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The information-seeking practices of engineers: searching for documents as well as for people

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Abstract

Engineers get most of their information from colleagues and internal reports. This study investigates how engineers' information-seeking practices intertwine looking for informing documents with looking for informed people. Based on case studies in two product-development organisations we find that engineers search for documents to find people, search for people to get documents, and interact socially to get information without engaging in explicit searches. This intricate interplay between document and people sources can be explained by the nature of the design task. Many possible solutions are normally available to the designer and in choosing one over the others the designer must take into account a complex set of issues involving both the product as such and its context. However, design documentation seems to be biased toward technical aspects of the chosen solution, while information about the context of the design process is typically not available. Hence, people become a critical source of information because they can explain and argue about why specific decisions were made and what purpose is served by individual parts of the design. While document retrieval is a well-established field, this study concludes by briefly outlining how computer systems could support searches for people. Given the immense practical importance of searches for people there seems to be a large need for such systems and, consequently, for addressing the open research questions involved in designing them. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

In the conduct of their day-to-day work engineers make extensive use of communications through interpersonal means as well as through information found in

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documents such as handbooks and internal reports. Communication is a crucial aspect of co-operative work, and several studies provide evidence that engineers spend 40–66% of their time communicating in order to get input to their work and to output results from their work (King, Casto & Jones, 1994). This study investigates how engineers' information-seeking practices intertwine looking for informing documents with looking for informed people. While information seeking is a well-established research field with respect to written information, it seems that support for the retrieval of oral information, i.e. searches for informed people, has been largely neglected despite its immense importance in engineering work.

Engineers are a diverse group of professionals. However, most engineers can be characterised as subject specialists who perform rather complex tasks. As task complexity increases, so does the complexity of the information needed by the engineers, while the number of useful information sources decreases (Byström & Järvelin, 1995). Engineers normally have a certain degree of freedom in choosing the way they want to accomplish their work, and they are expected to make informed decisions in a number of situations where many possible solutions are available. Apart from the specifics of the task at hand, the choices made by engineers depend to a large extent on their understanding of the context of the task and, consequently, on their success in obtaining information about this context. In design documentation, the technical solutions and the result of the design are usually well documented, while information about the context of the design process is typically not available or not indexed in a way that makes it easily accessible. These conditions explain several features of the information-seeking behaviour of engineers, as described below in the literature and demonstrated by our case studies.

We have studied engineers in two large product-development organisations. The first case study concerns a *corporate archive* and describes how the engineers utilise the archive to find documents as well as to track down colleagues with experience in specific areas. The case study also illustrates how keeping up-to-date with the developments in one's field is accomplished in an intricate interplay between written sources and personal contacts. The second case study concerns a *project file* and compares the information acquired to perform the project with the documentation produced during the project. This case study also investigates the barriers people experience in seeking oral and written information. These barriers are central to people's choice of when to seek information directly from other people and when to rely on written sources.

The next section covers related work on engineers' choice of oral vs written information sources. Section 3 presents the two case studies. Section 4 relates the empirical findings to the structure of the design task and presents a synthesis of when design information is acquired from documents and from people. Section 5 discusses how to support engineering designers in their searches for people. Section 6 summarises the paper.

2. Related work

The information-seeking behaviour of engineers has been studied extensively over the last 30 years. Yet, Pinelli, Bishop, Barclay and Kennedy (1993) say that "the literature regarding the information-seeking behaviour of engineers is fragmented and superficial. The results of these studies have not accumulated to form a significant body of knowledge''. However, a significant body of literature has accumulated (see King et al., 1994, for an excellent review). In the following we focus on two topics in the web of issues that have been treated in the literature: engineers' reliance on people as sources of information and factors that affect engineers' choices of information sources.

2.1. Engineers' reliance on people as sources of information

Most studies conclude that internal communication of any kind is generally more critical in engineering work than is communication with sources external to the organisation. Furthermore, engineers tend to rely on their own information and on colleagues before the library and other internal sources. Rosenberg (1967) presented 52 researchers and 44 non-researchers with three hypothetical situations and asked them to rank order eight information-gathering methods according to personal preference in each of the three situations. For the non-researchers, who more closely resemble engineers, the resulting ranking (aggregated over the three situations) shows a strong preference for nearby and oral sources, see Table 1.

A number of more recent studies have reported quite similar results. Based on responses from 1315 industrial engineers, Shuchman (1982) found that the combination of three internal sources — conversations with colleagues, consulting supervisors, and reading in-house technical reports — was the highest-ranking factor in a factor analysis of the 30 sources of information presented in the questionnaire. Internal sources were ranked as moderately or very important by 82% of the surveyed engineers. Based on a survey of 500 scientist and engineers in industrial R&D, Chakrabarti, Feineman and Fuentevilla (1983) reported that work groups were the most frequently used source of information followed by trade journals, handbooks, newspapers, in-firm experts, and 17 other information sources. Von Seggern and Jourdain (1996) asked aerospace engineers and scientists to indicate from a given list which information sources were consulted in solving a technical problem. Three sites participated in the survey and they displayed almost identical patterns of usage. Averaged over the three sites, the 228 respondents consulted their information sources as shown in Table 2. Further support for essentially the same findings has been reported by, for example, Bichteler and Ward (1989), Gerstenfeld and Berger (1980), Kasperson (1978), and Zipperer (1993).

