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"PRODUCT IN-USE" INFORMATION FOR ENGINEERING DESIGN ACTIVITIES

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1. Introduction

In the past, Original Equipment Manufacturers (OEM) focused on satisfying consumers' needs through the one-off sale of products. While product performance and reliability are important customer requirements, maintenance and repair activities were not considered the OEM's prime responsibility. In recent years, however, OEMs have begun to recognize that by providing a service associated with their product, they can better meet consumers' long term needs. For example, aircraft engine manufacturers lease their products on a "power by the hour" basis [Jagtap 2007a]. In other words, the perceived value is no longer the product itself, but the customer's utilization of the product [Mont 2000]. This paradigm, sometimes referred to as "lifetime service" or the "extended product" [Saaksvuori & Immonen 2004], allows for the added value of providing customer specific services along with the traditional tangible product. It is also referred to as the buying or selling of "capability". This change in strategy has brought with it the added responsibility of ensuring continuous product performance, so that companies must now offer sustainment (i.e. maintenance and repair) services.
Within this new framework, manufacturers have an increasing interest in minimizing the need for sustainment or ongoing support activities once a product has been put into service. A common strategy is for an OEM to develop methods allowing for earlier prediction, identification, tracking and resolution of performance issues once the product is in the customer's hands [Takata *et al*. 2004]. However, OEMs are in a position to eliminate many potential problems during the product development phase. Substantial savings can be made by identifying possible problems earlier in the lifecycle, such as at the design stage, rather than correcting them once the product is in-service [Herrmann *et al*. 2004]. Design changes can then be implemented that either eliminate the problem or facilitate necessary service and maintenance activities. Furthermore, by identifying and correcting possible performance issues early in the development process, the time between the completion of the detailed design and product launch, sometimes known as "fix up" time, can be substantially decreased [Ward 2007]. Companies therefore need to develop different strategies which facilitate the early identification of these performance issues.
Previous research has suggested this could be facilitated by the feedback of information from maintenance personnel to designers [Takata *et al*. 2004]. Jagtap *et al*. [2007a] have recently termed this in-service information. However, information concerning product failure can also be obtained from the results of testing and prototyping during product development [Ward 2007, Wasserman 2002]. Therefore, this paper introduces the term "product in-use" information, which takes a much wider view and can be defined as *all information collected throughout the lifecycle concerning product performance during use*. Possible sources may include, but are not limited to, information gathered from functional prototyping, product testing and in-service experience.

The broad objective of the current research is to identify the most appropriate methodology, information structure, and technology to ensure the efficient feedback and reuse of "product in-use" information within engineering design. The goal of this paper is to put this project in context with respect to current research, explain the challenges to be overcome, and describe the foreseen benefits. In section 2, the role of information feedback in design, as well as processes facilitating feedback, will be further described. Section 3 will explore the contents and structure of "product in-use" information, as well as its current role in engineering design. Section 4 will present a proposal for a "product in-use" information framework, and section 5 will elaborate the methodology to be used in this research project.

2. Information feedback in design

A necessary aspect of a successful Product Development Process (PDP) is the exchange of information between the various stages of the entire product lifecycle. Typically, downstream information flow (i.e. to a subsequent stage in the lifecycle) is widely supported by current engineering tools and methodologies. However, feedback from downstream operations to the design team is not formally supported by these various information management systems. This feedback can be defined "*as an evaluative or corrective flow of information in response to a particular event, process, activity or system*" [Fortin *et al.* 2007]. In figure 1, the extended product lifecycle is shown, including the flow of information from the in-service phase to the product development phase. Early in each stage, preliminary information is passed to the next stage, allowing for concurrent workflow. This is followed by a continuous flow of uncertain information, including feedback from the subsequent phase. At the end of each phase the completed, formalized information is transferred to the next stage, allowing for its completion. Note that information flows from in-service and testing will be dealt with in more detail later in this paper.

