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Towards Understanding the Role of Product Usage Information in Product Design Improvement

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Abstract. A critical factor that makes a product successful is its acceptance in its market. To achieve this goal, producers oftentimes collect and analyze feedback information from the market. This information allows them to get a deeper understanding about the product behaviors, customers, their usage patterns, future needs and expectations. The academic literature describes a variety of use cases that outline how development-related tasks can benefit from Product Usage Information (PUI). They differ, for instance, in the investigated product, task, communication channel, information source, and the type of the result. This diversity and the lack of a generally agreed vocabulary in this research domain facilitates a fragmentation of PUI-related research. This paper provides a first systematic overview of a selection of PUI application cases in product design improvement. The study sample consists of 17 research papers from the last 20 years. We characterize and classify the papers mainly through three dimensions: product type, product development phase, and information sources and channels. The results indicate that PUI can support different tasks during product improvement, both in the task clarification phase and in the product conceptual, embodiment and detailed design phases. Our findings suggest that organizations need to know more about PUI-related information sources and channels.

Keywords: Product Usage Information, Product Design, Product Improvement, Closed-loop PLM

1 Introduction

A critical factor that makes a product successful is its acceptance in its market. To achieve this goal, producers oftentimes use a quality management system (QMS) to monitor and improve customer satisfaction (ISO 9001:2015). Approximately 300,000 producers of durable products maintained an ISO 9001 QMS in 2017 [1]. Essential for this QMS is that the producer's employees collect and analyze feedback information from the market. This information allows them to get a deeper understanding about the customer, their future needs and expectations, and it supports the employees during root cause investigation in the case of low customer satisfaction or customer complaints

(ISO 9001:2015). Employees from different departments – especially product development – collaborate in these activities.

In the last decade, new information sources and computer-supported tools emerged that collect and analyze feedback information. Customers can give feedback via customer hotlines, online discussion forums, online review platforms, and weblogs. They review products, issue complaints, or discuss product features with other customers [2]. For products with a distinct usage phase, such as durable consumer goods and industrial goods, producers can create feedback information through product-embedded information devices (PEIDs) [3]. They measure, for instance, user interactions and environmental conditions, and send them to the producer. *Product usage information* (PUI) is a term that subsumes all product-related information that emerges in the usage phase of the product life cycle [2] [4].

We identified more than 70 scientific articles that describe the application of PUI in development-related tasks. These application cases differ in, for instance, the targeted product, task, information source, and communication channel. Their results include approaches, concepts, methodologies, methods and tools. This diversity and the lack of a generally agreed vocabulary in this research domain facilitates a fragmentation of PUI-related research. We experienced this when we started to collect the application case descriptions in 2016. Our sample indicates the existence of several researcher communities with few connections between each other. A problem that results from this fragmentation is that other researchers require significant effort and time to understand the maturity of this research domain. An overview of existing application cases can help other researchers to identify related work and to position their contributions better within the research domain.

This paper provides a first systematic overview of a selection of PUI application cases. It focuses on product design improvement, because the identified case descriptions mainly address this part of product development. Section 2 introduces important concepts and terminology that characterize PUI application cases. Section 3 outlines the methodology used for our literature analysis. Section 4 presents the results and Section 5 discusses two aspects of the role of PUI in product design improvement. Section 6 concludes this paper and provides an outlook for follow-up activities.

2 Concepts and terminology

This section clarifies important concepts that characterize PUI application cases in product development. It focuses on product-related typologies, information feedback, and the product development process. They refer to the main elements of many PUI application cases: product, information, and task.

2.1 Product-related typologies

Products with a distinct usage phase are durable. They degrade and are subject to service activities, such as maintenance and repair. A durable product can be a *consumer good* (CG) or an *industrial good* (IG) [5]. The former is for personal use and the latter

for the production of other goods. Producers can use durable products in combination with services, which results in *Product-Service Systems* (PSS). Complex PSS typically contain hardware, software and service components.

2.2 Information feedback

Information is data with meaning and oftentimes a critical resource in product development. *Product lifecycle management* (PLM) differentiates forward-oriented and backward-oriented information flows as illustrated in Fig. 1.

