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ENGINEERING *SOFT RELIABILITY* IN PRODUCT REALIZATION

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ABSTRACT

Understanding customers-in-context for actual product realization processes (PRPs) has become a pressing need since *a large and rapidly increasing share of complaints in the field cannot be attributed to violation of products' technical specifications*. While addressing this problem requires a multidisciplinary approach, more studies in the engineering design domain have of late been proposed on engineering contextual and emotional values in product design. However, it is not yet clear how these findings can be utilized within large-scale operational PRPs. Accordingly, in this paper, we propose an *operational* method empowering the stakeholders in collaborative PRPs with core decision templates, which provide (i) relevant information on customers-in-context, and (ii) corresponding guidelines to improve underlying processes. The *content* of these templates builds on the results of user feedback analysis with the subjective-feedback ontology from Soft Reliability, and their *structure* is based on the compromise Decision-Support Problem templates. Partial application of our method is demonstrated through two industrial cases. We envision that our method can help to evaluate and foresee the impact of new technology as it gets incorporated into the specific ecology of values and activities of its users.

Keywords: soft reliability, new product development, no fault found, affective engineering, contextual design

1. "NO FAULT FOUND": AN INDUSTRIAL PROBLEM

Misalignments between product capabilities and user preferences affect the overall success of a product in the marketplace. Especially in the past few years, it has been observed in the field that these misalignments increasingly lead to rejection of consumer electronics products that are actually working well according to their technical specifications [1]. A widespread industrial phenomenon relating to such cases is known as "No Fault Found", or NFF, which is used to label products with no diagnosable fault but are still being reported to create problems for users in the field. NFF cases have first been recognized explicitly within modern high-volume consumer electronics industry (Figure 1) and more recently within the mobile phone industry: In 2006, NFF returns cost the global mobile industry $4.5 billion [3]. Moreover, NFF cases already started to dominate over all other cases where problems occur due to defective parts [4]. Consequently, it has become an ever more pressing need to understand the factors that yield NFF and to adopt operational methods to timely treat them.

The solution to the NFF problem requires a multidisciplinary approach. This was realized when traditional quality and reliability engineering approaches proved no longer compatible to manage the fast-emerging NFF. Despite the usual measures taken to ensure prolonged quality and reliability, NFF revealed that increasingly users experience problems with products that

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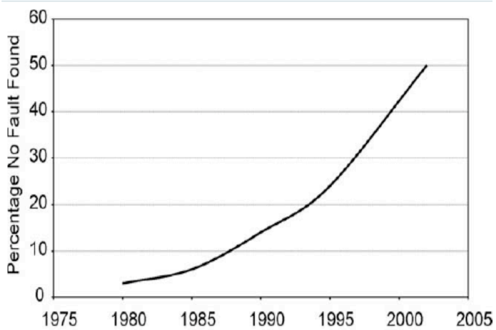

Figure 1. Rapid growth of "No Fault Found" in modern high-volume consumer electronics [2]

actually conform to their technical specifications. This realization signaled the lack of situational/contextual usage considerations in the traditional (i.e., hard) reliability approaches, which highlighted the growing need for managing Soft Reliability (Section 2) so as to get insights into NFF.

In the engineering design domain, more studies have, especially of late, been proposed on facilitating the engineering of contextual values in product design, such as affordance-based design [5,6,7,8], frontier design [9], and empathic lead user design [10]. However, it is not clear how the findings of such studies can be utilized within large-scale operational PRPs to foster collaboration among PRP stakeholders in preventing NFF. Therefore, in this paper, we propose an *operational* method that empowers the various stakeholders involved in actual collaborative PRPs with core decision templates[2], which provide (i) relevant information on customers-in-context, and (ii) corresponding guidelines that relevant stakeholders co-create to collaboratively improve the underlying PRPs. The core decision templates are formulated such that the *content* builds on the results of user feedback analysis with the subjective-feedback ontology (SFO) from Soft Reliability (Section 2), and the *structure* is based on the compromise Decision-Support Problem (cDSP) templates (Section 4). Applicability of the proposed method is demonstrated partially through two industrial cases, conducted in a multinational consumer electronics company, for products during maintenance and during development. Current operational ways of managing Soft Reliability information (Section 3) is finally compared and contrasted with the proposed overall approach (Section 5).

1.1 Gap Analysis within Engineering Design

Design to satisfy user's preferences is already recognized as being important in many industries, where competing products are hard to differentiate strictly on the basis of provided functions and their usability. According to Jordan's widely recognized work [11], people choose products that in some manner appeal to them and that fit within their contexts of use. In accordance with this market trend, and with the emergence of affective engineering, known in Japan as kansei engineering [12], design engineers have started to get involved in user-centered operations for supporting contextual design. However, tailoring for diverse users and contexts has many challenges, especially for businesses operating globally. In line with the evolving and expanding understanding of engineering design, new design methods have recently been proposed within the community (Table 1).

Table 1. Recent efforts in engineering design accounting for users

	Design View	Objective	Application
Maier and Fadel, 2001	Affordance -Based Design	Development of a theory of design to discover product relationships with users during use	Theoretical, with examples
Galvao and Sato, 2005	Affordance -Based Design	Development of a method to link technical functionality to users' tasks	Theoretical, with an example
Green *et al.*, 2006	Frontier Design	Development of a contextual needs assessment method	Theoretical, with an example
Lin and Seepersad, 2007	Empathic Lead User Design	Development of a customer needs analysis technique	Theoretical, with an example

In 2001, Maier and Fadel introduced the notion of affordance-based design [5,6,7,8]. They suggest the concept of affordance that captures the potential behavior of a system as consisting of subsystems such as users and artifacts. This design method, built upon systems theory and the theory of affordances from perceptual psychology, facilitates design engineers discover products' relationships with users during product use (i.e., what *does* and *does not* the product let the user do with it. For instance, a cell phone light *can be* utilized as a flashlight when in need, but not as front- or backlights of a bike). Galvao and Sato [13] propose a method to be used in affordance-based design, which provides an understanding of where in the product architecture these relationships are established and how they could leverage product architecture decisions.

In 2006, Green and co-authors [9] proposed the frontier design method for contextual needs assessment, to assist design engineers in discovering the 'how', 'where', and 'who' factors of the context framework. Putting the emphasis on the context of use, this method leverages the design process for frontier (i.e., unfamiliar) contexts, driven by the fact that multinational companies position products in a global marketplace.

Most recently in 2007, Lin and Seepersad [10] proposed empathic lead user design for rendering customer needs analysis techniques more effective in revealing latent needs that support innovation and generation of breakthrough concepts. Empathic lead users are defined as ordinary users who are transformed into lead users by experiencing the product in radically new ways via extraordinary user experiences; for instance, via experimental product use within a dark or noisy

[2] A *template* is the instantiation of a *construct*.

environment, with limited hearing or dexterity imposed by use of earplugs, or gloves, respectively.

Whereas the cited methods within engineering design exemplify the increase in user and context orientation, they still fall short of providing operational methods to be utilized *collaboratively* by various stakeholders (e.g., engineers, managers, designers) during various phases of complex PRPs.

