Oh My, Where Is the End of the Context? Dealing with Information in a Highly Complex Environment

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ABSTRACT
This paper reports on the preliminary results of a study in information production, transmission, access and use in aerospace manufacturing and maintenance. Multiple techniques were used in order to understand the context in which the information flow takes place. The complexity is such that after several meetings with users the full picture is not fully detailed yet. Previously unknown documents, user roles and tasks continue to emerge while the study progresses. The conclusion is that an iterative approach should be adopted when studying highly complex environments: starting from the broadest view, each cycle progressively focuses on a sub-context to identify important details. Researchers should also keep an open mind as unexpected findings are likely to impacts on the current understanding, i.e. discovering the importance of social networks or physical inspection of the hardware as means to access information.

Categories and Subject Descriptors
H.4.1 Office Automation, J.4 Social and Behavioral Sciences, H.3.5 Online Information Services

General Terms
Documentation, Human Factors

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engineering design, manufacturing and maintenance; user studies

1. INTRODUCTION
Ingwersen and Järvelin (2005) advocate the study of interactive information retrieval in context, thus taking into account cognition, social environment and personal motivations. Only by including the context, they claim, the whole picture can be created and the real meaning of information access fully grasped. However capturing the context can be an overwhelming task when the information access occurs in highly complex environments such as jet engine design, engineering and maintenance. The complexity of the domain affects the data, the tasks and the information flow. Moreover, large organisations have a complex structure and expertise dispersed world-wide. Finally, studying a real context requires the involvement of actual users, i.e. organisation employees, a precious resource available in just a limited amount.

This paper builds upon a study conducted in Rolls-Royce civil aerospace and uses this case to discuss criteria for a selective decomposition of a manageable context. An iterative and multifaceted approach is suggested as the most effective investigation tool as it can be readjusted on the bases of unexpected findings.

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2. THE SCENARIO
The next generation of Rolls-Royce (R-R for short) jet engines are designed for a new business model, i.e. the engine is sold together with a package of services for its maintenance. Jet engines have then to be designed with the aim of minimal disruption at minimised cost (Harrison 2006). Information is fundamental: "At the heart of the Design for Service process is the concept of understanding the engine's deterioration mechanisms, controlling their rate of occurrence and impact, and ensuring effective and low cost restoration of capability at overhaul" (Harrison 2006).

The information produced during the life of a jet engine (regular maintenance and/or detailed inspection) is efficiently used by a limited group of interested parties. However, a more systematic organisation and a wider distribution of information would be beneficial for improving information and knowledge management in R-R; the solution proposed is a desktop system (available across different departments) that facilitates the collection and access to relevant information. The goal is to allow service engineers (who plan the maintenance of engines), designers (who develop new engine solutions) and cost analysts (who decide about new business opportunities related to service packs) to share the same data, but still maintaining a different perspective.

The complexity of the environment is clear and the difficulties of study evident: understanding what type of information is generated, where, by whom and for which purpose; how information is transmitted and stored; which information is actually used, from whom and why are the main questions that need to be addressed before a design for an information retrieval

system can be sketched. A study was set up to understand the current practice and collect requirements for the future system.

3. THE STUDY

To understand the current situation a field study was set up. The intent was to collect evidence of the type of users, tasks, documents and processes involved in the design of a jet engine in order to map the information flow. The approach adopted was used-centred (Hackos and Redish 1998) and several techniques were used, each aiming to elicit information functional to the composition of the big picture. Although this is not a common research method in information science, it has been successfully used in a few cases to study complex phenomena (Ingwersen and Jarvelin 2005, p. 93). The strength of this approach is in the fact that, although each technique provides just partial evidence, the composition of the many results covers multiple aspects and supports cross-checking thus improving reliability and validity.

3.1 Focus groups

Through the discussion of a small group of Team Leaders (i.e. people responsible for specialised groups) the jet engine life information flow was sketched. In a day long meeting, a chief designer, a senior service representative and a strategy manager described the structure of the organisation and the role of the different departments, where the information was produced and to whom it was passed. No conflict or difference in interpretation emerged: the rigid structure and procedures dictated the (major) information flow.

3.2 Visits and Interviews

Visits (to the Operations Room - a 24h phone airline support service) or courses (on tools currently in use) were instrumental in refining the map of the information flow. A visit to the factory was also useful to understand the careful construction process, testing and validation.