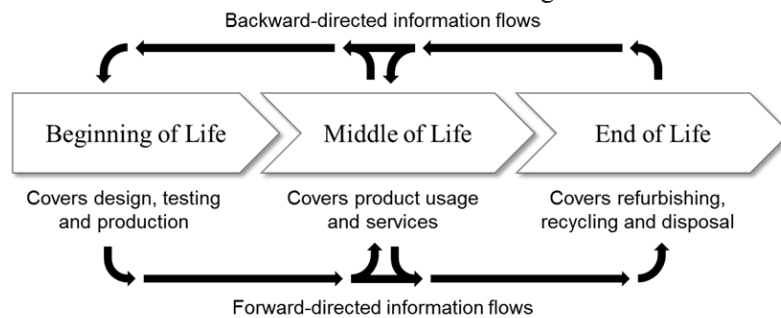


Fig. 1. Information flows in the product life cycle [2]

The product development process can have two information flows. Forward-directed information flows provide information for subsequent activities, such as product testing and production. Backward-directed information flows convey information from other business or stakeholder processes. Wellsandt et al. [6] identified this feedback as “[...] any response that the producer or its employees receive when they present their work to a stakeholder such as a customer, user, supplier or co-worker”. Employees that receive feedback include engineers, sales persons, service staff, quality managers, and product managers. Responses emerge for different reasons such as complaints, commendation, constructive critique, observation, and inspections. The employees can assess feedback information and use it to support decisions, for instance, about product design changes. This paper focuses on feedback from product usage to product design.

PUI can describe a specific product or groups of them. The former requires that the product has a unique identifier, such as a Serial Global Trade Item Number (SGTIN). Groups of products typically reference a product model (e.g. VW Golf or iPhone) or include shared characteristics, such as geography, user profile, timeframe, and performance. Information about specific items describes products on the so-called “item level”. Otherwise, it describes them on the “class level”.

2.3 Product development process and tasks

Many product development methodologies and process models are available in the literature. This paper uses the development process proposed by Pahl et al. [7]. We use it to ensure that this paper does not miss critical activities. Their process includes:

- *Product planning*. Analyses the company situation, develops and assesses product ideas. This task results in the requirements list.
- *Task clarification*. Plans the following work activities, and clarifies the requirements list where necessary.
- *Conceptual design*. Abstracts the essential problems, identifies function structures and working principles, and combines them into a working structure. This task results in the principle solution (concept).
- *Embodiment design*. Creates the technical layout in line with the requirements. After several iterations, this task results in the definitive layout.
- *Detail design*. Defines the arrangement, forms, dimensions and surface properties of the individual parts of the solution. This task results in the production documentation that is necessary to produce the product design.

Pahl et al. [7] differentiate original design, adaptive design and variant design. These tasks have different starting conditions in terms of the “unknowns”. The original design has the most unknowns, while the variant design has the least. Adaptive and variant design tasks base on existing product design. This paper focuses on these tasks, which we subsume under the term design improvement.

3 Research methodology

This paper uses a literature review to identify and analyze PUI application cases. Paré et al. [8] outline nine types of literature reviews, such as systematic review, descriptive review, and scoping review. Each type has a specific approach and research goal. This study seeks to provide an initial overview of the application of PUI in product improvement. It bases on 17 case descriptions identified in the literature. This is not an exhaustive review, but sufficient to provide a first overview about the nature of cases.

Our research has three steps: 1) literature search 2) screening 3) data extraction and classification. The literature search started in 2016 and contains more than 70 relevant articles about the usage of PUI in product design. In the screening stage, we include only publications that have concrete examples or use cases. In the stage of data extraction and classification, we characterize and classify the papers mainly through three dimensions: product type, product development phase, and information sources and channels.

In this paper, we group the aforementioned product design tasks into two phases: *task clarification phase*, and *product conceptual, embodiment and detailed design phase*. Product planning, as introduced in section 2.3, is more relevant to new product development. This paper does not focus on this task, though several application cases aim to support product planning.

We use the Big Data source classification schema proposed by the United Nations Economic Commission for Europe (UNECE) to structure the PUI sources and channels [9]. The UNECE uses it in their official statistics and thus we consider it as an acknowledged and credible schema. Furthermore, it aligns well with our previous PUI classifi-

cations derived from earlier use case analyses [6]. The schema differentiates three classes of data sources: human sourced information, process mediated data, and machine generated data.