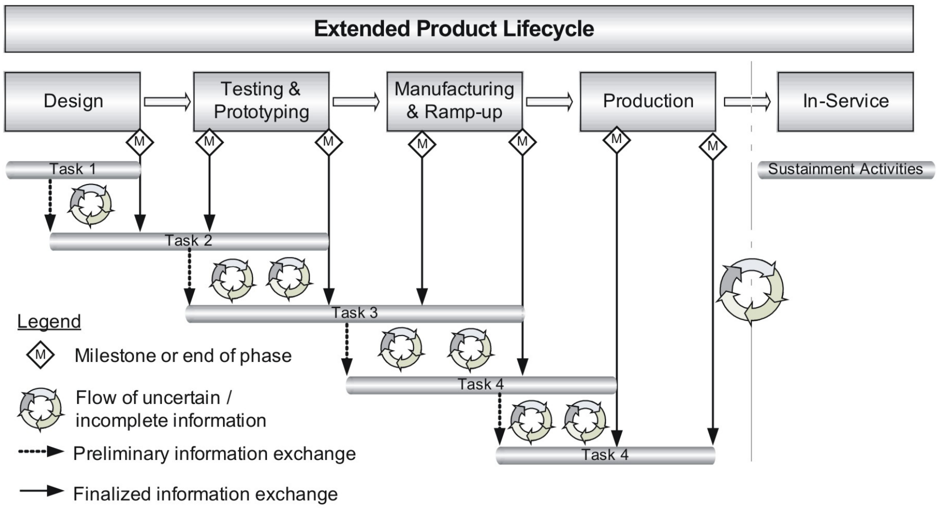

Figure 1. Information flow throughout the product lifecycle

One of the goals of this research is to facilitate the feedback of "product in-use" information to designers. As previously noted, this includes all information collected throughout the lifecycle concerning product performance during use. It is possible for a feedback process to be classified with respect to the level of formality with which it's communicated [Fortin *et al.* 2007]. For example, informal information is expressed by means of conversation or e-mails, and contributes to the daily progression of a product's development. Semi-formal information is transmitted by such measures as change requests and design reviews, and plays a key role in the progression of a project though the stage gate process. Information can be considered formal when it takes the form of design guidelines or knowledge management databases, referred to as lessons learned or best practice systems. This typically describes the knowledge acquired from previous projects.

While there are currently feedback mechanisms for certain elements of the "product in-use" information spectrum, these can take various forms and it is unclear whether they are necessarily the most suitable ones possible. For example, the communication of test results to designers is a well defined process and is typically communicated through semi-formal processes such as reports. In-service information, on the other hand, can be communicated through informal means such as discussions with in-service personnel. In order to ensure that this information is exploited to its full potential and can be reused in future projects, it is proposed to integrate it within a formal feedback process managed by PLM technology. This is not to say that informal and semi-formal feedback process should be eliminated, as they are necessary to ensure flexibility and creativity within the development process. However, unless this information is described in explicit terms so that it can be retained and properly used in design activities, the feedback process will rely entirely on potentially unreliable communication, leading to time wasted by repeating past errors.

In addition, if the information feedback is not controlled to a certain degree, it can lead to potentially productive feedback having disruptive consequences on the design process. Examples of productive and disruptive feedback are shown in figure 2.

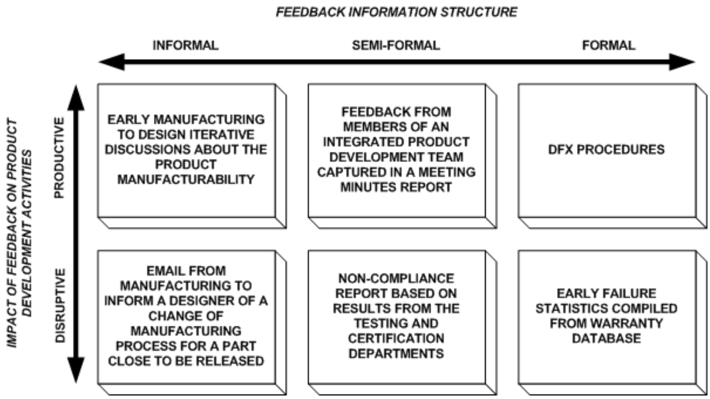

Figure 2. Examples of feedback information structures and their impact on product development activities [Fortin *et al.* 2007]

As explained by Fortin *et al.*, "productive" feedback can be seen as a flow of information that ultimately results in an improvement in the cost, time or quality of the adopted solution; in essence, it is a type of feedback that adds value to the product. The cost, time and quality evaluative criteria are interrelated in many ways, and a negative effect for one of these will often result in unforeseen changes which disrupt the normal product development process. Therefore, a "disruptive" feedback is a flow of information that results in a deterioration of at least one of the evaluative criteria of cost, time, and quality. It is important to note that feedback communicated informally is hard to classify as productive or disruptive, but in the proposed framework the information will be systemically formalized so that all stakeholders are informed of product performance issues and can take appropriate measures.

