Collaborative Information Seeking in Engineering Teams

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ABSTRACT
Engineers work in multidisciplinary teams, contributing the diverse expertise of their disciplines to solving complex problems and designing products. We studied how engineering teams seek information collaboratively. Their most common information needs were related to their product requirements and the consequences of design decisions. A common strategy for seeking information was to propose design ideas and request feedback instead of directly asking for design constraints or requirements.

Categories and Subject Descriptors
H.3.3 [**Information Storage and Retrieval**]: Information Search and Retrieval – *search process*

H.5.3 [**Information Interfaces and Presentation**]: Group and Organization Interfaces – *computer-supported cooperative work*

General Terms
Design, Human Factors.

Keywords
Collaborative information seeking, collaborative design.

1. INTRODUCTION
Sharing information within a team is essential to a team's success. Less attention has been directed to understanding how teams act collectively to seek information outside the team's boundaries. Viewing a team as a social unit, we may ask how it recognizes information needs, formulates queries, retrieves information, evaluates it, disseminates it within the team, and applies the results to address the initial need.

We investigated collaborative information seeking in field studies of two design teams, a hardware engineering team and a software development team [1, 2]. This paper focuses on our findings for just the hardware engineering team. We focused on design teams because design is an information intensive task and seemed likely to require access to information outside the team. We attended team meetings, interviewed team members, shadowed work activities, surveyed them about communication habits, and conducted focused interviews on specific information retrieval events.

The sections that follow describe the team and how the members of each team collaborate with one another and with people outside the team. We focus on how they collectively seek information from outside the team and share it with one another.

2. THE TEAM
The team was designing a system for a Boeing airplane in collaboration with a major jet engine supplier. The supplier designed the engine to meet Boeing's requirements, and the Boeing team designed the interfaces between the engine and all other systems on the airplane. The team designed the structural and spatial properties of every interface component, including the spatial properties of the installation and removal procedures for these components. The finished components were acquired from other smaller established suppliers. Some components were readily available as standard parts. The suppliers manufactured new components as specified in the designs and shipped them to Boeing where they would be assembled.

The team included a team leader, eight engineers and two technicians. The engineers on this team had 5 to 20 years of experience in mechanical engineering, and most of their experience was on engine systems for other airplane models. Each engineer was a *focal* for one or more of the subsystems that make up the system design, with responsibility for all the design issues related to that subsystem. For example, there were focals for the fire detection subsystem and for the anti-ice subsystem.

The physical work environment in relatively Spartan office space above the manufacturing floor for their system. The team leader, most of the engineers, and both technicians occupied a single open bay where they could (and did) talk to one another without getting up from their chairs. Not surprisingly, most of the communication within the team was oral, and they used email to distribute documents and for communication with people outside the team.

The design of this hardware system required much more time than the software design we studied. (For one thing, the consequences of errors reduced the ability to iterate and increased the need to consult others.) Our study was conducted during months 9 through 18 of a 36-month design and development period. In this interval the team performed the detailed design of many components. They negotiated and specified the interfaces of many components with their major supplier, created detailed representations of components in a computer-aided design (CAD) system, and provided component specifications to other suppliers.

3. FIELD STUDY METHOD
We first interviewed the team leader about the team's goals, objectives, and organizational context. Then we observed and recorded meetings, interviewed team members and some people who worked with the team, monitored group email communication, and observed members at work. We interviewed most team members twice, first asking general questions about their work, its organizational context, the decisions they make, the information they seek, and their work with other people, and the second time focusing on specific information-seeking events. We gave each team member a structured notepad on which to take notes about their information needs, how they searched for the needed information, and the results. In the interview we asked them to describe these events in detail. All interviews and team meetings were transcribed and analyzed.

4. INFORMATION SEEKING

4.1 Discovering Information Needs
Team members frequently discovered that they needed additional information when designing parts. Typically, the engineers began

their designs by looking at the design of their system for an existing similar aircraft. These designs were accessible as CAD models. Then they considered how they could improve the design, possibly reducing the cost or weight of components. Before embarking on these revisions, however, they needed to know about constraints the new design would have to meet. They needed to know whether other engineers were working on components in the same area, constraining the space available to them. They also needed to know about non-spatial constraints, such as the stress and thermal conditions that their components would encounter because these factors influence the choice and thickness of materials. They needed to know about constraints that influence assembly and maintenance of their components. This information was not available in any documents or repositories. It was only available from specialists in stress, thermal properties, and the manufacturing and maintenance processes.

The team as a whole discussed their information needs in Design-Build Team (DBT) meetings, and often the people who could fulfill their needs were present at these meetings. The meetings generally focused on the future, looking ahead to anticipate and avoid problems. In the early phases of their work, the meetings focused on their work processes. They needed information about schedules and procedures. For example, they needed to know when their supplier expected information about some of their components. They needed to know how to calculate the costs of test hardware. They considered how to work with one of their smaller suppliers.

When the engineers began to complete their designs, they needed to know whether these designs satisfied all requirements. Would the designed part be strong enough, how much would it weigh, and how much would it cost to manufacture? Did anyone have ideas about ways to improve other attributes of the design, such as ease of maintenance? Experts provided definitive answers to some of their questions. For example, the stress analyst calculated the strength of the part, and the materials expert provided information about weight. To answer other questions, they presented their designs in review meetings where everyone could offer their analysis and suggestions.

Their primary supplier was the focus of many of the team's information needs. They needed information about the supplier's designs, which were represented as CAD models but generated using a different CAD system. Two participants in the DBT meetings were responsible for integrating the supplier's models and the Boeing models, and this integration proved far more difficult than anticipated. Lacking the supplier's CAD models, the engineers were in doubt about the spatial constraints on their own designs.

