In-Service Information Required in a Redesign Task: An Analysis of Documents from the Aerospace Industry

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IN-SERVICE INFORMATION REQUIRED IN A REDESIGN TASK: AN ANALYSIS OF DOCUMENTS FROM THE AEROSPACE INDUSTRY

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This research was undertaken in an aerospace company, which manufactures aero engines and also offers contracts, under which it remains responsible for the maintenance of engines. These contracts allow the company to collect far more data about the in-service performance of their engines than was previously available. This paper aims at understanding what parts of this in-service information are accessed when components or systems of existing aero engines need to be redesigned, because they have not performed as expected in service. In an attempt to address this aim, five case studies involving the redesign of components of an aero engine are examined. The redesign is based on the in-service experience of the existing components. The findings provide an understanding of the different types of information, and in particular the types of in-service information, accessed by designers in a redesign task.

Keywords: Information types, In-service information, Aerospace engineering, Knowledge management, Redesign, Document analysis.

1. INTRODUCTION

Research in engineering design is motivated by the challenges that current manufacturing organizations are facing, and these challenges emerge from the development of a global market economy and increasing competition. Recently, a shift in business models from the selling of products to the provision of services is becoming noticeable [1]. In the case of mature products, this shift is driven by increasing competition and need to establish long-tem relations with customers. Such shifts in business models influence design of products. Since design is an information-intensive activity [2–4], this has a consequent impact on the types of information required and accessed by designers.

In the field of engineering design research, several studies focusing on the engineering information issues (such as designers' information-seeking practices, designers' accessing and retrieval of information from paper-manuals and electronic systems) have been undertaken in an industrial environment [5–9]. However, these studies do not focus on a specific type of information, for example, in-service information. This paper aims at understanding what in-service information is accessed by designers in the redesign of components or systems of existing aero engines. In-service information is the information on product and support services such as repair, overhaul, etc., and is generated after the product's entry into service. In an attempt to address the above aim, five case studies involving the redesign of components or systems of existing engines are examined.

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The outline of the paper is as follows. Section 2 presents the selection of the research method, the data collection method, and the method of data analysis. The findings of the analysis are presented in Section 3. Finally, Section 4 sets out the conclusions.

2. REDESIGN CASE STUDIES

2.1. Selection of the research method

Five case studies involving the redesign of components in an existing aero engine, based on their in-service information, were carried out. Redesign case studies were selected because the redesign was mainly based on the in-service experience, and this helped us to examine a large amount of in-service information. These case studies were aimed at seeing what in-service information was accessed by the designers in those redesign tasks.

Several studies [10–13], regarding designers' information requirements or their information-seeking activities, have been carried out in laboratory settings with experienced designers or students. Although the findings of these studies provide insights into the information requirements of professional designers, they do not necessarily reflect the actual information requirements of professional designers working in a company which operates in a competitive environment.

An alternative way to identify all pieces of in-service information accessed and used by the designers is to observe them throughout the design process. This type of study is hard to conduct in an industrial environment for the following reasons: (1) it is difficult to anticipate when the designers will access and use in-service information on a given day; and (2) the time-spread of the redesign task can be several months, and gaining access to the designers for this amount of duration is difficult.

Therefore, we examined the Design Definition Reports (DDRs) from the collaborating aerospace industry. These DDRs summarise the design changes made during a redesign task, and are written retrospectively by the designers themselves. The diary notes taken throughout the design process assist the designers in documenting a DDR.

The following positive aspects of document analysis are also applicable to the analysis of DDRs: (1) document analysis is a non-reactive method: that is, using documents does not have an effect on the thing you are studying [14]; (2) it saves time on the part of the company employees; and (3) there is no transcription burden.

Two of the main limitations of the analysis of the DDRs are as follows. Firstly, they are written by the designers themselves. It is likely that they might forget to document some information in a DDR. However, the diary notes taken through the design process help the designers in documenting a DDR, and minimise the likelihood of omitting any important information. Secondly, documents are written for many purposes, and may not include a researcher's purpose [14]. It was necessary to contact the designers and service engineers when we found any unfamiliar terms or concepts.