One technique to ensure "product in-use" feedback from past projects is productive is to integrate it early in the development of a new product when there is enough flexibility to use the new information without incurring the costs or delays associated with rework. By ensuring that "product in-use" information is collected and fed back on a regular basis and in a formal manner, it will be available to designers in a useable format early enough to add value to the design process, rather than disrupting it [Ward 2007]. It is possible that problems will be identified through later testing or shortly after product launch; however the suggested feedback process should minimize these late stage errors.

Furthermore, any information regarding emergent problems will be collected and made available during the development of future products, serving as productive feedback.

3. "Product in use" Information

As previously stated, "product in-use" information is derived from various sources, including functional prototyping, product testing and in-service experience and concerns product performance during use. This information type consists of data such as failure rates and modes, life cycle costs, etc. which are connected through their association to a specific product or type of product, as well as the conditions or environment in which the product is used. Since this term is being introduced for the first time, this section of the paper will give a more detailed explanation of the possible sources of this information as well as characterizing it according to accepted standards.

3.1 Prototyping and testing as a source of "product in-use" information

The first source of "product in-use" information is from prototyping and testing. Eppinger and Ulrich [2000] identify two testing phases, alpha and beta. Alpha testing is conducted on a prototype that is geometrically identical to the intended product, but is manufactured using different techniques. This testing typically is done in-house and is focused on determining whether the product as designed will meet customer specifications. The beta prototype is produced later in the PDP using the intended manufacturing process, but preliminary assembly techniques. This prototype is submitted to more extensive in-house testing as well as customer testing in the intended use environment. However, the information gained typically remains restricted to evaluation of the products ability to meet narrow customer specifications. Considering that it can cost up to $350 000 to create a prototype of a single automobile cockpit, it is important that as much information as possible be extracted from the testing [Wasserman 2002]. Ward [2007] suggests that Toyota offers a superior strategy of "testing to failure", and identifies this as a key step in lean product development. While testing to specification only allows the validation of a product in a certain use case, testing to failure allows a full characterization of potential failure modes. Lean product development, as practiced by Toyota and formalized by Ward [2007], also includes a higher than average number of initial prototypes, allowing for the characterization of a wide range of design options. This is a core aspect of set-based design, in which multiple concepts are examined and eliminated through an aggressive testing process [Liker *et al.* 1996]. Eventually this is narrowed to one concept which is then carried forward to completion. This is quite different from traditional point-based design methodology, known where a single concept is chosen early in the PDP and later refined through iteration [Liker *et al.* 1996].

3.2 In-service as a source of "product in-use" information

The second source of "product in-use" information for product design is in-service information feedback. Takata *et al.* [2004] and James *et al.* [2002] recognized that in addition to facilitating maintenance activities, information routinely collected by in-service personnel concerning product performance could be useful in the design process. However, their recommendations were limited to the creation of a shared database for use by the in-service and design departments. Petkova *et al*. extended this idea further by suggesting that in-service information could also play a role in the design of testing procedures to better replicate actual use conditions. Kraniak and Ammons [2001] have linked the in-service information database of Hydromat Corporation with the commercially available reliability and maintenance analysis software Relex. By using the same information structure in both the database and the analysis software, the information is made available for the appropriate R&M, FMEA and Life Cycle Cost analyses at both the component and assembly levels. However, this information is not linked to a product structure outside of the analysis software, and so cannot be considered part of a fully functional PLM system.

Recently, Jagtap *et al*. [2007a, 2007b] have conducted studies concerning in-service information within the aerospace field, with specific focus on engine manufacturers. This research includes the most thorough characterization of in-service information to date, as well as identifying the current obstacles to its efficient use in product design. Specifically, they have identified the needs of designers with respect to in-service information, as well as the information currently available from field personnel and the aftermarket service team. By comparing the two, they have determined which information is seen as most critical by designers, and which information is lacking in order to design more reliable products. Although Jagtap [2007a] identifies verbal communication with the design for service team as a valuable information source, a means must be determined to capture this information in a more stable format, such as through meeting minutes or reports.