1.2 Problem Statement

The merging of digital technologies allows for the development of innovative, multifunctional and adaptive products for use within rich socio-cultural contexts such as the high-end office, and the digital home. For the successful development of innovative products, rich insights are needed into how new technology transforms the design space, and to foresee the impact of new technology as it gets incorporated into the specific ecology of values and activities of its users. Currently, there is a growing market uncertainty regarding if, how, and when users *can* and *will adopt* such products, given that the large and rapidly increasing share of product rejections today tend to be not due to traditional (i.e., hard) reliability problems that can be resolved by repair/replacement of defective parts, but rather due to Soft Reliability problems that require either instructional guidance for the user or adaptive redesign of the product. Nonetheless, *current operational quality analysis and evaluation methods do not employ a Soft Reliability perspective, and as such, user feedback from the field (about situational/contextual factors that yield usage problems) is not effectively utilized in PRPs to collaboratively improve the quality of products and processes.*

Recent contributions towards addressing the problem are summarized in Table 1. Whereas the authors there have introduced new methods and techniques that partially address improving the Soft Reliability of products, they are:

1. intended for use by design engineers only, instead of use by various collaborating stakeholders involved at design,
2. still for use only during the early design phase of a PRP, instead of all PRP phases,
3. untested in a real operational context, and are instead tested only in academic examples.

In this paper, we describe an operationalizable method to render the currently deployed PRPs systematically responsive to the growing and uncontrollable problem of unforeseen poor user experiences. Our method, addresses all three requirements that are not satisfied by the recent work listed in Table 1.

2. SOFT RELIABILITY

Soft Reliability (SR), introduced in 2005 [2] and substantiated by 2008 [4], serves as a conceptual basis for formulating product- and process-related reasons that trigger NFF. The SR view is an enhancement to the currently deployed quality and reliability analysis operations within the industry that are mainly product-component based and logistics-driven; and as such, it complements the traditional Hard Reliability view, which focuses on broken hardware and software, but not broken expectations of users [14].

According to the Kano model of customer satisfaction [15] (Figure 2), the extent to which a product fulfills expected "basic features" do not contribute to customer satisfaction, whereas the lack thereof leads to severe dissatisfaction. Fulfillment of "performance features" contributes to satisfaction in a linear fashion, as these are the features that customers explicitly base their buying decisions on. Whereas these two groups of features typically comprise essential components of a product that are *specifiable*; "excitement features" comprise additional surprises for the customer that offer delight during product use. Since customer delighters are often user-specific, and largely unknown in advance, these are not specifiable. In addition to studying broken expectations of users, SR research also explores this unknown territory of customer delighters.

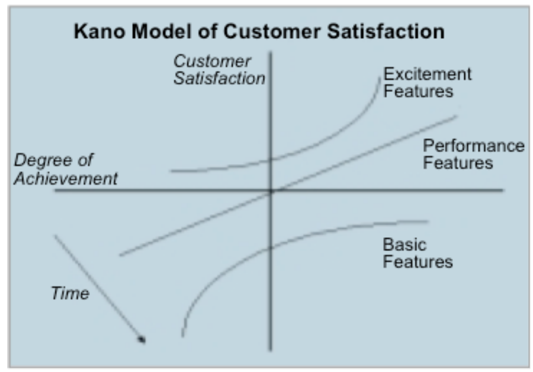

Figure 2. According to the Kano model (cf. 'Time'), "what was considered as exciting yesterday becomes asked for today and expected tomorrow" [15].

As shown in Figure 3, SR depends on the conformance of the actual product to individual user's requirements *over time*, whereas hard reliability depends on the conformance of the actual product to its formal technical specifications over time. Since there is *one* set of technical specifications per product, but *many* users with *individual* user expectations, hard reliability can be defined as a one-to-one relationship, while SR as one-to-many. Moreover, each user has dynamically changing *explicit* and *latent* expectations over time, as addressed by the Kano model, making SR management especially challenging.

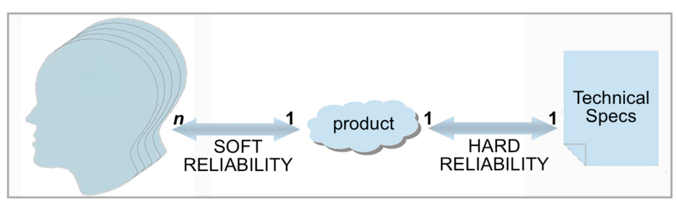

Figure 3. Soft reliability is about *making the right product*, whereas hard reliability is about *making the product right*. One does not ensure the other.

Current logistics-driven field feedback collection, yielding the measure for quality and reliability assessment, is not tailored to capture incidents about SR. User reports are typically tested for hard reliability problems. Therefore, such incidents lead to large and growing numbers of ‘product assistance’ calls at helpdesks, NFF labeled products at service/repair centers, returned products at dealers that function well, and to top it all, damaged brand image of companies. In Section 2.1, an ontology is proposed for effective capturing of SR incidents from the field to feedback to the relevant phases of PRP.

2.1 Subjective-Feedback Ontology (*SFO)*

In order to systematically capture and utilize valuable field feedback information to better meet user expectations with better design and to tackle the growing problem of currently unknown NFF cases, the subjective-feedback ontology, or SFO, has been developed (Figure 4, see [17] for a complete view of SFO). SFO conceptualizes user satisfaction and dissatisfaction levels and reasons, which can in turn be linked with the capabilities of the product. Taking each individual user-feedback (e.g., question, complaint, remark) as the unit of analysis, an efficient and effective classification and analysis means is provided by SFO to link relevant user remarks to their respective originator activities in a PRP for improvement. Furthermore, SFO is built to be a domain-independent ontology and hence extendible for different (i) products, (ii) sources of feedback data, (iii) stakeholders involved in PRPs, and (iv) model implementing tools and coding mechanisms.

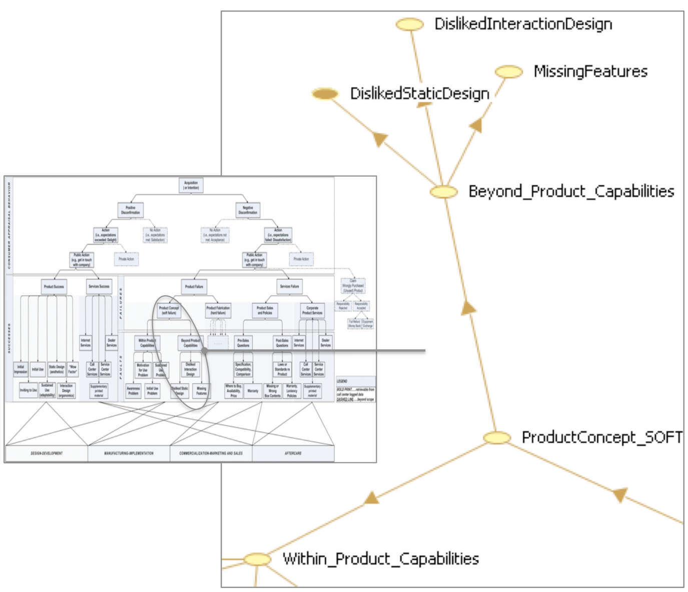

Figure 4. A bird’s-eye view of SFO on the left side, and the circled part of it enlarged on the right side, as built with the modeling language WSML [16].

In SFO, *hard failures* are recognized as product failures where the product is incapable of performing its functions as listed in its technical specifications without the intervention of authorized technical support for recovery by means of repair or replacement of parts. On the other hand, *soft failures* are recognized as product failures where the product, despite being capable of performing its functions as listed in its technical specifications, still necessitates professional intervention for recovery (but not repair) through instructions or information from an unexpected user-product interaction state.