Table 1
Information-gathering methods used in problem solving, study by Rosenberg (1967)

Rank	Information-gathering method
1	Search your personal library
2	Search material in the same building where you work, excluding your personal library
3	Visit a knowledgeable person nearby (within your organisation)
4	Telephone a knowledgeable person who may be of help
5	Consult a reference librarian
6	Use a library that is not within your organisation
7	Write a letter requesting information from a knowledgeable person — 20 miles away or more
8	Visit a knowledgeable person — 20 miles away or more

2.2. Factors that affect engineers' choice of information sources

A number of studies find that the cost associated with using an information source is the most important determinant of its use and thus counter any assumption of information quality as the single criterion upon which source selection is based. This has given rise to a law of least effort saying that in selecting among information sources, engineers act in a manner intended to minimise the expended effort, not to maximise gain. Gerstberger and Allen (1968) measured the perceived cost of using an information source in terms of source accessibility and ease of use. Based on a 15-week study of 19 electronics engineers they found a strong relationship between accessibility and frequency of use. When accessibility was held constant both ease of use and technical quality showed little relation with frequency of use. Gerstberger and Allen (1968) concluded that "apparently, in the minds of the [studied engineers], there is some relation between their perceptions of technical quality and channel accessibility, but it is the accessibility component which almost exclusively determines frequency of use". Further, the engineers' perception of accessibility seemed to be influenced by their experience: The more experience an engineer had with an information source, the more accessible it was perceived to be.

Similar results have been reported by Rosenberg (1967) but a couple of more recent studies grant the utility of the information more influence on people's choice of source. Chakrabarti et al. (1983) found that work groups, which were the most frequently used information source, were perceived to be highest in terms of utility of the provided information and second highest in terms of availability and ease of use. On the other hand machine-readable tapes, which were the least frequently used information source, were perceived to be high in cost and low in ease of use, availability, and utility of information. The positive correlations between frequency of use and both utility, availability, and ease of use were statistically significant, as was the negative correlation between frequency of use and cost. Based on five interviews and a follow-up questionnaire, Zipperer (1993) identified several reasons for the studied exhibit design engineers' strong preference for getting information from their colleagues: (1) the engineers often sought feedback on their ideas or designs, either as trusted opinion or as impetus for creative discourse; (2) quite often the only access point to filed documents, other than manually looking through the files, was a colleague's memory, and; (3) the engineers' close working relationship with their colleagues enabled them to select the person to approach in a given

Table 2
Information sources used in problem solving, study by Von Seggern and Jourdain (1996)

Information source	Consulted by (%)
Personal store of technical information	99
Spoke with a co-worker or people inside my organisation	99
Spoke with colleagues outside my organisation	93
Used literature resources found in my organisation's library	88
Searched an electronic database in the library	72
Spoke with a librarian or technical information specialist	62

situation based on such fine details and informal distinctions as the person being very helpful, too slow, or inefficient due to lack of experience with this particular topic.

In explaining the differences between engineers and scientists Allen (1988) makes use of an input–output model, which includes an explanation of the relationship between design documentation and oral communication. The scientist uses information to produce information and consequently the input and output, which are both verbal, are compatible in the sense that the output of one stage is in a form that can be used as input for the next stage. Thus, the problem of supplying information to the scientist becomes a matter of collecting and organising these outputs and making them accessible. Contrary to this, the engineer consumes, transforms, and uses information to make a product which is information-bearing but usually no longer in verbal form. Verbal information is produced only as a by-product for documentation purposes. Since outputs are usually in a form different from inputs, they usually cannot serve as inputs for the next stage. Neither can the verbal documentation because it is a by-product of the process and incomplete without some human intervention to interpret the information contained in the documentation. "Thus, technological documentation is often most useful only when the author is directly available to explain and supplement its content" (Allen, 1988).

3. Case studies

In the following, we present two case studies which illustrate how experiences, insights, results, and other kinds of information acquired in engineering design projects are communicated within the projects and at a later stage, possibly, utilised by engineers involved in other projects. The first case study concerns how engineers acquired information from previous projects internal to the organisation as well as from external sources. The second case study concerns a single project and investigates what information was needed and how it was acquired and recorded. It is crucial to engineering organisations that design information flows effectively both within and among projects.