4. Research Methodology

The overall methodology can be considered to be of a descriptive nature using a controlled study at the École Polytechnique de Montréal (Canada) and possible industrial case studies in the aerospace sector. The role of these studies is to assist in answering the questions set out in the project description, concerning the collection, integration and application of "product in-use" information. The project will also be completed with the collaboration of the Innovative design & Manufacturing Research Centre (IdMRC) of the University of Bath (UK), which will provide extensive experience in the research of engineering information and knowledge management. The complete list of steps has been summarized in table 1.

Table 1. Project stages

Project Stage	Focus
Literature Review	Current research perspectives
Controlled study of aircraft pylon	Utility of reliability & risk assessment and PLM tools
Study of general role of "product in-use" information in an industrial setting	Information flow, content and access
Study of "product in-use" information in the design of a specific product	Design tools and methodologies Designer perspectives
Revision and evolution of initial methodology	Application of methodology in an industrial PDP

The study at École Polytechnique de Montréal will be based on the Virtual Environment Project: a simulation of an industrial project which consists of the design of an aircraft pylon, including a complete mock-up with related design and manufacturing information. Initially, this will be a preliminary study based upon the experiences of the trainee engineer team. Later, it will re-examined in light of information gained from an industrial setting. The study will begin with FMEA and FTA analyses of a critical subassembly, the results of which will be integrated in a PLM tool. It then will be determined whether the previous analyses can be supplemented with additional "product in-use" information or could benefit from the use of additional types of analysis.

This controlled study will be used as a basis for discussion with an industrial partner concerning "product in-use" information feedback in the context of product design. As part of the industrial case study proposed, the processes currently used for "product in-use" information feedback will be identified. Specific focus will be placed on the content and format of the "product in-use" information available within the company and how it is integrated into the PDP. This will include the utility of the information within the design process and the tools used by designers when applying this information. The study will be carried out by means of interviews and discussions with the stake holders involved, namely members of the design, testing, prototyping and in-service teams. Part of this work will be based on Jagtap et al. [2007a] who have already identified the typical in-service information requirements of designers. This study will be of a descriptive nature using a naturalist observe strategy consisting of both an analysis of "product in-use" information already collected by the company, as well as discussions with designers, reliability and test engineers, and members of the in-service department.

The mechanisms for "product in-use" information feedback identified in this study will then be compared to methodology used in the initial controlled study, as well as those mechanisms identified through the literature review. A new methodology will then be created and reapplied to the initial study. The results of the studies will then be compared and analyzed in order to identify the value of the changes, and possible areas for further improvement. As this part of the project involves the study of the effects of a novel design methodology, it can be considered to be of prescriptive nature [Huet 2006]

5. Proposal for a "product in-use" information management framework

While this project is still in a preliminary stage, it is still possible to propose an outline for a new "product in-use" information management framework, as shown in figure 3. Typically, information is created at each stage of the product lifecycle, and stored for later use. However, while there is information transfer between the lifecycle stages, it is usually informal and the databases from one stage are not easily accessible by stakeholders at other stages. This is especially true for in-service information, and to a slightly lesser degree testing and prototyping information. Furthermore, the reuse of this information by designers during the development of later products is limited due to the current difficulties in accessing relevant information from testing, prototyping and in-service information databases. Therefore a framework is proposed as shown in figure 3, where relevant information would be drawn from testing, prototyping and in-service databases and stored in a "product in-use" information database for use by designers. The content and format of this information would be aimed specifically at the needs of designers. The information would then be accessible for later projects (e.g. product 2 in figure 3). The likely content and format and a possible interface with the database are described below.