In the scope of this paper, only the soft failures part of SFO is described: Soft failures are sub-classified first at the product level, before they are classified deeper at the phases-of-use level. The product level classification makes a distinction between (i) problems that can be resolved *within* the capabilities of the product by the user upon getting supporting guidance and instructions; versus (ii) problems due to users’ higher or other expectations that are *beyond* what the product is capable of (Figure 5). This distinction corresponds to the widely acknowledged "errors of omission" and "errors of commission" as referred to by Krippendorff [18], in that order. Consequently, failures captured at this level indicate if the product can be improved by (i) *adjusting* current capabilities so that they are easily noticeable, inviting, and accessible in general; or by (ii) *enhancing* current capabilities or *adding* new capabilities to eliminate particular explicit user disillusionment. In engineering design terms, this distinction reveals whether a (i) *variant*; or an (ii) *adaptive* (or even an *original*) redesign of the product is needed, respectively.

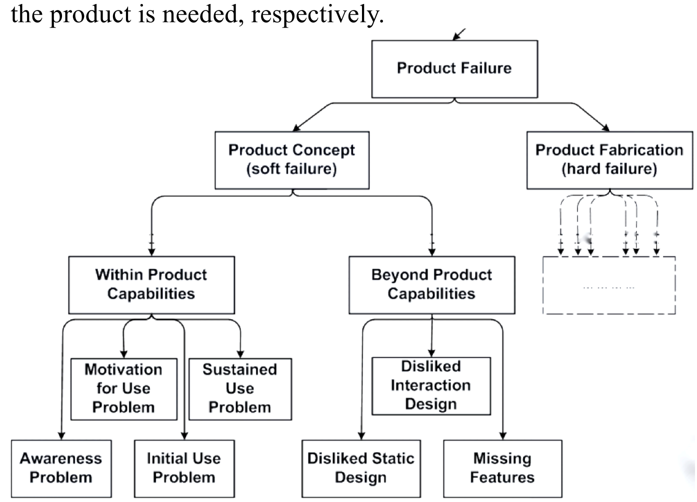

Figure 5. Part of SFO, with product level classification of (i) within product capabilities, versus (ii) beyond product capabilities, and then with the deeper phases-of-use level classification.

The deeper phases-of-use level classification of soft failures is based on the different "phases of use" [19] that users are intended to consecutively pass through (Figure 5). These phases include, in order, *awareness* of capabilities, *motivation* to use, *orientation* for figuring out how to use, *adoption* in daily life, and *incorporation* for extended use. Failures captured at this level indicate usage issues of a product, likely to prevent its successful communication to its users, ultimately leading to poor acceptance and adoption.

The part of SFO discussed here, offers an expressive replacement for the currently named NFF category of unidentifiable failures and hence provides relevant classes to work with to improve the design. Since the unit of analysis of this ontology is an individual user feedback, each of which is typically recorded as freetext data (cf. Section 2.2), further product specific information can be retrieved from each classified feedback if needed, either manually, or automatically by text mining. This can be done by first observing the occurrence frequencies of the classes of SFO in the dataset, and hence identifying the largest proportions, which reveal the most impactful aspects of a product. As a result, prioritization among necessary improvement points can be made.

Last but not least, for a comprehensive evaluation of the SR of a product, its negative as well as positive soft 'qualities' should be *comparatively* analyzed over the phases of use as induced by time. Such an evaluation will reveal how users experience a product over time, and whether they will embrace or reject it eventually. Therefore, SFO also captures the positive disconfirmations of users (i.e., "excitement features" in Kano model) via its soft *successes* classes, which have been derived from- and complementary to the soft *failures* classes. While failure classes are important to identify weaker aspects of a product; success classes hint at stronger aspects that may contribute to establishing the unique selling proposition.

2.2 Application Domain of *SFO*

As SFO can be used to capture negative and positive SR issues from user feedback data, it can be applied where resources for such data are available. In a typical industrial setting, various data resources exist for obtaining user feedback with varying degrees of richness regarding qualitative user accounts:

Service centers are where all returned products are examined strictly for violation of technical product specifications. Data logged at service centers lack content regarding the user and use context [20]. **Call center**s are where users call up to consult agents mostly about their questions and complaints. Data logged at call centers by agents have qualitative descriptions of the -typically negative- user feedback, with variable detail [20, 4]. **Internet** proves to be an emerging source of user feedback data, where users exchange rich qualitative accounts of products - both positive *and* negative - on product forums, or post on web-based helpdesks of manufacturers, or get involved in co-designing products through initiatives of third party companies (e.g., www.redesignme.com) or of first-hand manufacturers (e.g., http://www.dellideastorm.com). **Test** data logged at field studies and lab tests usually have qualitative accounts of users depending on the specific focus of the study, with variable detail [21]. **Trade** data logged by dealers are mostly sales and logistics focused and lack qualitative descriptions as to why a certain product is returned.

Analyses performed on user feedback data with SFO do not only facilitate in improving industrial products and services, but also help researchers gain rich insights into how a new technology transforms the design space over time. After all, the impact of an innovation can only be seen when it is fully incorporated in the specific ecology of values and activities of its actual users. Therefore, *operational* mechanisms for efficient knowledge transfer from real users to designers are crucial.

3. OPERATIONAL CONTEXT OF SOFT RELIABILITY INFORMATION

Product information flows in between the different phases of a PRP are typically triggered by verification milestones (Figure 6). However, the transfer of feedback generated at these milestones is usually imperfect in most industrial settings due to the complexity of business organizations and the communication overhead among their dispersed units. Additionally, channeling feedback from the field to these phases is even a greater challenge once a product is released out to the market. Such a challenge depends also on the type of industry: The information channels are relatively different within business-to-consumer industries (e.g., consumer electronics industry), and within business-to-business industries (e.g., medical systems industry) where there typically is minimal contact with end-users. In this paper, the scope is limited to business-to-consumer industries, since the industrial cases in Section 4 identify with that group.

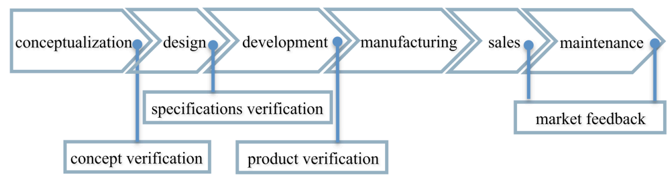

Figure 6. Phases of a generic PRP with verification milestones

In the field, abundant information about the SR of products and services are existent during the maintenance phase, as can partly be justified by the increasing numbers of NFF cases. However, the operational methods in place for collecting such 'market feedback' do not facilitate (i) recognition of SR related information about users and their contexts of use, and (ii) communication to early PRP phases, such as design and conceptualization. Consequently, valuable field feedback on SR issues remains uncovered under the currently unidentifiable NFF label, and cannot be incorporated into current or next generation products as such.

Besides the ultimate market verification, other kinds of verification milestones are 'concept', 'specifications', and 'product' verifications (Figure 6). Such early feedback, when obtained from user studies in the field, is of potentially great value to *different* stakeholders active in early PRP phases (e.g., designers, engineers, marketing specialists, managers). This is not only because early field feedback may reveal the otherwise unforeseen experiences relating to social, contextual and emotional aspects of product use relating to SR; but also, in the context of collaborative PRPs, an essential aim is to increase the impact of user research on actual design decisions, and thereby foster expert collaboration for developing better-designed products. However, there currently exist no standards for capturing and communicating especially SR related field data. Instead, especially in developing really new products, feedback data from costly field studies are processed in an expert-dependent (i.e., subjective) manner, the learning from which cannot be scaled up or across.