3.1. The corporate archive: Novo Nordisk

Novo Nordisk, the world's largest producer of industrial enzymes, builds on a strong commitment to research and has a long tradition of emphasising the importance of documentation work in ensuring maximum benefit of the performed research. The case study took place in one of the research departments in the Bio Industrial Group and consisted of ten interviews with people representing all groups involved in handling R&D information: chemists, laboratory technicians, secretaries, archivists, and librarians. The chemists worked in project groups, which dealt with the development and production of industrial enzymes for different industries such as tanneries and pulp & paper. The interviews with chemists and laboratory technicians were based on "a tour of their office" where they explained what information they had, how it was related to their work activities, how it had been acquired, and from whom. The interviews with secretaries, archivists, and librarians covered their involvement in filing documents written by the chemists and in seeking information needed by the chemists. The interviews lasted approximately one hour each.

3.1.1. Seeking information from internal sources

The corporate archive contains documents produced or received by Novo Nordisk employees, including incoming and outgoing mail. Most additions to the archive are in electronic form but the archive also contains a substantial number of paper documents, which were filed before the introduction of the computer-based filing and retrieval system. With this system the engineers have access to the archive directly from their PCs. Filed documents are retrievable by author, keywords, and a number of other attributes, and the electronically filed documents are furthermore available in full text. Formally, the engineers are expected to file all documents of potential value to the organisation in the archive, which is intended to be for the entire organisation what personal work files are for the individual engineers. In practice, the archive plays a much different and more indirect role.

Within Novo Nordisk it is generally recommended that engineers in need of information search internally before they turn to external sources. The reason for this advice is to avoid spending time and resources on work that has already been done by others within the organisation and that getting into contact with a well-informed colleague has time and time again proved a source of valuable input. Several of the interviewees explicitly acknowledge this mediation of personal contacts as a key function of the archive. The filing and retrieval system is often used for this purpose though it lacks facilities directed specifically at supporting it. In the absence of dedicated facilities, the engineers search for documents on the subject they need information about in order to find colleagues knowledgeable about this particular subject. When a relevant document has been found its author is a likely source of information on issues relating to its subject, and many documents include references to other people as well. In the case of paper documents, information about who initially received a copy of a document is often handwritten on the cover page in the form of an instruction to the secretary who did the copying and mailing. Searching in this way it is often enough to find a single relevant document.

The archive is mostly consulted in the beginning of new projects in areas where Novo Nordisk has products already. Though Novo Nordisk is a large organisation the engineers who approach the archive usually know from a colleague that some work of potential relevance to the new project was done say ten years ago. The engineers may be unable to specify the relevant material in terms of searchable attributes but they seem reluctant to approach the archive unless they have positive indications that it contains something of interest. In this sense the archive is a secondary source of information — it is typically searched to retrieve material that is to a considerable extent known to exist, rather than to check whether relevant material does exist. The primary way to become aware of relevant material is through interpersonal communication. This way, the material is normally supplemented with some advice, background information, and inspiration. One of the interviewed engineers has been employed in Novo Nordisk for one and a half years and has never used the archive. He explains: "If you want an old article or report then the method is to find the person who wrote it, or the person to whom the project has been handed over, and ask if he has it. This method is almost always successful." Several of this engineer's colleagues agree that this approach is faster and more rewarding than getting the document from the archive.

3.1.2. Seeking information from external sources

None of the interviewed engineers make frequent use of searches in external sources, and they rarely perform such searches themselves. In the straightforward cases the engineers write down what they need and send the request to the library, which is responsible for obtaining material from external sources. In the more complex cases the engineers make an appointment with a librarian, who performs the search on behalf of the engineer. Often the engineers are present during the search sessions to interactively evaluate the outcome and suggest new paths to follow. The special-purpose databases the librarians frequently use are made available to the engineers if they have a real need and prefer to search themselves, but most of the engineers prefer to use an intermediary. Several of the interviewed engineers mention that they suffer from systems overload in that they need to master an ever increasing number of systems to perform their day-to-day activities.

Through their contacts with the local universities the engineers also make use of another kind of intermediaries in seeking information from external sources. The engineers frequently supervise students who are given access to Novo Nordisk to write projects within an engineer's current area of work. As part of their projects these students perform a number of external searches, digest the literature, and write a chapter on previous work. These literature overviews are of great value to the engineers. Another important supplement in obtaining external information is to attend conferences. One engineer explains: "Despite our efforts we miss a lot in the searches. That's one of the opportunities you get at conferences. You get to talk to somebody who has been doing something similar and has a report you can have. I have received a few things that way. Things we hadn't found ourselves."

The engineers who have been working within the same area for an extended period of time find that they have little need for searches. Their information seeking consists primarily in keeping abreast within a known area. They accomplish that by leafing through relevant journals and proceedings, and generally rely on conferences as their primary source of information about new research results. The number of key conferences in their areas is quite small so though the individual engineer is only at some of the conferences someone from Novo Nordisk is almost always present. The engineers agree that the personal contacts within their respective groups are an essential source of information. By relying on work group colleagues and conferences the engineers display a strong preference for obtaining new information from people, with documents as an important, but usually concomitant, source.