- *Human sourced information* (HSI) is the record of human experiences. It is available through, for instance, Social Networking Services, weblogs, online discussion forums, and email. This information is weakly structured (e.g. XML or JSON format) and often ungoverned. Example PUI in this category include online discussion forum threads, call center transcripts and audio records, product reviews, and emails.
- *Machine-generated data* (MGD) originates from sensors and actuators integrated into products or installed in rooms and areas. This data typically has a structure and specialized databases for documents and time series store it. Example PUI in this category include data from product-embedded sensors and actuators.
- *Process mediated data* (PMD) emerges from business processes and records, for instance, related events. It includes transaction data, reference tables and relationships, and metadata. Information systems for business areas, such as Enterprise Resource Planning and Manufacturing Execution, create, store and convey these data. Process mediated data is highly structured. Example PUI in this category includes service records and warranty claim records.

The next section presents the first results of our analysis. It is not comprehensive, but it gives a rough overview of the nature of our findings and a preliminary insight into the literature about PUI applications in product improvement.

4 Results

The identified literature includes case descriptions from the last 20 years. The earliest article is from 1997 and the most recent ones from 2018. One of the main findings of our analysis is that the identified PUI application cases differ in the focused product type, product development phase, and the information sources and channels. Many articles about application cases take a position somewhere between engineering, business administration and informatics. Oftentimes, they focus on the former or the latter. An engineering focus means that the authors describe the benefits of PUI in a specific development-related task. An informatics focus typically details the applied methodology to collect and process data into information or even more useful knowledge. Table 1 contains characteristic example cases that clarify the nature of the investigated articles.

Table 1. Excerpt of the identified PUI application cases

Ref.	Topics	Products	Channels
[10]	Support for quality improvement methods.	Fly fishing equipment	Usenet

[11]	Decision support for product developers in product improvement	Centrifugal pumps	Sensor data repository
[12]	Product defect discovery with Social Media information.	Cars and car components	Online discussion forum
[13]	Discovering safety concerns mentioned in children's toy reviews	Children's toys	Online customer review platforms
[14]	Analysis of service records to identify improvement potential.	Rotary spindle unit	Service records
[15]	Insight on quality of product attributes with correlation to online reviews	Cell phone	Online customer review platforms

The identified application cases cover a range of different products. They include comparably simple and low cost fly fishing equipment and toys, cell phones, and more complex and expensive components of machinery. Table 2 summarizes the application of PUI in the two product development phases and the used data source types. Some cases used more than one data source type to support a task. We use the category “mixed data” in the tables for this purpose. An article’s focus on one source type does not exclude other sources from being useful for development-related tasks.

Table 2. Overview of PUI application cases in product improvement

Source types	Task clarification phase		Conceptual, embodiment and detailed design phase	
	CG	IG	CG	IG
HSI	[12] [13][15] [16] [17]	-	[10][18]	-
MGD	[19][20][21]	-	[22][23]	[11]
PMD	[24]	[14]	-	-
Mixed	-	[25]	[26]	-

Most of the identified cases focus on CG, while only three of them concern IG. The majority uses HSI, especially conveyed through channels on the Internet. Relevant channels include online discussion forums, shopping websites (typically Amazon) and Social Networking Services (typically Facebook). The PUI is typically a part of product review texts and text posts within discussions. The applications oftentimes use it with a methodology that uses machine learning, which is a sub-domain of artificial intelligence. These methodologies oftentimes use existing algorithms that the article authors customized to work with the specific sources, channels and tasks of the respective case.

Sensors are the second most used source type. They are oftentimes a component of the targeted product (e.g. a component of a machine). Some application cases refit a small number of products with sensors. The collection and processing of MGD use methodologies that use machine learning as well.

5 Discussion

Our study sample consists of 17 research papers. 65% of them relate to the task clarification phase, and 35% relate to product conceptual, embodiment and detailed design phase. Regarding data sources, most of them are HSI (41%) and MGD (35%). These numbers are sensitive to the selected sample of case descriptions. The following observations are only indicative and may provide useful information to build hypotheses for a larger sample.