In the following two sections, feedback operations in practice during the latter and the earlier phases of PRPs are respectively described, also making the connections with the involved data resources as introduced in Section 2.2. The main motivation in *separately* discussing feedback operations *after* product release (Section 3.1) versus *during* product development (Section 3.2) is their respective primary use in *reactive* versus *preventive* or *predictive* reliability management.

3.1 Feedback Operations after Product Release

Once a product is officially released to the market, field feedback operations start functioning: Upon interacting with the product, users whose expectations from or perceptions of it differ from those of the designers' may initiate the feedback loop. Depending on the degree of disconfirmation the user experiences while using the product, s/he may like to (i) hand in the product to a nearby authorized service center for repair; (ii) contact a designated call center for questions, complaints, and requests; or (iii) post questions, complaints, and general comments on product forums on the Internet (Figure 7). In all cases, the feedback gets registered in a respective electronic data repository, later to be analyzed by the relevant members of the product development team, such as the "Knowledge Engineer", or the "Quality Manager". Note that feedback data from trade, logged by dealers, is not included in Figure 7, since it is mostly about inventory management and lacks descriptions as to why a certain product is returned.

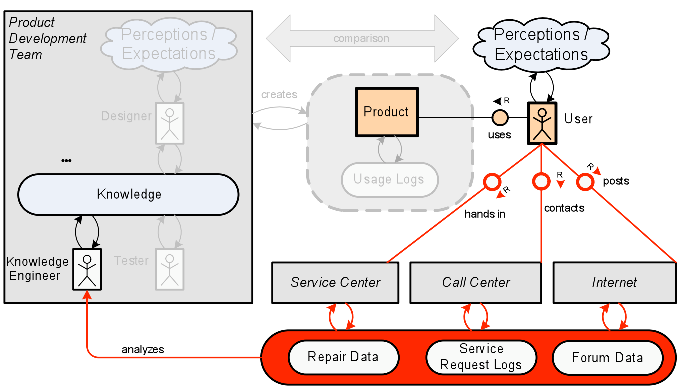

Figure 7. Depending on the degree of expectations disconfirmation the user experiences while using the product, s/he may initiate the feedback loop back to the manufacturing company.

The maintenance of feedback data at **service centers** is customarily done by service center engineers, who record the defect and repair data of returned products into a central repository, utilizing a universal code list (e.g., IRIS: International Repair Information System [22]). The primary purpose for maintaining data repositories at service centers is two-fold in effect: First, to keep track record of defective product parts that have been repaired or replaced; and second, to claim costs from upper management, for those products treated under warranty. An illustrative case about how a service center functions, and the structure of the electronic repository deployed there is outlined in [20].

At **call centers**, the logging of feedback data is done by call center agents. Service requests from customers may come in as phone calls or emails, which then get treated directly by call center agents or get forwarded to a service center for hands-on repair if needed. In logging service requests into the call center's electronic repository, agents follow certain classification schemes. The primary purpose of these schemes is to assess and improve customer relationship management, while identifying the surfacing "cost of non-quality" of services, in order to devise ways to minimize such costs. Two examples of currently deployed classification schemes are compared and contrasted in [20], where their performance shortcomings are demonstrated.

Internet feedback data repositories refer to web-based product forums, where users exchange their questions, complaints, and general comments with their peers or with the manufacturing company's officials. Since these repositories are compiled by users themselves without having to conform to any codification or classification scheme; and due to the abundance of such repositories on the web that enable sharing different modalities of information about a product (e.g., text, image, video), the resulting data are often quite unstructured. Nonetheless, as the Internet has been developing into the ultimate communications medium among users of innovative products; developers are also starting to tap on this resource by inviting users to submit their ideas online for co-designing new products [23].

3.2 Feedback Operations at Product Development

During the conceptualization, design, and development phases of PRPs, various tests are run -ideally at repeated intervals- to verify the product concept, specifications, and the product itself, respectively (Figure 6). Tests with fully functional prototypes are especially of value when conducted in the field with real users, for ensuring the SR of products. In such field studies, the aim is to understand how users initially perceive the potential product, and their expectations about a prolonged use experience.

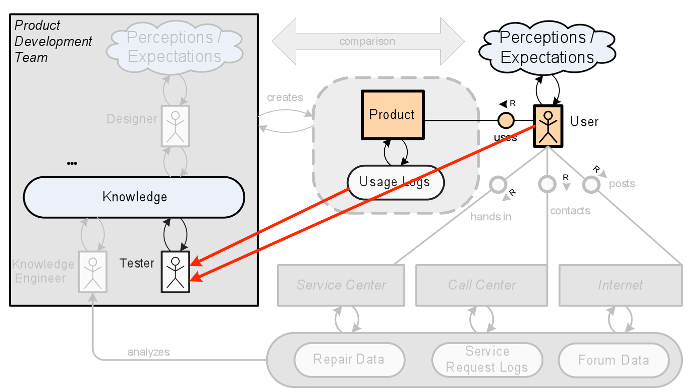

Figure 8. Early feedback data from tests during product development come from (i) in-product logs; and (ii) users via, e.g., interviews, surveys, or questionnaires.

The test data collected from field studies come in two types (Figure 8), (i) objective product usage data automatically logged within the product that reveals, e.g., *when* the product is used, *what* feature of the product is used; and (ii) subjective user feedback data collected from, e.g., semi-structured interviews, automated surveys, or questionnaires. These data do not get collected jointly, which yields biased data; and the unsystematic collection of user feedback data per study is often followed by subjective processing.

4. DECISION TEMPLATES FOR COLLABORATIVELY IMPROVING SOFT RELIABILITY

In order to effectively engineer SR into new product design within complex PRPs, the use of SFO is necessary but not sufficient. The analysis results from applying SFO to user feedback resources further need to be *communicated to the collaborating stakeholders in a way that supports their joint decision-making activities so that they can then take appropriate actions*. To realize this outcome, we propose the utilization of the compromise Decision-Support Problem (cDSP) construct [24, 25, 26], together with SFO.

The cDSP is a multi-objective decision model that constitutes a hybrid formulation based on mathematical programming and goal programming. The structure of the cDSP consists of four key components: Given, Find, Satisfy, and Minimize. The "Given" section consists of information available to the stakeholder for decision-making, such as from prior analysis results achieved with SFO. The "Find" section captures the outcome of the decision, such as the actions that need to be taken to improve a product's SR. The "Satisfy" section captures the constraints and goals, such as those of the stakeholder. Finally, the "Minimize" section captures the ultimate objective of the decision, which is to minimize the unfavorable disconfirmation of user expectations due to situational or contextual use. The cDSP construct can be adapted to different decision-making scenarios. A cDSP template specifically adapted for SR problems is shown in Box 1.

Given	Feedback category (as captured by SFO) Importance feedback category (as captured by SFO) Values of use-context parameters • User type and characteristics • Physical setting • Social setting • Other connected products Feedback instance
Find	How to improve associated PRP activities, i.e., why, where, what, which, how, when
Satisfy	Relevant stakeholders' constraints, goals, and bounds, in performing respective PRP activities
Minimize	Use-context deviations

Box 1. The compromise Decision Support Problem (cDSP) construct for improving Soft Reliability.