For internal and external information alike the engineers seem somewhat biased toward getting information without deliberately searching for it. They spend time leafing through journals, talking to each other, attending conferences, and participating in other activities that subject them to a lot of information they had not consciously set out to look for. This is most evident in the periods where the engineers describe their information seeking as keeping abreast with new developments in an otherwise known area. But the basic requirement for getting information without explicit searching, namely that information is volunteered, is also formally supported with respect to the current activities of their colleagues. Each week the engineers write a brief account of what they have been doing during the week and post it in a shared area on the local area network. These so-called *week infos* are used by middle management when they report to the head of the division, and they are used by the engineers to get a picture of what their colleagues are presently doing. The *week infos* are also used to produce monthly *highlights*, which are available in paper copy as well as on the local area network. This double distribution provides an illustration that the value of the *week infos* and *highlights* is that they provide current information. While the electronic version of the *week infos* and *highlights* is used and considered useful by the interviewed engineers, they find that the paper copy of the *highlights* is often delayed to the point where it is no longer of interest when it arrives on their desk.

3.2. The project file: The PVE project at Danfoss

The second case study concerns a large engineering design project carried out at Danfoss, a large Danish company producing equipment for heating and refrigerating systems. The aim of the project was to design and plan the production of Proportional Valve Electronics (PVE II), an advanced electronic control unit for hydraulic fork-lifts, trucks, and other power tools for construction work. In addition to the functional specification, very strict fail-safe characteristics were required due to the hazards of losing control with high power tools. The PVE project lasted four years and most of the time about 10 engineers were involved in the project. The project manager, three electronic engineers, and a mechanical engineer were physically located in the same room, and an engineer from production planning had his office close by. The four remaining project participants had their offices in other buildings. The case study is based on 18 interviews conducted by one or two of the three researchers involved in the data collection process, a questionnaire, and inspection of the project documentation. We focused mainly on what information the engineers needed and used in their work and how they obtained and managed this information. The research approach was heavily inspired by both work analysis (Rasmussen, Pejtersen & Goodstein, 1994) and ethnographic approaches to studying engineering work (Bucciarelli, 1987). It should be noted that the PVE project was finished when the case study was conducted so the data are retrospective.

3.2.1. Perceived barriers for seeking oral and written information

The information seeking in the PVE project, illustrated in Fig. 1, involved a number of domains representing the perspectives of different stakeholders: (1) the customer domain concerned with matching the properties of the product to the customers' needs; (2) the marketing domain concerned with customers' attitudes to new solutions, with maintaining a competitive price/performance relationship, and with which parts to produce in-house and which to purchase from sub suppliers; (3) the production domain concerned with production costs, the capacity of existing equipment, and the qualifications of the staff; (4) the recycling domain concerned with the physical processes related to disposal of materials when pasting replaces soldering in the manufacturing of the new product; and (5) the general market concerned with maintaining awareness of other branches of industry where hydraulic valves were applied or could be introduced and with exploring the feasibility of a joint venture with another company. An example of an important information-seeking activity was to obtain information about people in order to determine the expertise of other companies such as potential sub suppliers.

The people involved in the PVE project made use of a large number of heterogeneous information sources (Carstensen, 1997). To identify and procure this web of information the involved people have time and time again made a choice between asking people and consulting documents. This way the engineers have gradually built quite firm beliefs as to the barriers for seeking oral and written information. We administered a questionnaire to the people involved in the PVE project to collect information about, among other things, their perception of these barriers. Based on a fixed set of barriers the respondents selected those they considered of significance and optionally provided a comment for each selected barrier. A couple of engineers use the sweeping expression "ask first, read afterwards" to express their preferences, but most of the engineers distinguish between different situations in explaining when they ask other people and when they look for written information.

The most frequently cited barrier for seeking both oral and written information is cost/time, see Tables 3 and 4. This is in accordance with previous studies of engineers' information-seeking behaviour and implies that easy access is of paramount importance. Another important barrier for seeking oral information is the intellectual and social effort required to present the information need in a way that triggers the other person's attention and gets him/her constructively involved. Otherwise, the answer may very well be too general and fail to account for the details of the concrete situation. This may help explain engineers' tendency to ask their nearby colleagues since they will often be somewhat familiar with the context of the question and thus need less information about the concrete situation to provide an appropriate answer. Several of the top barriers for obtaining oral information indicate that while the engineers are confident they have found a person who knows the answer to their question they frequently find it difficult to get this person to provide them with the information they need. Furthermore,