A few individuals belonging to different departments were then interviewed at work: two junior designers, a junior cost analyst and a tester. Questions posed were driven by a very generic interview framework and highly influenced by what emerged in the conversation. This part of the study provided details on the user classes and their tasks.

3.3 Questionnaire survey

On the basis of the knowledge cumulated up to this point, a questionnaire was distributed to measure how much the identified sources of information were accessed and to which extent each individual was feeding-back their knowledge to the community. The questionnaire was addressed to R-R employees belonging to service engineering or design community. Questions covered: i) respondent's job and responsibilities; ii) information behaviour including digital or paper preferences; iii) information sharing and investigated the use of common resources in comparison with personal ones; iiii) the contribution to the community and the perceived impact of this feeding back.

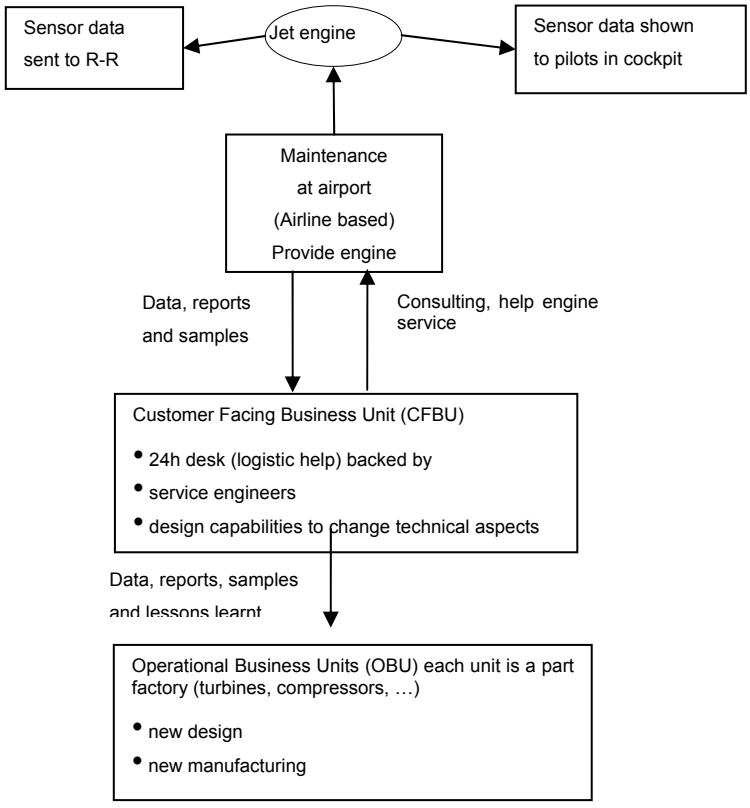
4. MAPPING THE CONTEXT

The data collected was heterogeneous. The analysis was qualitative and inductive, as evidence was expected to emerge from the data collected (Mason 2002). The intent of the analysis was to find out the main elements of information production, access and use in R-R. This section summarises the result of the study respect those different dimensions.

4.1 Information flow

The production of basic information during the engine life is well established and is captured in Figure 1. The airport workshop is a primary source of information as engines are inspected and service data is collected. A 24-hours help desk is available to support airlines, mainly for logistic arrangements (i.e. sending an engineer). Often problems are solved immediately; more complex cases are passed to engineers and/or designers. In few cases the fixing of a problem implies the redesign and the remanufacturing of a specific piece.

Figure 1. The main entities involved in the production of information during the engine life.