2.2. Data collection method

A DDR is structured in three main sections: (1) Specification Requirements — this section describes the in-service experience of version-1 (the component before re-design) and the requirements for version-2 (the component after re-design); (2) Alternative Solutions — describes the different alternative solutions; and (3) Solution Description — describes the various decisions made in the actual design changes, and the rationale behind these decisions.

Semi-structured interviews were also conducted with service engineers and designers. The explanations provided during these interviews helped us to understand further details about the in-service experience of version-1, and the design changes carried out on version-1 to obtain version-2. In addition to the above, all relevant documents containing the in-service experience of version-1 were collected.

In selecting the five case studies, attention was directed to cover different modules of an aero-engine (see Table 3.1.). Two components were selected from combustors, and one from each of the other assemblies, namely turbines, compressors, and transmissions. Due to our confidentiality

Table 1. Case study components and engine assemblies.

Component	Engine assembly
Burner seal	Combustor
Combustion liner inner wall	Combustor
Low pressure turbine blade damper	Turbine
Lockstrap	Compressor
Front bearing housing rear panel	Transmissions

agreement with the collaborating company, the components' details such as their structure, the in-service experience of version-1, and the design changes, cannot be presented in detail.

2.3. Method of analysis

In this research, individual sentences of the DDR were used as segments, for the following reasons: (1) it seemed appropriate for a document that is created by the designers retrospectively, after completion of the redesign task; (2) it fulfilled our aim of identifying the in-service information that was accessed by the designers; (3) it helped to objectively maintain consistency in the segmentation process, and to compare the findings quantitatively (e.g. the percentage of sentences under the different topics of in-service information helped to measure the relative frequencies of accessing information under these topics); and (4) It helped to achieve the sufficient degree of detail in our analysis. This degree of detail, for example, would have been unlikely to attain by using paragraphs of the DDRs as segments.

The coding scheme consisted of labeling each sentence with the relevant categories, as discussed later in this section. For example, as the research focus is on the in-service information requirements of designers, 'in-service information' was one of the categories. Thus, whenever the designers appeared (based on our interpretation of a DDR's content) to be accessing the in-service information, the relevant sentence was marked with that category.

The context in which the sentence appeared played an important role in the coding process. The following items helped to establish the context: (1) the paragraph in which the sentence was embedded; (2) the previous and subsequent paragraphs; (3) the section of the DDR; (4) any additional explanations provided by the designers and service engineers during the semi-structured interviews.

As the coded data was concise, it was easy to handle for answering the research questions. In addition, the designers' in-service information requirements could be quantitatively observed. The findings are presented in terms of the different categories. Figure 1 explains the steps involved in

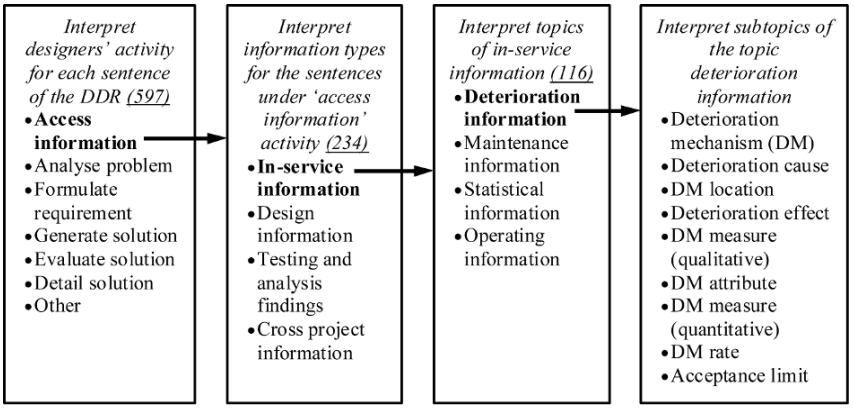

Figure 1. Steps in the coding process. Notes: (1) The bulleted lists show the outputs of the coding process; (2) The underlined numbers in brackets show the number of sentences (e.g. for 234 sentences under the 'access information' activity, we interpreted information types).