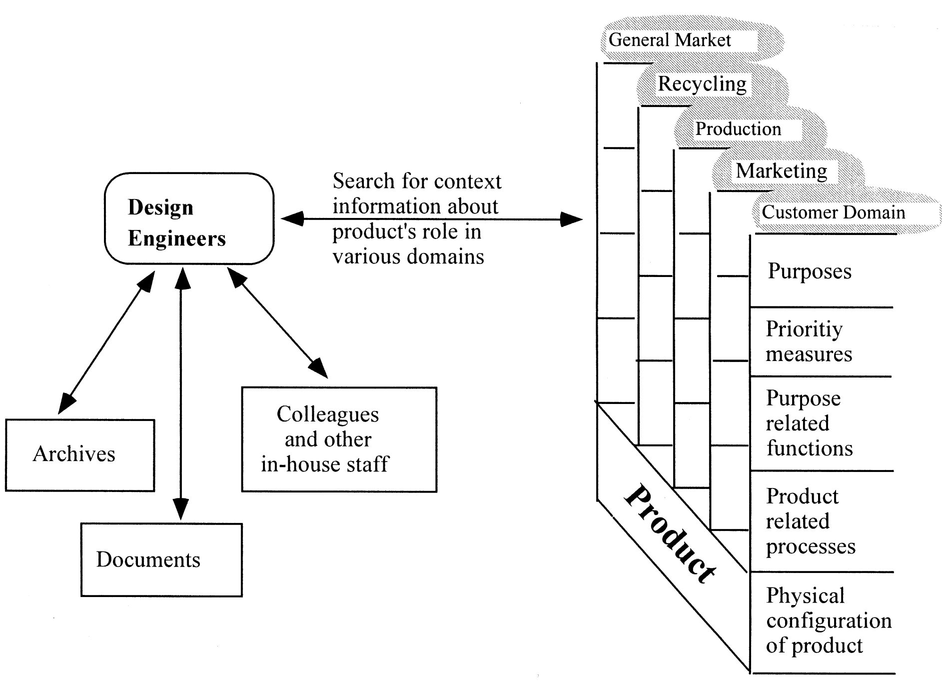

Fig. 1. Context information was central to the development of PVE II.

Table 3
Top five barriers for seeking oral information from other people ($n = 18$)

Barrier	No.	Sample citation
Cost/time	9	"It takes time to travel around [in order to visit people abroad]"
Intellectual/social effort	7	"Very difficult if you don't know people, but if you do you get a lot"
Confidential information	6	
Your memory	5	"Cannot remember details"
Inappropriate information	5	"Experts have a standard explanation"

oral information is ephemeral and therefore details and complex explanations are easily forgotten or misremembered.

The general picture conveyed by the top barriers for seeking written information is that the major problem is finding the right sources. Massive amounts of irrelevant information surround the few relevant pieces of information and the tools available to support retrieval are too difficult to use competently, and there are so many of them that the choice of tool becomes a problem in itself. Moreover, information is not available in written form unless someone has felt a need to write it down and spent the time doing it. Consequently, there is a risk that though the needed information actually exists it is wasted effort to search for documents containing it as it may not exist in writing.

3.2.2. The project file

The project manager put much emphasis and effort into documenting all design ideas, problems, considerations, decisions, etc. during the project. The resulting project file consists of 29 binders organised in a structure which grew up ad hoc, as the project manager or others in the project thought there was a need. The only facility available to aid searching in the project file is an overall table of contents with 20 top-level entries and a depth of from one to four levels. In addition to this hierarchical structure the documents pertaining to an entry are in most cases ordered chronologically. The project file contains a variety of document types including specifications, reports, minutes of meetings, release notes, authorisations, test samples, photos, work plans, financial status reports, calculations, overheads, incoming and outgoing mail, and some computer aided design (CAD) drawings. After the project officially finished, one of the project participants volunteered to take over the administration of the

Table 4
Top five barriers for seeking written information ($n = 17$)

Barrier	No.	Sample citation
Cost/time	11	
Irrelevant information	8	"Internet!"
Availability of information	7	"[Relevant information is often] not available in written form"
Unfriendly tools	6	"Too many tools are required. Would like one integrated tool"
Intellectual effort	4	"Abstracting your needs, formulating it in words"

project file. This file manager, as we will call him in the following, works on the maintenance of the PVE design and helps people in getting information from the project.

Information related to the PVE project and product is mostly requested by people who participated in the project. These people have some knowledge about the structure and contents of the project file. This knowledge leads them to seek information in the file in the first place, and it supports their search process by providing them with an understanding of the file that goes beyond its explicit content. There are, however, also requests from people who were not involved in the PVE project. These people have, so far, always accessed the file via the file manager, who was part of the PVE project team. The external requests concern diverse issues such as the experiences gained with flex-print technology, which are of interest to another project planning to use flex prints. To answer this request the file manager would scan through the binders containing the design specifications and through the flex-print binder. There are no means to narrow the search to a smaller set of documents. Alternatively, the file manager could refer the requester to the person who was responsible for the flex prints during the project. This piece of information can, however, not be found in the file and is thus only available because the file manager was involved in the project and knows who was responsible for the flex-print design. In this very important sense the file resembles a personal file in that it has not been prepared for use by people external to the PVE project.