4.2 Contacting People Directly

The most common strategy for getting information was to ask other people. Because most team members were collocated in the same room, they could easily ask one another questions throughout the workday. Some engineers were focals for subsystems that had been designed for the predecessor system by other engineers on the team. While considering how to improve the older design, engineers often asked their colleagues for advice or for the rationale of their design decisions. They also talked about how their parts would fit together.

Finding the person with knowledge about a design decision was not always so easy, but it was the only source of that information. While reusing information in a prior requirements specification one engineer decided he needed to understand its rationale and contacted the original authors.

"So we had to go through and specify all these things, and I looked though some of the requirements, and I said, 'gee, this doesn't make sense. Why did they do this?' So, I spent a couple days hunting down various people that had been involved with the spec ten years ago and said, 'well, do you remember any of this? Well…I think we did it this way.'"

Early in the project this engineer proposed that the team record its rationale while designing the system, but this was received with little enthusiasm. Others observed that recording rationale would add to their work load, and there was no way to ensure that future design teams would even know that this documentation existed.

The likely source of needed information was defined by roles on the system development team. The stress engineer would answer questions about the stresses that a subsystem would encounter and whether a specific design was sufficiently strong to withstand those stresses. The thermal engineer would answer similar questions about temperature. The engineers could walk down to the factory, just below their office, and talk to the factory representative about installation issues related to their system. Asked whether they talk to the shop floor staff, an engineer said, "Yeah, exactly, what they've had problems with, or you show them a little picture...does this look reasonable? Does this look like something that you'd have a problem with? Yeah, we do that all the time. Just try to keep from adding new problems to the design."

4.3 Invite an Information Source to a Meeting

The most common place for generating and resolving common information problems were the weekly DBT meetings and the meetings with suppliers. One engineer was responsible for the agenda of the DBT meetings. When issues required the presence of people who were not on the team, or were of interest to other people, he invited them to the meeting. In one instance, he invited a Designated Engineering Representative (DER) to tell them about formal requirements. A DER is a highly trained engineer who represents the Federal Aviation Administration (FAA) and interprets FAA regulations. They had just learned that their system would experience greater stress in this new higher performance airplane, and some design changes would be required to compensate. The DER helped them understand the design consequences for their major supplier and for their own designs. This example highlights the important role that people play in communicating the requirements for an airplane and its systems.

Many of the items on the DBT meeting agenda were information needs. Usually, the team discussed the situation and either got answers at the meeting or devised a plan for finding what they needed to know. The team would then decide whether to keep the item for the next meeting. This was done in a systematic manner. It was not unusual for an information item to be on the agenda for several consecutive meetings.

Obtaining information from their major supplier was more difficult, and meetings were one way to obtain this information. They held weekly teleconferences in which they systematically worked through lists of issues. For example, they documented all the interfaces between their parts and the supplier's parts, and they expected the supplier to review, negotiate, and finally approve all these documents. These agreements were critical because they could not complete a design if the interface had not been resolved. They repeatedly asked the supplier for information about their progress reviewing each one of these interfaces.

Infrequently, they held face-to-face meetings in which some engineers flew to the supplier's site or some of the supplier's engineers flew to the Boeing site. These meetings were anticipated as opportunities to answer many outstanding questions. They planned the agendas around these issues.

4.4 Feedback Elicitation

A common strategy for obtaining information was to request feedback about a design or part of a design. The engineers presented the complete but not finalized designs of their parts in the DBT meetings, and these meetings had the most attendees. It seemed that everyone wanted a chance to comment on the design before it was finalized, and many useful suggestions emerged in these meetings. In the first such meeting, for example, the factory representative suggested a change that would make the part easier to install.

The strategy of requesting feedback was not reserved for meetings. When considering a design change, engineers asked more senior members of the team for advice. They produced two-dimensional pictures of their preliminary designs and showed them to the factory representative or specialists. In some cases they sent pictures to their major supplier for comment.

5. COLLABORATIVE INFORMATION SEEKING

Information seeking involves identifying an information need, formulating a query, retrieving information, evaluating it, and applying it to address the need. Collaborative information seeking involves these same activities and also disseminating the retrieved information to the team.

The engineers collaborated in each of these information seeking activities. Frequently one team member brought or raised a question, such as how test hardware costs will be covered, and the teams pondered and discussed, recognizing that they lacked the information needed to answer the question. Sometimes a person outside the team, such as the factory representative, brought an information need that the team took on.

The engineers sought information about design requirements or constraints, and a common strategy was to solicit feedback to a design or design concept. We view the design or concept as a query intended to elicit information.

The division of labor often guided how information was retrieved. One engineer acted as the weights focal, and when an issue arose in a meeting about weights, he was assigned to find the information and report to the team at the next meeting. This method simultaneously addressed how the information would be disseminated.

Another method was to invite someone to a meeting to talk about the needed information. In a meeting they could concurrently acquire the information, disseminate it to the team, and explore related issues interactively. The meeting also provided a forum for evaluating the information and determining how to apply it.

The most common sources of information were people closely associated with the team. We can view these information sources as members of larger teams that included the engineering team. This was, in fact, the accepted view at Boeing, where the larger group was called the Design Build Team, and it in turn was viewed as part of a much larger Systems Integration Team. Collaborative information retrieval by a team often involves retrieving information from a member of a larger team.

6. CONCLUSION

Engineering teams have collective information needs that are met through collaborative information seeking. Seeking and sharing information is an integral part of designing any complex system. Individual designers may have unique information needs that they resolve by seeking information independently. Many of their information needs, however, have consequences for other team members. Any information retrieval activity (identifying information needs, formulating queries, retrieving information, evaluating it, and applying it to address the need) may be performed by an individual on behalf of the team, by an ad hoc group, or by the team working together in a meeting.

7. REFERENCES

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