the coding process and the outputs of these steps. For each sentence of the DDR, designers' activity was interpreted. As shown in Figure 1, these activities are 'access information', 'analyse problem', 'formulate requirement', 'generate solution', 'evaluate solution', 'detail solution', and so on. All sentences under the 'access information' activity were selected, and for these sentences the information types were interpreted. Different topics (e.g. 'deterioration information', 'statistical information', etc.) were interpreted for the sentences that were classified under the in-service information type. The topic 'deterioration information' was further classified into different subtopics (e.g. 'deterioration mechanism', 'deterioration effect', etc.) because deterioration information plays an important role in redesign, and this is clear from the findings of our analysis. These findings are presented further in this paper. We could not explain the outputs of the coding process due to the limitation on the number of pages.

The different categories, which are the outputs of the coding process, evolved during the analysis. After reading a sentence and understanding the context, the sentence was categorised under the current categories if possible. Sometimes, the current categories required refinement or clarification of their meaning before a sentence could be categorised. New categories were created when a sentence could not be categorised under the existing set of categories.

We used Cohen's kappa coefficient of reliability (described in Bakemann and Gottam, 1997) to test the reliability of our coding process. 50 sentences from a randomly selected DDR were coded to identify designers' activity (e.g. access information, analyze problem, etc.) by two people — the researcher and one coder. Prior to this coding, the coder was explained different activities of designers with examples. The coder read the complete DDR before coding the given 50 sentences. The kappa coefficient calculated was 0.85. This indicates high inter-coder reliability.

3. FINDINGS

The collective findings of the five case studies are presented.

3.1. Activities

In total, 597 sentences were identified in the five DDRs. Figure 2 shows the distribution of these sentences under the three sections of the DDR. The Solution Description (SD) section includes slightly less than one half of the sentences. About one fourth of the sentences are identified in the Specification Requirements (SR) and Alternative Solutions (AS) sections of the DDR.

Figure 3 shows the percentage of sentences classified into the different activities. Figure 4 shows the percentage of sentences for different activities found in the three sections of the DDR.

Figure 4 shows that the main activities of the designers seen in the SR section are 'access information', 'analyse problem', and 'formulate requirement'. The prominent activities interpreted in the AS section of the DDR are 'generate solutions', and 'evaluate solutions'. In the case of SD, the prominent activities are 'evaluate solution' and 'detail solution'. The activity 'detail solution' encompasses defining the arrangement of components and specifying materials, geometrical shapes, dimensions, manufacturing processes, etc. Pahl and Beitz (1996) state that, in the task clarification phase, information on the problem is collected, the problem is analysed, and design specifications

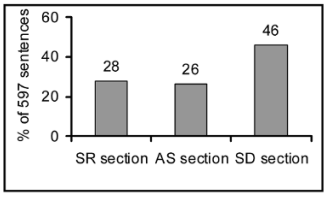

Figure 2. Percentage of 597 sentences for the different sections of the DDR.

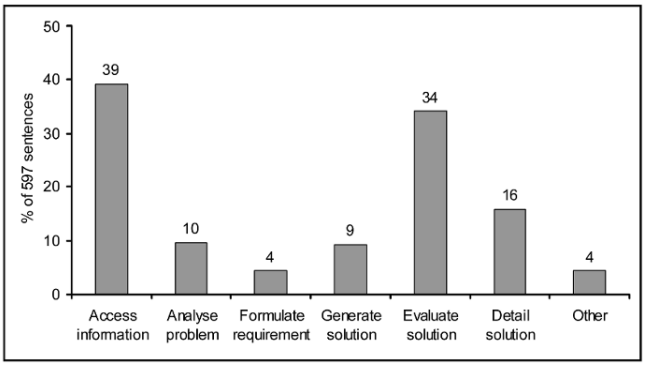

Figure 3. Percentage of the 597 sentences classified into the different activities. *Note*: In the case of some sentences, more than one activity was noticed. Therefore, the total of all percentages (39+10+4+9+34+16+4) is greater than 100.