4. Design documentation and informed designers

Design unfolds around a transformation of a specification of the *function* of a product into a *form*, which constitutes the configuration of its physical parts (Hubka, 1982). The designer is normally confronted with a complex set of possibilities and constraints, because the design task involves both defining, in detail, the function of the product and giving it a usable form. The complexity of the design task arises partly from the simultaneous presence of several different sets of concerns regarding the future product. It is not enough to pay close attention to the customers' needs; the design must also take account of needs arising from a number of other domains such as marketing, production, service, training, maintenance, recycling, and quality control (Pejtersen, Sonnenwald, Buur, Govindaraj & Vicente, 1997). This multitude of involved domains was very evident in the PVE project because it was explicitly organised as a concurrent engineering project, but similar issues confront all projects because all products have to be marketed, produced, serviced etc. Thus, a central aspect of the design process is the acquisition and exploration of a web of information from different domains and therefore familiar to people with different professional backgrounds. No single designer knows all the involved domains in the necessary detail, and designers may find it more reassuring to obtain information on unfamiliar issues from a competent colleague than attempt to figure it out themselves based on the available design documentation.

Designers also need to address their design task at several levels of abstraction. The abstraction hierarchy developed by Rasmussen et al. (1994) distinguishes between five levels of abstraction. At the most abstract level a design can be discussed in terms of the goals it is intended to fulfil and the constraints it has to operate within. The second level concerns the priorities that settle the relative importance of the parts that are going to constitute the system. The third level concerns the general functions to be performed by the designed system irrespective of how they are implemented at the lower levels. The fourth level concerns the actual system processes and work activities to be performed by and with the system. The fifth and most concrete level concerns the involved material objects and their configuration. During the design process designers repeatedly move up and down in the abstraction hierarchy to clarify what the system is to achieve and how that can be implemented, as well as to clarify what is implementable and how that constrains what the system can possibly do.

Our case studies and other studies of design suggest that while the resulting technical solutions are usually well documented, only scarce information is available about the context of the design process and the reasons for adopting the chosen solution among the alternatives available. Fig. 2 (reproduced from Rasmussen et al., 1994) illustrates how an actual design process progressed in terms of the domains and levels of abstraction that entered into the process. The design process depicted in the figure spanned several months and concerned the design of an improved manufacturing process for a door lock. It is evident that handling the complexity of the design task involved approaching it from a number of domains and at several levels of abstraction. It follows that for the design documentation to be complete it should inform about the product at all these levels, otherwise it will fail to meet the needs of some future work situations — when the product is redesigned or similar tasks are performed.

Typically, documentation of design work is found in manuals and reports that contain a technical description of the functionality of the product supplemented with drawings and blueprints showing its physical configuration. This documentation, which corresponds to the crosshatched part of Fig. 2, represents the essence of the function–form transformation. However, the choices made during this transformation depend heavily on criteria derived from the other domains, on considerations made at the upper levels of abstraction, and, in general, on the situated activities of several people. The information collected across these additional domains and levels of abstraction will normally exist as knowledge possessed by people and embedded in company practice or it will be present

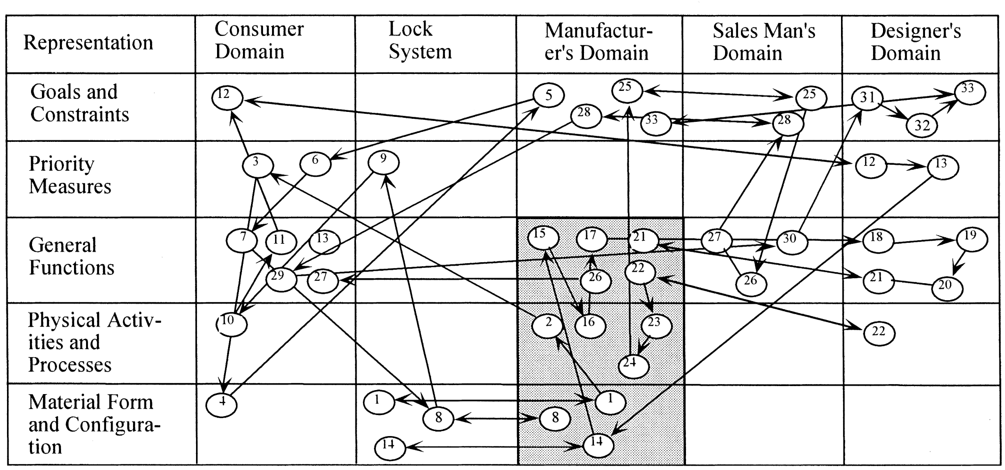

Fig. 2. The trajectory of a manufacturing design process (Rasmussen et al., 1994). The numbers give the sequence of the activities.

in informal notes, correspondence, and minutes of meetings. Without easy access to information about the context of the primarily technical documentation it will be difficult to reuse information from previous design cases. Furthermore, the information in informal notes, correspondence, minutes of meetings, etc. is normally not indexed in ways that enable a designer who is unfamiliar with the context to perform successful searches. The PVE project is a case in point and illustrates that effective access to information about the project is dependent on contact with a person who was involved in the original design process. In addition, several studies have found that design documentation is made only reluctantly and may therefore be incomplete or out of date (Button & Sharrock, 1996; Hertzum, 1999; Parnas & Clements, 1986).