The cDSP construct is suitable for achieving the aforementioned aim in mainly two ways. Firstly, the template provides a standardized and modular representation of design information that can be computer interpreted and, accordingly, can be effectively used and reused within and across PRPs in an operational context. Secondly, this unique application of cDSP to soft (i.e., qualitative and subjective) information, supports decision-making activities of various collaborating stakeholders by jointly providing the required information for- and of- all relevant stakeholders, on each template. Since multiple stakeholders' requirements are captured on the same cDSP template, collaboration among them is encouraged. Based on the given SFO-categorized feedback instance, and the various stakeholders' evolving requirements to satisfy; appropriate procedural actions to be taken to improve the PRP and the end product can dynamically be identified, as listed in the "Find" section of the template.

The cDSP construct is suitable for use in conjunction with SFO also due to its hierarchical and composition capabilities [24, 25]. SFO can be used to capture negative and positive SR issues from detailed user feedback data available at various resources, such as call centers or the Internet as described in Section 2.2. The information from each of these resources can be stored in separate cDSP templates. Then the information from different resources can be organized and integrated into a *master* cDSP template, which has a hierarchical structure corresponding to the different elements of SFO. This would then allow multiple stakeholders to extract the information that is relevant to their domains from the master cDSP, to further specify and formulate on the template their own constraints, goals, bounds, and decision problems to collaboratively improve the product and relevant processes with peers. Such a combined view of SFO with cDSP templates would leverage the systematic use of the different abstraction levels of SFO by stakeholders, although this has not yet been tested in practice.

4.1 Industrial Case I: After Product Release

A specific test of applying SFO on early user feedback data collected through a call center of a multinational consumer electronics company revealed some intriguing findings in terms of comparing SFO analysis with in-house expert analysis. The analysis is further developed by demonstrating the potential use of utilizing cDSP templates in collaborative PRPs.

4.1.1 Objectives

Our aim in this study is to illustrate the real need for and benefits of utilizing SFO together with cDSP templates within an operational context of a collaborative PRP regarding a product that is newly released to the market. The general hypothesis is that there is a strong need for structured SR analysis tools to filter the qualitative user feedback data from the field such that stakeholders can make sense of it and can collaboratively take corresponding improvement actions.

4.1.2 Setup

As a response to the increasing numbers of NFF cases in the field, the hosting multinational consumer electronics company takes the following approach: Whenever a new product is released to the market, user feedback data coming from the field during the first six months gets compiled to be analyzed in detail for quality checking. Specifically, the service requests of users filed to call centers in the form of incoming e-mails within the first six months of product's release are analyzed by the knowledge engineers and the quality manager of the new product. Depending on the data quantity and quality, the predominantly manual analysis takes at least a few days, before it is known what the most prominent issues about the product are. During the root-cause analysis through manual processing and subjective clustering of user feedback, finding out about NFF cases are especially targeted. Since call center classification schemes do not recognize these cases, the quality checking stakeholders of the product have to process the dataset irrespective of the pre-assigned labels by call center agents, to ultimately uncover the most prominent (e.g., mostly complained about, or most impactful in terms of costs of non-quality) issues about the product. This whole process, so-called "Fast Field Feedback Analysis" track, then needs to be repeated anew for every new product just released to the market.

In the described operational setting of one specific case, we joined the knowledge engineer and the quality manager in their analysis efforts of the data that comprised user reports from the UK and Germany, collected during the first half of 2007, about a newly released DVD recorder at the time. The reports were initiated by emails from users and handled over time with both email and telephone exchanges between call center agents and users. While the knowledge engineer and the quality manager used their own subjective expertise to do the analysis, we used SFO, and in the end the findings from both analyses were verified with each other.

4.1.3 Results and Discussion

The complete dataset analyzed has 244 service requests initiated by users, which is an equivalent to 336 individual user feedback instances relating to failures. It should be noted that call center data, in this case, is biased with only negative feedback. The result of classifying 336 failures with SFO shows that 251 are product related failures whereas 85 are services related failures. From 251 product failures, *74% can be identified as soft failures*, whereas 8% can be identified as hard failures: in other words, product concept failures occur 9 times more than product manufacturing failures. Furthermore, the result of sub-classifying all 186 soft failures shows that 55% are setbacks *within* current product capabilities, while 45% are due to users' higher or other expectations that are *beyond* what the product is capable of. In addition to these higher-level SR analysis findings with SFO, more detailed findings are also achieved on a lower level, as corroborated by the results of the analysis done by the knowledge engineer and the quality manager. That is, the product-specific problems they are interested in knowing are also captured with use of SFO. However, due to the differences in the nature of these two approaches, some benefits of utilizing SFO are identified, as listed in Table 2.

Table 2. Comparison of expert and SFO analyses of field feedback.

Comparison criteria	Expert Analysis	SFO Analysis
NFF cases identified?	yes	yes
SR information captured (e.g., implications of each feedback on product's phases-of-use)?	no	yes
Consistent objective analysis possible with well-defined classes?	no	yes
Generic (i.e., product-independent) classification possible?	no	yes
Analysis results scalable across projects (e.g., product generations)?	no	yes
Analysis results can be tailored to the interests of various stakeholders?	no	yes
Analysis results yield prioritization of product issues?	yes	yes
Analysis results yield actionable items?	no	no
Analysis automation possible?	no	yes

Based on the comparison criteria listed in Table 2, there are many differences between the expert analysis and the SFO analysis, mainly due to the fact that the latter utilizes an established hierarchical ontology structure, while the earlier is based on a flat classification dependent on subjective expert opinion. As stated earlier, the expert analysis has been devised in response to the increasing NFF cases that have emerged in the recent years, and is mostly serving short-term needs of identifying such cases, such as to prioritize the current product's issues. However, this costly analysis process is highly subjective in nature, and hence the knowledge developed therein cannot be reused in systematic comparison of field data within and across PRPs in the long-term for product roadmapping. SFO analysis on the other hand proves as a competitive alternative that addresses the drawbacks of expert analysis and provides long-term solutions, which may also potentially be cost-effective due to analysis automation possibilities. While a first step from expert analysis towards SFO analysis can be through experts utilizing SFO elements in clustering field feedback, rather than product-specific classes that they derive ad hoc; the second step can be replacing the classification schemes used at call centers with a classification scheme based on SFO. In fact, company-internal initiatives to adopt both steps have already been put to effect, in "Fast Field Feedback Analysis" tracks for some similar products, and at call centers of the company around the world, respectively.

SFO analysis, due to the hierarchical structure of the ontology, provides results at different abstraction levels that tailor the interests of various PRP stakeholders, e.g., higher level results on overall user satisfaction levels for product managers concerned with maximizing the Net Promoter® score; or, lower level detailed results on services failures for operations engineers concerned with maximizing overall performance of corporate product services such as call center services, service center services, Internet services, etc. Such information requirements of multiple stakeholders can be systematically organized and stored in cDSP templates, that can be jointly used among all relevant stakeholders to leverage their decision-making processes while determining procedural guidelines to improve reported product issues. Accordingly, a cDSP construct is *instantiated* with a field feedback instance in Box 2.

Given	**Feedback category & definition** *Missing feature*: User expected the product to have a feature that the product actually does not have. May potentially affect the adoption of the product in user's daily life during extended use. Requires adaptive or original redesign of product. **Feedback category importance** B (Second biggest category), 21% **Values of use-context parameters** *User type and characteristics:* • Hard of hearing *Physical setting:* - *Social setting:* - *Other connected products:* - **Feedback instance** How do I add hard of hearing sub titles to an HD recording that has been recorded via Guide+?
Find	*Why* is the redesign needed? *Where* in product will the redesign be? *Who* will the redesign target as users? *Which* redesign choices will be tested? *How* will redesign be tested? *When* will redesign be implemented?
Satisfy	*Quality Manager:* • *Constraints:* - • *Goals:* Minimize field call rate • *Bounds:* - *Operations Manager:* • *Constraints:* - • *Goals:* Maximize resolve-on-first-call rate, minimize time spent on each call, maximize Net Promoter® score • *Bounds:* - *Product Manager:* - *Design Engineer:* - *Software Engineer:* - *Interaction Designer:* - *Marketing Specialist:* -
Minimize	Use-context deviations

Box 2. The cDSP template with negative field feedback from industrial case I (i.e., after product release).