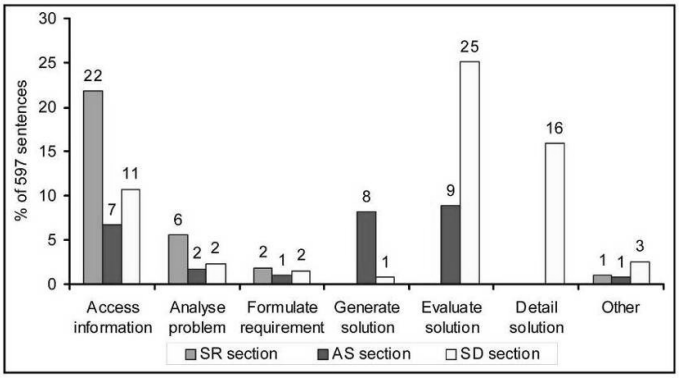

Figure 4. Activities identified in the different sections of the DDR (percentage of sentences based on 597 sentences in the DDRs).

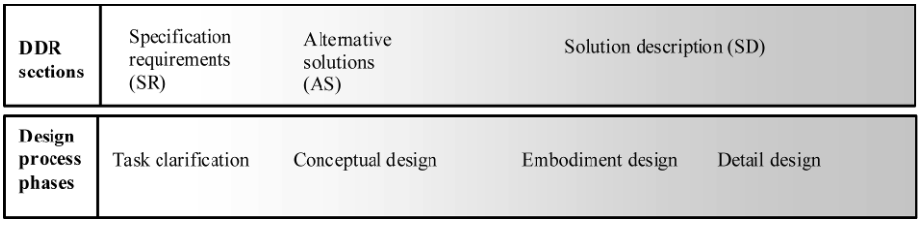

Figure 5. DDR sections provide insight into the different design process phases proposed by Pahl and Beitz [3].

are formulated. In the conceptual design phase, broad solutions are generated and evaluated. In the embodiment phase the layout of the assemblies and components are outlined and in the detail design phase, dimensions, tolerances, materials, surface properties, etc. are fully specified. This suggests that the SR, AS, and SD sections of the DDR provide an insight into the task clarification phase, conceptual design phase, and embodiment and detail design phase respectively (see Figure 5). The designers have a similar view regarding the DDR.

The following points can be noted from Figures 3 and 4.

The major share of the sentences is devoted to the activities 'access information' (39%) and 'evaluate solution' (34%).

The 'access information' activity is identified in all the three sections of the DDR. The sentences that are classified under the 'access information' category are analysed in detail to identify the different information types. Therefore, this analysis covers the complete spectrum of the different phases of the design process.

Sentences corresponding to the activities 'analyse problem' and 'formulate requirements' are identified in all the three sections of the DDR.

All activities are seen in the SD section of the DDR. This may either be because this section consists of about one half of the total number of sentences, or because it is a characteristic of the embodiment and detail design phases.

3.2. Information types

In total, 234 sentences were identified under the 'access information' activity. The designers have used different sources such as documents, electronic databases, communication with colleagues, etc. to access information. In the case of some sentences, more than one type of information was noticed. Figure 6 shows the percentage of sentences for the different information types. The in-service information was interpreted when the sentence described or referred to in-service experience, or to the findings of root cause analysis (RCA). The design information was coded when a sentence described or referred to design information, for example, information regarding precedent designs, previous design modifications, design standards, materials data, etc. The cross-project information was coded when a sentence described or referred to the information from another project in the company. The information on testing and analysis findings is interpreted when a sentence described or referred to the findings of testing or analysis (except for the findings of RCA, which are categorised under the in-service information type).

Most of these sentences refer to in-service information (50%) and design information (35%) (see Figure 6). Note that the sentences under the in-service information type include those that describe in-service information from components similar to the one being re-designed. Sentences under each of the information types are noted in all sections of the DDR (see Figure 7). Most of the sentences corresponding to in-service information appear in the SR section. In the case of the design information, the percentage of sentences gradually increases from the SR section to the SD section. This suggests that this specific type of information is more relevant to the later phases of the design process.