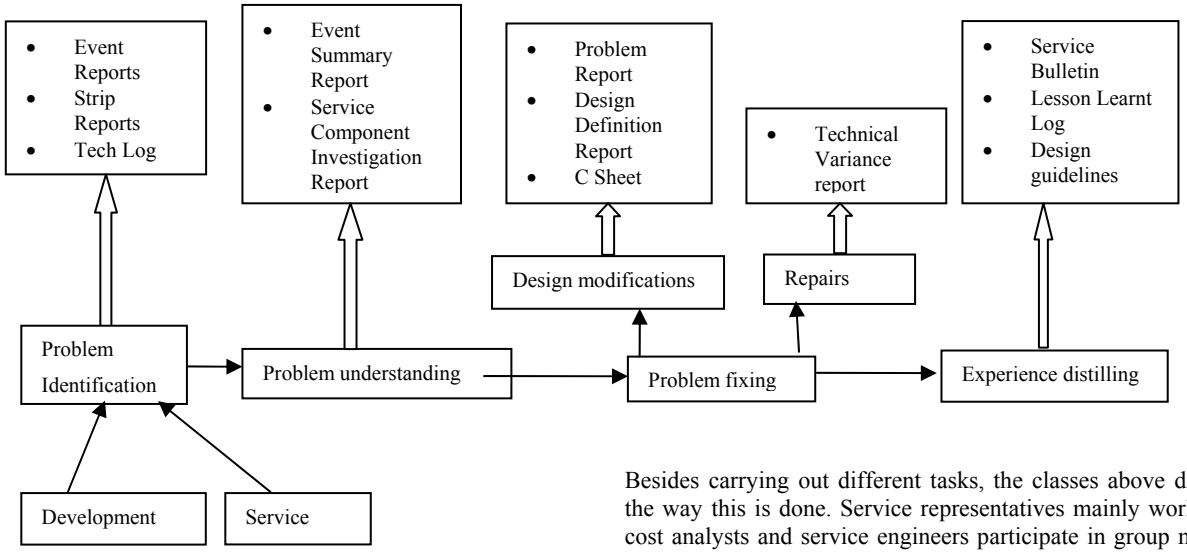
4.2 Information types

The types of information were difficult to map. As information is generated by different people for different purposes whilst following a specific procedure, it was not unusual to discover new types of documents every time an interaction with users took place. The four information classes identified so far are:

– **Numerical data:** during the flight, sensors in the engine register telemetric data that are then directly transmitted or downloaded-and-sent to R-R in Derby (UK) from all around the world.
– **Text:** fifteen (15) different types of textual documents were identified; each is produced as a consequence of a specific

event or in fulfilment of a predefined procedure. Figure 2 shows the documents and their generation in the context of a problem solving activity. Documents are of a large variety ranging from Event Data Reports generated all around the world every time a jet engine experiences a problem, even a very minor one, to Lessons Learnt Logs summarising the actions taken to fix a problem; to invoices and business summary tables.

Figure 2. The textual documents produced during a problem solving activity.



- **Images:** pictures are taken to show the position and the type of damage (e.g. bending in blades due to a bird flying into the engine vs. blades deterioration due to desert sand friction). Picture can be included in textual documents.
- **CAD:** as fundamental instrument of engineering work, CAD plots are heavily used on computers and on paper as discussion facilitators.

4.3 Users and tasks

Several user classes are involved in the process of creating and using information:

- **service representative:** located in airports around the world, they are in contact with the airline mechanic team that inspect the engines and carry out maintenance tasks. They write Event Reports, collect service data to be sent to R-R and provide daily and weekly summaries. Their task is well specified and mostly routine based but can encompass problem solving and decision making (i.e. deciding to substitute a component in the jet engine, decide to have a jet engine taken off the wing). They have a certain degree of autonomy but may consult with service engineers in CFBU before taking decisions, as from Figure 1.

- **service engineers:** members of the CFBU located in R-R in Derby (UK), they provide expert support to detect and solve emerging problems. They access information on previous events and produce new information, e.g. Lessons Learnt Logs, Technical Variance reports, Service Bulletins. Their job is largely a problem solving one.

- **design engineers:** this user class is responsible for new designs. Their job is both creative (i.e. propose innovative solutions) and analytical (i.e. understand what was unsuccessful in previous designs and why). They access information produced by others and by themselves in the past (previous designs). Part of the creative process is captured when formal communications are written to fulfil procedures, but part of the rationale could be lost if it emerged from individual analysis or group discussion.

- **cost analysts:** are responsible for calculating the economical impacts of certain events and writing business reports. Their job is analytical and they make use of multiple information types.

Besides carrying out different tasks, the classes above differ for the way this is done. Service representatives mainly work alone; cost analysts and service engineers participate in group meetings at times; designers rely heavily on their social network and on frequent meetings to discuss ideas. Each designer is responsible for a component and teams of engineers discuss together possible solutions. The bonds in the group are strong; weaker relations connect members of different areas.

The role of social networks (Nardi et al. 2000, Nardi et al. 2002) emerged: when a specific need occurs is not unusual to ask a more experienced colleague where suitable information can be found. Area managers often act as bridges toward information sources, because of their expertise, the broader view of the company and the network of personal connections they have.

