more time on innovation and adding value rather than conducting 'rework'. LPD represents an extended framework of KBD, which means that the two concepts are more-than-compatible in many respects [15].

2.1. Lean documentation tools

One challenge in LPD is to make knowledge capture and reuse more efficient. The knowledge brief (K-brief) may be used as a collaborative problem-solving tool, providing a concrete documentation structure to implement PDCA following the lean principle of continuous improvement [7]. Overall, the K-brief is a type of mentoring tool, whose purpose is to make the author's thoughts visible while the documentation follows important targets of the whole organization or team. A common type of K-brief is the so-called A3 report [16] named by the paper size used. When used as a problem-solving tool, it serves to visualize problems at hand, goal, process, solution and risk elements in a standardized form, depending on the application and problem formulation. The mindset of A3 thinking includes some important elements such as logical thinking, objectivity, and systems viewpoint [16].

2.2. Knowledge processes and management

Knowledge documentation and reuse are frequently related to the two dimensions of knowledge: tacit and explicit [17]. Tacit knowledge includes an individual's belief, viewpoint, specific know-how, craft, and skill. Explicit knowledge, on the other hand, is articulated and communicated between individuals. Using a K-brief for documentation challenges the author to express seemingly tacit knowledge in a visual manner, and turns it into explicit knowledge which serves as a tool for organizational learning. In knowledge management, four basic processes are essential [9], see Table 1. A K-brief deals with all these processes.

Table 1. Knowledge process types and their typical requirements

Knowledge process.	Typically requires
Creation	Organizational culture
Storage / retrieval	Dynamic and updated systems
Transfer	Adequate searching functions
Application	Ability to turn knowledge into effective action

Two major issues are reported in connection with research on learning cycles [7] with K-briefs [16]. First, writing a K-brief is important for the writer's understanding of the problem. Going through this documentation process, the author will have to rethink his/her work, fit it into the framework of A3 thinking, and get a deeper understanding (tacit knowledge). The second point is that a standardized way of documenting knowledge makes it easier and more effective for the reader to uncover important material. K-briefs speed up communication and improve transfer of explicit knowledge, letting the graphics 'talk' [16].

2.3. Tolerance Engineering

Tolerances represent limits of product or process specifications that typically are defined at an early stage of PD [2]. This stage represents the "developers' dilemma" as decisions with significant impact on costs are taken, typically with lacking insight in all limiting conditions [18]. Thereby, tolerances sometimes end up being defined on previous design legacy by draftsmen or basic level designers [19]. Despite good design practice in industrial companies, inappropriate tolerance definitions still occur in many of the same companies. Zhang (1997) states "*many parts and products are certainly over-toleranced or haphazardly toleranced, with predictable consequences"*. As a consequence, negative effects of inappropriate tolerances can become visible at a later stage of product-development increasing cost and degrading product quality [20]. At the later stages, changing tolerance definitions requires very high efforts [21], which makes front-loading of the NPD process a desirable strategy [4]. Good TE relies on the ability to address relevant