From Figure 7 it is clear that, in the case of the SR section, the dominant information type is in-service information. In the same section, the activities 'access information', 'analyse problem' and 'formulate requirements' are seen (see Figure 4). It therefore seems that the in-service information has played a key role in the task clarification stage, i.e. in analysing the problem and formulating requirements.

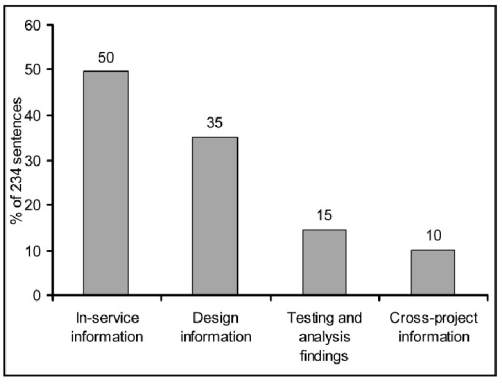

Figure 6. Distribution of the information types (percentage based on the 234 sentences under the 'access information' activity).

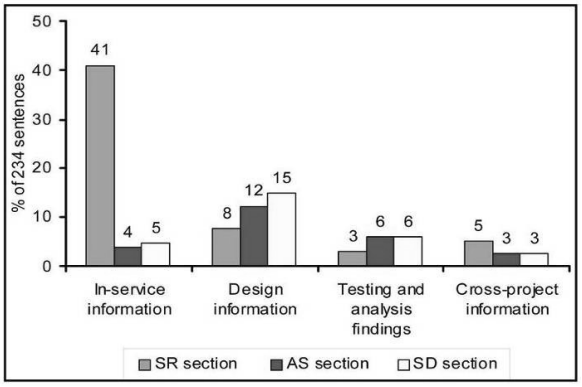

Figure 7. Types of the information in the different sections of the DDR (percentage based on the 234 sentences under the 'access information' activity).

3.2.1. In-service information

Figure 6 shows that one half of the sentences under the access information activity come under the in-service information type. 91% of these sentences are categorised into the 'deterioration information' topic, followed by 'maintenance information' (15%) (see Figure 8). This suggests that the information on the topic 'deterioration information' is frequently accessed by the designers in these redesign tasks.

Figure 9 shows distribution of the different subtopics under the topic 'deterioration information'. The subtopics, — DM, deterioration cause, DM location, and deterioration effect account for over 80% of the sentences under the in-service information type.

These findings are consistent with the expectations of designers, and the experts who deal with the management of in-service information for the designers. This increases our confidence in the method of analysis and the findings.

The sentences that are classified into in-service information type cover those that consider in-service information from components similar to one being re-designed. In total, 12 percent of the sentences under in-service information type take into account such information. It appears that designers have used the type of component as criterion to search for similar components.

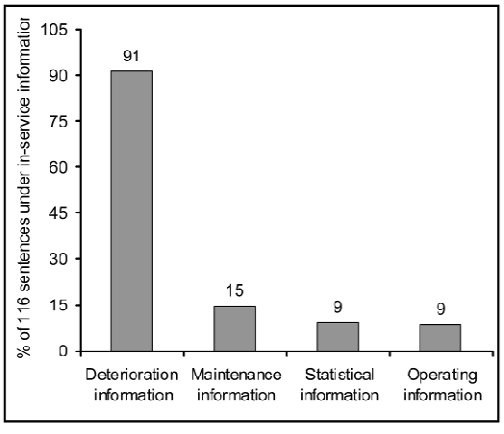

Figure 8. Distribution of sentences under different topics of in-service information (percentage based on 116 sentences under the 'in-service' information type).