As a consequence, engineering designers tend to seek information by identifying a colleague, who is able to elaborate on the work context and the available written sources. This way designers use their colleagues as entry points to the written documentation in order to get the background understanding necessary to read the documentation competently. In addition, the designers are directed to the relevant parts of the documentation and they get into a dialogue, which enables the actors to adjust to each other. Oral questions often lead to queries about the situation that gave rise to the question to provide the person being asked with a more solid basis for interpreting and answering the question. In the course of the conversation the person asking a question may also encounter that it misses the real problem and rephrase it or ask additional questions. In this way, neither the question nor the answer exists beforehand, both are products of the communication process. Contrary to this, the wording of a document is frozen and does not adapt to the questions that cause people to consult it. Thus, documents require more work than oral communication in the sense that it is left entirely to the reader to ask the right questions and reach an answer that is a correct interpretation of the text. To do this successfully requires that the document is interpreted with due respect to the context in which it was produced, but this context is largely implicit. Aspects of the context can be spelled out in the document but this is a time-consuming activity and such elaboration will often not be welcomed by the primary readers who know the context beforehand and can see the elaboration as redundant (Brown & Duguid, 1996). Further, the production of such elaborated accounts also entails the introduction of a permanent record of something that was hitherto left implicit. While this is often unproblematic it is sometimes critical to honour what belongs to the implicit realm of knowledge as a precaution against unintended use of the information in some unknown, future situation. In these situations people tend to prefer oral communication, which informs the involved actors without leaving a permanent record.

5. Implications for design

To support engineering designers' information-seeking activities effectively it is necessary to consider not only document retrieval but also the use of people as information sources. Engineers frequently need to consult people with specific competencies, because people are able to offer advice based on their previous experiences and to explain and argue about the multifarious issues involved in specific properties of existing designs. Searches for people can be supported by means of extensions to systems for filing and retrieving documents and by systems dedicated to searching for people.

5.1. Using document archives to search for people

In a way the authors of archived documents have been indexed with their documents. The contents of the documents tell a lot about the experiences and competencies of their authors and just as keywords and other pieces of information assigned to a document tell something about the document they add something to the description of the author. Thus, document archives can be, and in fact are, used to search for people. However, if searching for people is explicitly acknowledged as an essential function of the archive, a number of issues and design decisions are affected:

- *Working-paper archive*. A document does not have to be complete to be valuable as a means of mediating contacts among people, and insofar as the purpose is to bring people together the author gets an opportunity to point out deficiencies in his documents. Almost completed documents are often delayed in their transfer from the authors to the archive because the authors' new responsibilities are given priority at the expense of the completion of the documentation of their old projects. To support people in finding informed colleagues it seems advantageous to transfer documents to the archive as soon as they are created and periodically update them with the latest version. This can be done automatically with applications similar to those that backup people's computers over the local network. Obviously, the draft status of such documents should be emphasised to searchers.
- *The people identifiable through a document*. The author of a document is not the only potential source of information about its subject. For example, documents often report from co-operative projects where everybody in the project group will know something about the subject. Therefore information about who have been in contact with a document is of potential value to searchers. Who participated in the project? To whom was the document circulated upon completion? Who has retrieved the document from the archive lately? Etc. In searching for people, the role of an archived document is not to provide the searcher with the needed information directly but to describe its subject area in terms sufficiently precise to enable a searcher to determine whether the document can be used as a directory of people who may possess the needed information.
- *Current contact information*. Internal documents will usually include the author's department, phone, and e-mail at the time of writing the document. However, the searcher needs current contact information. The system should provide the searcher with an easy way to obtain current contact information for authors and other people mentioned in the documents. It may also be of interest to be able to restrict the output of searches to persons who are still employed by the organisation, i.e. persons who are easily accessible.
- *Effective subject search facilities*. Currently a primary way of searching corporate archives is by author, partly because people turn to the archive only when a colleague has brought a specific document, identified by its author, to their attention, and partly because the subject search facilities are inadequate. To enable searching for people it is essential that the system provides at least one effective access point besides authors. There is a large need for lead-in facilities such as thesauri or a means to browse the list of terms used to index the documents (Bates, 1986). These facilities will not bridge the gap between the searchers' queries and their information need, but may support searchers in bridging the gap between their wording of their queries and the index terms.

5.2. Services dedicated to searching for people

Extending document archives in ways such as those described above will presumably yield positive results, but as a means of supporting searches for people it represents a quick and dirty approach. Given the immense importance of interpersonal communication in engineering work it seems well worth the effort to consider designing services dedicated to searching for people. Many companies maintain a directory of their employees with basic contact details and a few keywords describing their major competencies. Usually, the information in these directories is collected through a simple questionnaire that is filled in by each employee. There are, however, several open research issues involved in the design of more comprehensive directories.