The benefits of utilizing SFO analysis together with cDSP templates as exemplified above, offers substantial efficiency improvements in collaborative PRPs. The ideal use of this approach requires firstly, SFO analysis of user feedback data to reveal occurrence frequencies of SFO elements, and secondly, based on highest frequency occurrences, communication of corresponding feedback instances to the relevant stakeholders on cDSP templates. The "Find" and "Satisfy" sections of these templates can dynamically be modified/enhanced by the stakeholders as and when necessary. Although such use of templates together with SFO has been acknowledged to prove useful by the stakeholders in the given case, this has not yet been verified in practice.

4.2 Industrial Case II: At Product Development

A specific test of applying SFO on early user feedback data from two consecutive field studies conducted with functional prototypes of a conceptualized product at a multinational consumer electronics company revealed some intriguing findings in terms of comparing SFO analysis with in-house analysis methods. The analysis is further developed by demonstrating the potential use of utilizing cDSP templates in collaborative PRPs.

4.2.1 Objectives

Our aim in this study is to illustrate the real need for and benefits of utilizing SFO together with cDSP templates within an operational context of a collaborative PRP regarding a product that is still at its conceptualization phase. The general hypothesis is that there is a strong need for structured SR analysis tools to filter the qualitative user feedback data from field studies such that stakeholders can make sense of it and can collaboratively take corresponding improvement actions.

4.2.2 Setup

In order to prevent *unforeseen* experiences relating to social, contextual and situational aspects of product use in the field during extended use, the hosting multinational consumer electronics company starts conducting exploratory field studies with fully functional prototypes early on during a PRP, especially when conceptualizing really new products. In such field studies they try to get insights on how a product is actually deployed in its natural use context by potential users and further identify its value proposition for the users in comparison to other similar products on the market. Technical conformance issues are of less relevance; hence data of interest for the stakeholders in the product development team at that PRP phase are predominantly SR related, e.g., user likes, dislikes, struggles, suggestions with respect to their use experiences. The product development team typically collaborates with specialist organizations that are subcontracted for carrying out such individual field studies. The specialist organizations utilize their own tools and methods to collect and interpret data from field use. While their methods to collect data vary from conducting semi-structured interviews to creating private online communities wherein users exchange opinions and sometimes are polled for questions posed by official moderators; their ways of analyzing such data are typically expert dependent, subjective, and not generalizable.

In the described operational setting of one specific case, we joined the product development team in their user feedback collection and analysis efforts from two consecutive field studies during the conceptualization of an Internet on TV product. The first study was conducted with 20 trusted users from 8 different countries around the world for 5 weeks. While the users used the prototypes in their home environments, they were able to post textual comments on a private and closed forum that was provided and moderated by a subcontracted specialist external organization. Stakeholders of the product development team were also members of the closed forum to be able to closely monitor the user feedback data getting collected there, and to help the users with any technical issues in using the prototypes. The feedback data collected from users were afterwards analyzed offline by both the external specialist organization using subjective expertise, and also by the product development team, which we were a part of, using SFO.

In the second field study, more limited in scope, 8 trusted users participated from the Netherlands for 10 days mainly to test the browsing and searching features of the product. Also in this study, the users used the prototypes in their home environments, but the means with which they provided their feedback was different: There were Thumbs-Up and Thumbs-Down buttons on the input device of the prototype for when the user wanted to give positive or negative feedback, respectively. Upon pressing either button, users could fill in the respective survey form that popped up onscreen (Figure 9). Both surveys comprised the following four parts: (1) description of the feedback, (2) degree of satisfaction or dissatisfaction due to the topic of the feedback, (3) reason of the satisfaction or dissatisfaction, and (4) product feature that led to the satisfaction or dissatisfaction.

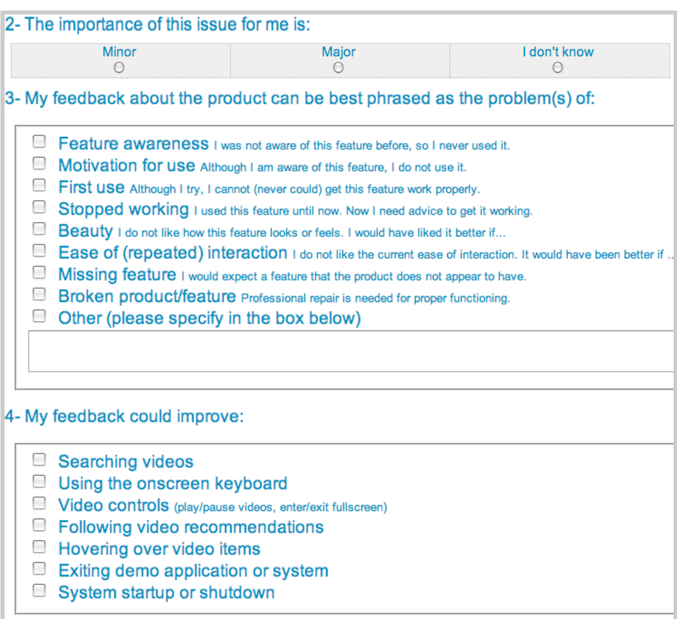

Figure 9. Screenshot of parts (2), (3) and (4) of the user-initiated Thumbs-Down survey. Thumbs-Up survey is similar in structure, but tailored to capture positive feedback.

While part (1) of both surveys captured rich qualitative data that may be needed for detailed analysis later on, parts (2) and (3) captured categorical data that map to various elements of SFO. On the other hand, part (4) also captured categorical data that maps to a product-specific feature ontology regarding the Internet on TV product. The data collected on real-time (on a central system) from users filling in Thumbs-Up and Thumbs-Down surveys were analyzed by us, to verify and validate if textual feedback they provided indeed match with their responses to parts (2) and (3) of both surveys.

4.2.3 Results and Discussion

From the first field study, the analyzed dataset has 423 postings made by the 20 participants. The result of classifying these 423 postings based on SFO shows that 21% is about user likes, whereas 77% is about user dislikes or struggles, namely product related failures[3]. Furthermore, this 77% can be sub-classified as 24% struggles *within* current product capabilities, and 53% as suggestions or dislikes due to users' higher or other expectations that are *beyond* what the product is capable of. In addition to these higher-level SR analysis findings with SFO, other findings are also achieved on a lower product-level, as corroborated by some of the analysis results obtained by the external specialist organization. That is, the product-specific problems that the product development team is interested in knowing are captured also with use of SFO.

From the second field study, the analyzed data set has only 23 submitted surveys by users of 7 out of 8 prototypes. From these 23 surveys, 18 are Thumbs-Down and 5 are Thumbs-Up surveys. In this smaller scale study, it was possible to test the automatic collection of qualitative user feedback through user-initiated surveys that are based on SFO. As opposed to the first field study for which manual post-processing was needed to structure and interpret all user feedback data to apply SFO, the second field study proved to be much more efficient in achieving the same level of analysis, with a higher level of automation, and hence with less involvement of experts. This conclusion leads from the fact that textual feedback provided by users on part (1) of Thumbs-Up and Thumbs-Down surveys, match with responses to parts (2) and (3) of both surveys, which are essentially users' mapping of their own feedback to corresponding elements of SFO.