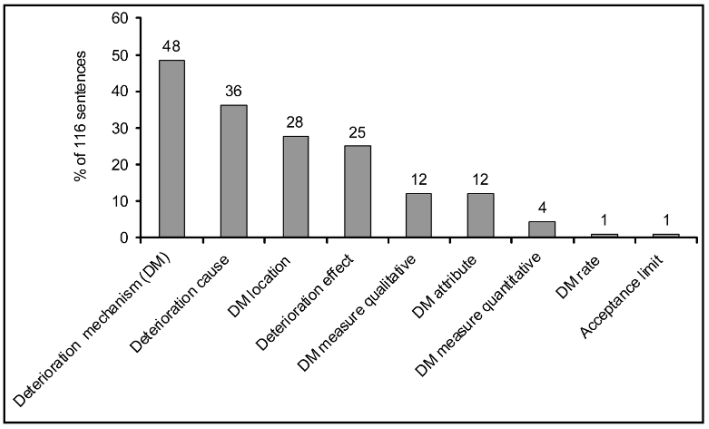

Figure 9. Distribution of the different subtopics under the topic deterioration information (percentage is based on the 116 sentences that are classified under the in-service information type).

4. CONCLUSIONS

Analysis of the DDRs, facilitated by the explanations provided by designers and service engineers, was found to be a pragmatic and useful way to identify the in-service information considered by the designers in the redesign of components or systems of an existing engine. Analysing sentences of the DDRs helped to identify the topics and subtopics of the in-service information that is accessed by designers during redesign tasks.

The important findings of our analysis are as follows.

The SR, AS, and SD sections of the DDR provide an insight into the task clarification phase, conceptual design phase, and embodiment and detail design phases respectively. The activity 'access information' is seen throughout the DDR, and indicates that the analysis covers the complete spectrum of the design process phases.

Half of the sentences under the 'access information' activity belong to the 'in-service information' type. This high usage of in-service information can be attributed to the type of design task studied here, namely redesign aimed at tackling an in-service issue.

It is inferred that the prominent activities of the designers based on the in-service information are 'analyse problem', and 'formulate requirements'.

The designers have mainly accessed in-service information from the topic 'deterioration information'. The subtopics of deterioration information, namely deterioration mechanism, deterioration cause, DM location, and deterioration effect cover the significant proportion of the sentences.

The designers have considered in-service experience of components similar to the one being re-designed.

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REFERENCES

1. Mont, O., C. Dalhammar and N. Jacobsson, A New Business Model for Baby Prams Based on Leasing and Product Remanufacturing. *Journal of Cleaner Production*, 2006. 14(17): 1509–1518.
2. Eder, W.E. Information Systems for Designers. in *Proceedings of the International Conference on Engineering Design*, ICED89. 1989. Harrogate, UK.
3. Pahl, G. and W. Beitz, Engineering Design. 2 ed. 1996, London: Springer-Verlag.

4. Wallace, K.M. and C. Hales. Engineering Design Research Areas. in *Proceedings of the International Conference on Engineering Design*, ICED89. 1989. Harrogate, UK.
5. Aurisicchio, M., Characterising Information Acquisition in Engineering Design. 2005, University of Cambridge, U.K.
6. Court, A., The Modeling and Classification of Information for Engineering Designers. 1995, University of Bath.
7. del-Rey-Chamorro, F., Understanding the process of retrieving information in aerospace design, in Department of Engineering. 2004, University of Cambridge: Cambridge.
8. Hertzum, M. and A.M. Pejtersen, The information-seeking practices of engineers: searching for documents as well as for people. *Information Processing & Management*, 2000. 36(5): 761–778.
9. Marsh, J.R., The Capture and Utilisation of Experience in Engineering Design. 1997, University of Cambridge, U.K.
10. Cross, N., H. Christiaans and K. Dorst, eds. Analysing Design Activity. 1996, John Wiley and Sons Ltd: Chichester.
11. Khadilkar, D. and L. Stauffer, An Experimental Evaluation of Design Information Reuse During Conceptual Design. *Journal of Engineering Design*, 1996. 7(4): 331–339.
12. Kuffner, T.A. and D.G. Ullman, The information requests of mechanical design engineers. *Design Studies*, 1991. 12(1): 42–50.
13. Restrepo, J. and H. Christiaans, Problem Structuring and Information Access in Design. *The Journal of Design Research*, 2004. 4(2).
14. Robson, C., Real World Research: A Resource for Social Scientists and Practitioner-researchers. 2 ed. 2002, Oxford, UK: Blackwell.