4.4 Tools and logistics

The study has confirmed Raghavan (2004) claims that only part of the company's information is structured and stored in databases. Several DB exist in R-R, e.g. for technical of business information. The Service Data Manager database (or SDM) is the repository of the relevant technical information produced during the engine life. Important legacy documents (e.g. 18.000 old Event Reports) are not currently stored in SDM and should be read and manually entered; however their frequency of use is currently not clear and might not be worth the effort. Another critical case is that of the legacy of Technical Variance reports: these documents are essential to understand jet engine design evolution but are currently recorded as images (i.e. the output of microfilm scans) and are therefore unsearchable.

In order to understand the maintenance cost of each jet engine component, the data in SDM has to be crossed with the content of

the invoice database. This analysis informs the designers of new jet engines as it reports which components have the highest cost; it provides useful directions for the Design for Service (see section 1).

4.5 Perception and actions

Informal channels (i.e. asking people, using email) play a big role in finding the right information, but using personal connections is not necessarily perceived as a way of searching. Most of R-R employees largely rely on online resources. They state that "most/needed/relevant information is online". Other motivation for using online resources include commodity ("easier/quicker to access and distribute") whilst reasons for not accessing paper documents is the accessibility ("printed information [from] outside the department is becoming less accessible", "paper is hard to search and find").

Some stated that they directly inspect the physical object (e.g. a damaged blade) to have a sense of the actual damage. The physical inspection may not be just visual: the tactile experience of feeling the damage seems to be important and the smell (e.g. of oil) could be useful in some cases.

A minority use legacy information, read through paper archives or access numeric data. The motivation seems to be analytical tasks carried out to discover emerging problems and trends. This digested information is then formally written and used by other (mainly jet engine designers) who rely on colleague expertise and never access the original source of information.

5. STUDYING COMPLEX DOMAINS THROUGH NESTED CONTEXTS

The result of the study is far from being exhaustive in contextualising the production, storage, access and consumption of information in R-R. Nevertheless the picture gained is rich enough to provide evidence on which areas need more study:

- a jet engine design lasts for decades, it is therefore important to make the most of legacy data and transform it into a searchable collection but the acquisition has to be done at a minimal cost;
- information produced is heterogeneous (e.g. rough data [sensors, images, punctual events] vs. summary of events vs. analysis vs. alerts) and has different functions and use; a further study is needed to understand if part of that information can be classified as knowledge and needs to be managed in a different way (Alavi & Leidner 2001, Nonaka et al. 1996);
- tasks carried out by users seems to be more diverse than initially assumed; a further analysis conducted internally by R-R has identified thirty-six (36) different roles organized in five (5) classes depending on users' activities and responsibilities; though useful, this classification does not reflect the user's relation with information (i.e. production, search and use) and further study is needed;
- colleagues heavily rely on each other expertise and base their work on evidence provided by others: the role of social networks in exchanging and retrieving information requires further investigation as group search has great potential in technical environments (Poltrock et al. 2003, Miller et al. 2006).

Although limited, the result of the study was instrumental to outline the landscape of the information flow in R-R. The next step is to identify self contained use cases that can be investigated in depth. Possibilities are several: select an important document (e.g. strip report or technical variance) and follow its creation, storage and use; analyse a user activity that requires accessing past information to create new material or make decision (e.g. access the history of a jet engine component to decide airport intervention); select individuals and investigate their everyday activities over a period of time (e.g. conduct a diary study of a community of designers)[1]. Each study will provide details on a sub-context: a single class of users, a small number of information types, tools and tasks. The identified focus and the simplification in terms of components allow a deeper exploration of each sub-context; the coherence is maintained through the super-context (the generic one). The result is a hierarchy of nested context each providing progressive levels of details.

6. CONCLUSIONS

The study has shown that in highly complex domains a full and precise understanding of the information production, transmission, use and sharing is unlikely to emerge soon. Building a partnership with the user is essential in sustaining a long term study. Users are instrumental in providing descriptions of the context as well as to act as mediators within the complex domain. However, users are a scarce resource that needs to be used wisely. Our experience suggests adopting an iterative approach that begins with the composition of the big picture and then focuses on those areas where the introduction or improvement of IR systems would impact more. In the early phases a "light touch" with users (i.e. just a few people) should be adopted and variety should be preferred to details: even a single user from a different department can be useful to add a further piece to the information puzzle. Multiple techniques should be used as they provide several perspectives and reinforce correct findings by triangulation. The complexity of the context could be such that a coherent picture would not emerge until later when more studies have been done and details have been added. The lesson learnt is to adopt an iterative approach to the study and design of interactive information retrieval in the context of highly complex environments and to be open to redirection or to rearrange the goals depending on what emerges along the way.

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