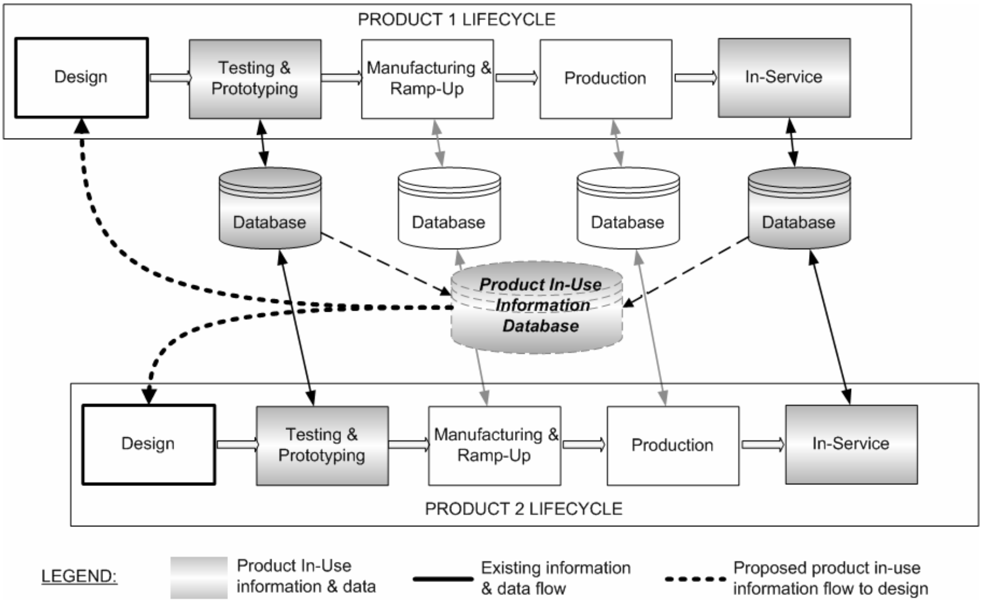

Figure 3. "Product in-use" information management framework

More and more frequently, designers rely on engineering software and information systems such as Computer Aided Design (CAD) packages and Product Data Management (PDM) systems. The integration of all these tools for the sharing of data and information between partners, clients and suppliers in a virtual product development environment is referred to as Product Lifecycle Management (PLM). As such, a reasonable proposal is that the information would be stored in a database linked to a PLM environment. This information would also need to be associated to specific components or assemblies (either standard or proprietary), and as such would be linked to any instances used within an OEM's product family.

The exact format of this information will depend on further research, but reasonable suggestions are the trade-off curves used in lean development [Ward 2007], failure modes along with causes and effects as used in FMEA, contextualized numerical data concerning failure rates and/or lessons learned and best practices. As a product is designed, the information associated to its various components would be assembled into an appropriate prediction of actual product performance. This prediction would then be supplemented as necessary with new information concerning the expected performance of novel product components. It is expected that by facilitating this analysis, designers will be able to perform a more robust determination of product performance earlier in the lifecycle, cutting down on possible disruptive feedback later in the development process.

An example of how this system could work can be drawn from the aerospace industry. Consider a clamp used to dampen the vibrations in a fuel line due to engine vibration. Initially, a series of tests will be carried out to determine the magnitude of the vibrations in question and to select an appropriate clamp, the results of which are stored in the proposed database. However, it is possible that the actual vibrations once the aircraft is in service are greater than expected. This may result in the loosening of the clamp and more rapid wearing of the fuel line. Service personnel would then modify the maintenance plan, shortening inspection times and possibly time to replacement. This information would also be stored in the "product in-use" information database. When designers come to design the next generation pylon, this information would be available to them, as well as the results of the previous tests. This information will allow for a more efficient resolution to the design problem than would otherwise be possible. As well as facilitating information storage and access to designers, the system would have to manage the filtering, formatting and grouping of information. As explained above, the numerous information sources are varied in content and format. Designers must be provided with information pertinent to a particular task, in this case the selection of an appropriate clamp.

6. Conclusions

While "product in-use" information is currently used to some extent to optimize the product lifecycle, it is not managed in a way that exploits it to its full potential. In particular, the consideration of all the stages and all the elements in an integrated manner has not been considered. By assembling the output of all the "product in-use" information sources (section 3.1) within a coherent database and enabling its management through PLM strategies, designers will be able to more efficiently apply the information in the design of new products. This would save costs during the provision of aftermarket services, decrease the rework time necessary in the PDP and increase overall customer satisfaction by providing more reliable products. However, a significant challenge will be the creation of a consistent database containing information from disparate sources, such as statistical information, trade-off curves, failure modes and lessons learned. This information must be collected from various stakeholders and then filtered and formatted so that the "product in-use" information that reaches designers is pertinent to their particular needs.

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