Ideally, such a directory should contain the information people rely on in their searches for colleagues capable of helping them. Thus, an important issue that has to be explored further is how to model people as information sources (Pejtersen, 1998). Part of the required information will be factual information about people's educational background, the projects they have participated in, their responsibilities in these projects, etc. However, people also choose their information sources based on soft information such as whether a person owes them a favour or is currently very busy. Detailed empirical studies are necessary to bring about a reasonably complete scheme for classifying the information that is needed to model people as information sources and to investigate whether the important pieces of information can be determined with sufficient certainty and made available in an appropriate way. The development and trial application of such a classification scheme would both tell us something about the basics of co-operative work and give us a platform for devising systems that provide well-structured information valuable to searchers, while carefully balancing searchers' needs against privacy concerns. Foner (1999) focuses explicitly on how privacy concerns can be honoured in a system intended to make people aware of other people with like interests based on an automatic matching process. In our preliminary work on classifying people's expertise we have used the abstraction hierarchy (the vertical axis in Fig. 2) to model how expertise ranges from insights concerning concrete, material issues to an understanding of how specific issues fit into a larger context.

A classification scheme is a prerequisite for collecting reasonably complete data about people via a questionnaire. It is, however, difficult to maintain a timely description of the persons in the directory if all data are collected manually. Automated data collection can be a continuous process independent of people's diligence in filling in questionnaires, but we lack robust techniques to extract and integrate information about people's expertise from their personal files and from corporate databases. The documents written by engineers are a rich source of information about the kinds of customer domains, products, projects, tasks, technologies, people, etc. with which they have working experience. The organisation's intranet is another source of information which provides a different picture of the employees and requires modifications of the techniques used to extract information about people's expertise. These sources are biased toward factual information and thus leave it to people's personal network to provide the supplementary information that often determines whether someone is considered the right person to contact. This highlights the fact that systems to support searches for people should be built with recognition of the importance of interpersonal communication, rather than in an attempt to replace part of it with yet another computer system. Others have given priority to interpersonal communication by directing their efforts toward making computer-mediated communication channels that enable people who are physically distributed to interact in the same unplanned, informal ways as people who are located close to each other (for example, Root, 1988). We do, however, believe there is a definite need for systems that support people in the process of finding colleagues with specific competencies. In future work we will develop a classification scheme for people's expertise and design a prototype system for evaluation purposes.

6. Conclusion

Previous work has repeatedly found that engineers' primary source of information is their colleagues within the organisation and that the major reason for this is that colleagues are easily accessible. This study investigates how engineers' information-seeking practices intertwine looking for informing documents with looking for informed people: engineers search for documents to find people, search for people to get documents, and interact socially to get both oral and written information without engaging in explicit searches. They do so to obtain information in effective ways but still find that the major obstacle to seeking both oral and written information is the cost/time involved in getting it. Further, oral information lacks permanence while written information, such as design documentation, seems to give an incomplete account of the context surrounding the specific issues treated in the documents.

We propose to classify design information according to a model involving two dimensions — stakeholder domains and levels of abstraction — and hypothesise that design documentation is strongly biased toward technical descriptions of the resulting product (i.e., the lower abstraction levels of the manufacturing domain). This leaves it largely undocumented how the various goals and constraints involved in the design were transformed into a product and thus makes it necessary to get into contact with a person who was involved in the project to subsequently understand and learn from the design process. Thus one important factor in engineers' choice of written vs oral information sources seems to be that while concrete product information can be found in documents, context information must be obtained from people. It is an open question whether it will be beneficial to apply the model to the production of design documentation in order to ensure coverage of all stakeholder domains and levels of abstraction. The extra documentation has to be weighted against the considerable effort involved in making it and people's inclination to talk to the author rather than read her documents.

One advantage of written information is the widespread existence of archives and retrieval systems, which provide facilities for finding relevant documents. Since engineers tend to prefer easily accessible information sources the almost complete absence of systems supporting searches for people with specific qualifications is likely to increase the number of decisions that are based on advice from nearby colleagues because it appeared prohibitively difficult to find someone better qualified. One approach to support searches for people is to extend document retrieval systems by explicitly exploiting the fact that documents tell a lot about the work activities of their authors and thereby provide a rich description of the authors' experiences and competencies. Another approach is to develop models for classifying people's expertise. The purpose of these models is not to elicit people's expertise and put it in a system but to index it to support people in the process of finding a human being with specific competencies. To develop such models, or classification schemes, we need to know what information engineers repeatedly rely on in deciding whom to approach in a range of concrete situations. We must also investigate what types of information it is acceptable to record and make available to searchers, and how this varies with, say, whether the situation is of a safety-critical nature. The need for systems that support searches for people is evident in our case studies where a document retrieval system is used for finding people though it has not been designed for that purpose.

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