5.1 Support in product development tasks

This paper's results indicate that PUI can support different tasks in product improvement. In the *task clarification phase*, the support focuses on changing the requirements list by adding, removing or editing entries. The main role of PUI is to change the employees' understanding about, for instance, product behavior, usage conditions, failure causes, and customer opinions. In the *product conceptual, embodiment and detailed design phase*, the focus is on the evaluation of product designs under market conditions. The application case acquires information from product usage to solve a specific technical problem for the next product generation. We assume that the analysis of more application cases can lead to detailed recommendations when and how to apply PUI for product improvement.

5.2 Role of information sources and channels

The application of PUI in product development can benefit from a detailed understanding of the information sources and channels. This is because each source/channel requires different approaches, methods and tools to extract the PUI from the available information. A second reason is that processes, such as data creation, storage, processing and distribution, differ amongst source types and channels. Different factors related to these processes influence, for instance, the PUI's accuracy, precision, timeliness, accessibility and credibility. The lack of regular sensor calibration, for instance, can turn accurate measurements into information that gives employees a false understanding of environmental conditions or product behavior. A second example why quality matters is the influence of the data format on the information's accessibility. Computer programs can access and process structured data with less effort compared to semi-structured or unstructured data. The tools that process unstructured data typically require that an organization involves experts that are familiar with machine learning. They are an important cost factor that affects the applicability of PUI from these sources and channels.

Table 3 provides an overview of information channels mentioned in the application cases. It is not comprehensive but provides a first overview of relevant characteristics of PUI-related sources and channels.

Table 3. PUI channels usable in product development

Channels	Typical contents	Data formats	Source types
Sensor data repository	Environmental information; performance	S / SS	MGD
Log file of embedded control system	Product behavior	SS	
Service report	Maintenance, repair and failure information; product condition	SS / US	PMD
Online discussion forum	Opinions; ratings; complaints; customer/user profiles; constructive critique		HSI
Online customer review platforms			
Telephone	Opinions; complaints; customer profiles		
Email	Opinions; complaints; customer/user profiles; constructive critique	US	

S = structured ; SS = semi-structured ; US = unstructured

MGD is mostly structured or semi-structured. It typically originates from sensors and the log files of product-embedded control systems. Producers can control the quality of *MGD* if their employees take the product development's information needs into account during the design of the product's sensor systems.

PMD integrates *HSI* and *MGD*. Service records, for instance, have text input from service personnel and data from measurements. They contain maintenance, repair and failure information, which are helpful for producers to identify a product's weaknesses.

HSI is mainly semi-structured or unstructured data created by consumers. The latter can provide feedback information as opinions, complaints and expectations. This feedback refers to the product instances of the respective consumer but there is often no unique identifier. This is a problem, because the employees cannot combine it with other information about an instance (e.g. sensor data). Therefore, *HSI* can provide insights about many product aspects but often without much detail. The amount and quality of this kind of information rely on the involved consumers and the available channels.

This research focuses on product-related information that emerges after the product was delivered to the user. One subset of the investigated articles (e.g. [21]) describes applications for product prototypes, i.e. products used by test users. They collect information about product usage and then improve product designs accordingly. In comparison to *PUI*, the usage information from prototypes entails the same features, but likely contains contents for different purposes. Producers can try sensors in prototypes, which may not appear in the marketed product. They can choose lead users to test prototypes, but the involvement of consumers at a larger scale for testing and feedback is typically too expensive and time consuming.

6 Conclusion

This paper presented an initial overview of PUI application cases in product design improvement. We identified 17 cases and analyzed them along three dimensions: product type, product development phase, and information sources and channels. The results indicate that PUI can support the task clarification phase and the product conceptual, embodiment and detailed design phases. We cannot provide more detailed recommendations without analyzing more cases. The main conclusion of this paper is that organizations need to know more about PUI-related information sources and channels. This is important because each source type and channel requires different approaches, methods and tools to extract the PUI from the available sources. Producers could design solutions that supply their employees with PUI, if they gain a precise understanding in this domain. A *limitation* of this research is the risk of sample bias. The investigated sample is small and the inclusion or removal of papers can have a substantial impact on the conclusion. We will perform a review with a larger sample to address this issue.

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