While the comparison listed in Table 2 also holds between the SFO based analysis and the other expert-opinion based analyses applied at field studies during product development, the reasoning behind is slightly different: Expert analyses done early on at product conceptualization mostly target answering specific questions about the intended value proposition of the product. Therefore, they are limited in scope, and address the interests of only a few stakeholders in the product development team. Since these analyses are highly subjective in nature, the knowledge developed therein cannot be reused in systematic

[3] The remaining 2% of the data is partly unusable and partly relates to services failures.

comparison of field data within and across PRPs. SFO analysis addresses such drawbacks, and may potentially be cost-effective due to automation possibilities, such as demonstrated with the use of Thumbs-Up and Thumbs-Down surveys.

SFO analysis results can be further utilized together with cDSP templates, to leverage decision-making processes of various stakeholders in collaborative PRPs. An instantiation of a cDSP template with positive feedback data from the first field study about the Internet on TV prototype is listed in Box 3.

Given	**Feedback category & definition** *<u>Inviting to use</u>*: User is motivated to use the product based on its perceived potential added value. **Feedback category importance** B (Second biggest category), 23% **Values of use-context parameters** *User type and characteristics:* • Tech savvy medical doctor *Physical setting:* • Living room *Social setting:* • Use at leisure-time with family, friends, and for daily necessities like shopping, video calling, etc. *Other connected products:* • TV, (potentially) home cinema **Feedback instance** My TV is in the living room where I have sofas and it's really cozy. It is the perfect place to watch a film, not in my study. I think it would be quite sociable to have a family gathering around and looking at each others Facebook, Myspace on the TV. You could browse pictures from Picasa and do your shopping all with your remote. In the future you may even be able to video call people etc.
Find	*What* is the perceived added value? *Where* in product can the perceived value be strengthened? *Who* are target users and how to explicitly address them?
Satisfy	*Product Manager:* • *Constraints:* - • *Goals:* Find Internet sites suitable for TV • *Bounds:* - *Interaction Designer:* • *Constraints:* - • *Goals:* maximize frequency of positive feedback category *<u>interaction design</u>* on the use of input device • *Bounds:* -
Minimize	Use-context deviations

Box 3. The cDSP template with a positive field feedback from industrial case II (i.e., during product development).

The "Find" and "Satisfy" sections of cDSP templates can dynamically be modified and enhanced by the stakeholders as and when necessary. Although such use of cDSP templates together with SFO has been acknowledged to prove useful by the stakeholders in the given case, this has not yet been verified in practice.

4.3 Discussion

In order to effectively engineer SR into product design within complex PRPs, the use of both SFO and cDSP templates are necessary. While SFO alone can ensure the correct capturing of relevant feedback data, cDSP templates facilitate their efficient and effective *communication to the collaborating stakeholders in a way that supports their decision-making activities so that they can then take appropriate actions*.

As described in Section 3, current market feedback mechanisms do not recognize SR related information, and most of the feedback is rendered useless with the unidentifiable NFF label. In Figure 10, it is shown where the remaining feedback is channeled to in a typical PRP. In most cases there is hardly relevant information that gets channeled back to earlier PRP phases, hence the light colored arrows in Figure 10. However, the communication of relevant SR related information can conveniently be provided to the discretion of the relevant stakeholders when organized in cDSP templates. As a result, the growing NFF problem can be managed reactively.

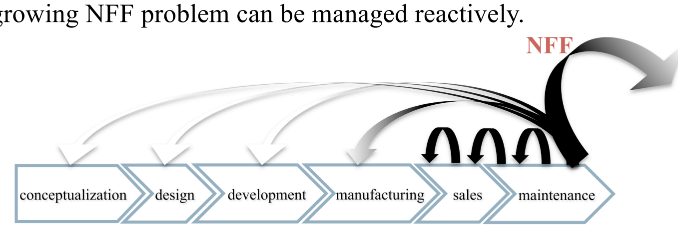

Figure 10. Current operational market feedback management during PRPs.

In terms of a preventive approach to the growing NFF problem, cDSP templates can be utilized in a similar manner, only with feedback data from earlier verification milestones in PRPs. Conformance checking between the preventive and reactive approaches can eventually yield the development of NFF prediction mechanisms that would, in turn, significantly contribute to SR management by advancing it to a level, where it can be statistically managed like hard reliability.

Furthermore, the hierarchical structure of SFO, when combined with the hierarchical and composition capabilities of cDSP templates, facilitates in organizing and integrating information from different data resources/countries/etc. Therefore, collaborating stakeholders can be further empowered through the systematic communication of declarative qualitative user feedback information from comparative perspectives and a co-developed (with peers) procedural guide towards working with actionable items for effective overall design improvement. The cDSP construct can be instantiated with different kinds of information – both qualitative and quantitative. If the construct is instantiated with quantitative information about the product failures, utility-based decision-making approaches can be applied for determining the best course of action to address the

SR issues [27]. Such an approach would facilitate the integration of diverse preferences from different users into a common set of metrics that can be aggregated using multi-objective utility functions. Further, the instantiation of the cDSP template from multiple data sources can be automated through a web-based interface, supporting efficient decision-making by the stakeholders.

5. CLOSURE

There are four major market trends in the industrial world that contribute to the exponential growth rate of NFF:

- Increasingly complex products, due to new technology becoming available at lower prices faster
  - ⇒ Increasingly incomplete product specifications
- Strong pressure on time-to-market due to competition
  - ⇒ Development times decrease, whereas feedback mechanisms still slow
- Increasingly global economy, where business units and markets of companies become distributed
  - ⇒ Communications overhead, and cultural/contextual use differences
- Increasing expectations and decreasing tolerance of users
  - ⇒ Lowered threshold for complaining or seeking instructional help

Currently deployed user feedback management mechanisms are not up-to-date to accommodate these four trends. Most design relevant information is not recognized and hence lost under the NFF label, or the information arrives too late. Thus, rich market feedback of great value for various *collaborating* stakeholders throughout PRPs is underutilized or lost altogether. As a result, NFF keeps increasing, as PRPs cannot be aligned with actual user expectations and perceptions. To address these issues, in this paper, we present an operationalizable method to improve SR engineering within the currently deployed PRPs by rendering them systematically responsive to the growing and uncontrollable problem of unforeseen poor user experiences.

Our method is differentiated from related work in engineering design in that:

1. It is intended for use by various collaborating stakeholders involved at design,
2. It is usable during all PRP phases,
3. It is already partially tested in an operational context and is welcomed by stakeholders for its offered added value.

These three differentiator aspects are realized through the empowering of stakeholders in collaborative PRPs with core decision templates, which provide (i) relevant information on customers-in-context, and (ii) corresponding guidelines that relevant stakeholders co-create to collaboratively improve the underlying PRPs. The core decision templates are formulated such that their (semantic) *content* builds on the results of user feedback analysis with SFO from Soft Reliability, and their (syntactic) *structure* is based on cDSP templates (e.g. their hierarchical and composition capabilities). Partial application of method is demonstrated through two industrial cases. Complete verification and validation are also realized, on both theoretical/empirical and structural/performance grounds, through the Validation Square construct [28], but have not been included in this paper.

Future work involves complete integration of the SFO analysis with cDSP templates through the joint implementation of the two in an industrial setting. Additionally, there are many interesting open questions for further research, as hinted at various places in this paper, e.g., demonstrating hierarchical and composition capabilities of cDSP templates instantiated with SR information from various data resources, developing NFF prediction mechanisms, comparing and contrasting analysis findings from different countries to monitor product and process trends over time.

Successful development of innovative products is somewhat paradoxical: Rich insights are needed into how new technology transforms the design space early in the development of a product. However, the impact of new technology cannot be foreseen until it is fully incorporated in the specific ecology of values and activities of its users, hence the increasing NFF problem. We envision that our approach can help academics as well as practitioners to gain a competitive edge in establishing successful innovations especially in value-rich contexts.

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REFERENCES

1. Ouden, E. d., Lu, Y., Sonnemans, P.J.M., Brombacher, A.C., “Quality and Reliability Problems from a Consumer’s Perspective: An Increasing Problem Overlooked by Businesses?” Quality and Reliability Engineering International, Wiley InterScience, 22(7): 821-838.

2. Brombacher, A.C., Sander, P.C., Sonnemans, P.J.M., Rouvroye, J.L., 2005, “Managing Product Reliability in Business Processes 'Under Pressure',” Reliability Engineering and System Safety, Elsevier, 88(2): 137-146.

3. Overton, D., “”No Fault Found” Returns Cost the Mobile Industry $4.5 Billion per Year,” WDS Global Media Bulletin, July 2006 issue, (http://www.wdsglobal.com/news/whitepapers/20060717/20060717.asp).

4. Koca, A., Brombacher, A.C., 2008, “Extracting "Broken Expectations" from Call Center Records: *Why* and *How,”* CHI '08 Extended Abstracts on Human Factors in Computing Systems, Florence, Italy, ACM Press, 2985-2990.

5. Maier, J.R.A., Fadel, G.M., 2001, “Affordance: The Fundamental Concept in Engineering Design,” ASME

Design Theory and Methodology Conference, Pittsburgh, PA, ASME DETC01/DTM-21700.

6. Maier, J.R.A., Fadel, G.M., 2002, "Comparing Function and Affordance as Bases for Design," ASME Design Theory and Methodology Conference, Montreal, Canada, ASME DETC02/DTM-34029.
7. Maier, J.R.A., Fadel, G.M., 2003, "Affordance-Based Methods for Design," ASME Design Theory and Methodology Conference, Chicago, IL, ASME DETC03/DTM-48673.
8. Maier, J.R.A., Fadel, G.M., 2005, "A Case Study Contrasting German Systematic Engineering Design with Affordance Based Design," ASME Design Theory and Methodology Conference, Long Beach, CA, ASME DETC05/DTM-84954.
9. Green, M.G., Linsey, J.S., Seepersad, C.C., Wood, K.L., Jensen, D.J., 2006. "Frontier Design: A Product Usage Context Method," ASME Design Theory and Methodology Conference, Philadelphia, PA, ASME DETC06/DTM-99608.
10. Lin, J., Seepersad, C.C., 2007, "Empathic Lead Users: The Effects of Extraordinary User Experiences on Customer Needs Analysis and Product Redesign," ASME Design Theory and Methodology Conference, Las Vegas, NV, ASME DETC07/DTM-35302.
11. Jordan, P. W., 2000, Designing Pleasurable Products, Taylor & Francis, London.
12. Nagamachi, M., 1995, "Kansei Engineering: A New Ergonomic Consumer-Oriented Technology for Product Development," International Journal of Ergonomics, 15: 3-11.
13. Galvao, A.B., Sato, K., 2005, "Affordances in Product Architecture: Linking Technical Functions and Users' Tasks," ASME Design Theory and Methodology Conference, Long Beach, CA. ASME DETC05/DTM-84525.
14. Bly, S., Schilit, B., McDonald, D.W., Rosario, B., Saint-Hilarie, Y., 2006, "Broken Expectations in the Digital Home," CHI '06 Extended Abstracts on Human Factors in Computing Systems, Quebec, Canada, ACM Press, 568-573.
15. Kano, N., Seraku, N., Takashi, F., Tsuji, S., 1984, "Attractive Quality and Must-Be Quality," The Journal of Japanese Society for Quality Control, 14(2): 39-48.
16. Bruin, J. de, Lausen, H., Polleres, A., Fensel, D., 2006, "The Web Service Modeling Language WSML: An Overview," (Y. Sure and J. Domingue, Eds.), ESWC, Vol. 4011 of LNCS, Springer, 590-604.
17. Koca, A., Brombacher, A.C., 2008, "User-Centered Analysis of Feedback Operations for Quality Improvement in New Product Development," International Annual EurOMA Conference, Groningen, The Netherlands, EIASM.
18. Krippendorff, K., 1989, "On the Essential Contexts of Artifacts or on the Proposition That 'Design is Making Sense (Of Things)'," Design Issues, 5(2): 9-39.
19. Bouwmeester, den K., Bosma, E., 2006, "Phases of Use: A Means to Identify Factors that Influence Product Utilization," CHI '06 Extended Abstracts on Human Factors in Computing Systems, Quebec, Canada, ACM Press, 117-122.
20. Koca, A., Schouwenaar, A.J.M., Brombacher, A.C., 2007, "Field-Feedback in Innovative Product Development: A Comparison of Two Industrial Approaches," International Product Development Conference, Porto, Portugal, EIASM, 657-668.
21. Koca, A., Funk, M., Karapanos, E., Rozinat, A., Gaarden, N.v.d., 2008, "Grasping Product Pragmatics: A Case with Internet on TV," International Conference on Designing Interactive User Experiences for TV and Video (uxTV '08), ACM Press, 193-202.
22. IRIS coding, URL: http://www.eicta.org/index.php?id=37. Latest access: January 2009.
23. Panchal, J.H., Fathianathan, M., 2008, "Product Realization in the Age of Mass Collaboration," ASME Design Automation Conference, New York, NY, ASME DETC08/DAC-49865.
24. Panchal, J.H., Fernández, M.G., Paredis, C.J.J., Mistree, F., 2004, "Reusable Design Process Modeling via Modular, Executable, Decision-Centric Templates," AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference, Albany, NY, AIAA-2004-4601.
25. Schnell, A.R., Messer, M., Panchal, J.H., Allen, J.K., Hesketh, P.J., Mistree, F, 2006, "Extending Reusable, Decision-Centric Templates to Facilitate Collaboration Using Game Theory," AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference, Portsmouth, VA, AIAA-MAO-63412.
26. Mistree, F., Hughes, O.F., Bras, B.A., 1993, "The Compromise Decision Support Problem and the Adaptive Linear Programming Algorithm," Structural Optimization: Status and Promise, Washington, D.C.: AIAA, 247-286.
27. Seepersad, C.C., Mistree, F.M., Allen, J.K., 2005, "Designing Evolving Families of Products Using the Utiliy-Based Compromise Decision Support Problem," International Journal of Mass Customisation, Inderscience, 1(1): 37-64.
28. Seepersad, C.C., Pedersen, K., Emblemsvag, J., Bailey, R., Allen, J.K., Mistree, F., 2006, "The Validation Square: How does One Verify and Validate a Design Method?," Decision Making in Engineering Design, (K.E. Lewis, W. Chen and L.C. Schmidt, Eds.), ASME Press, 305-326.
29. Soft Reliability, URL: http://softreliability.org/

