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Design engineers and technical professionals at work: Observing information usage in the workplace

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This exploratory study examines how design engineers and technical professionals (hereafter referred to as engineers) in innovative high-tech firms in the United States and India use information in their daily work activities including research, development, and management. The researchers used naturalistic observation to conduct a series of daylong workplace observations with 103 engineers engaged in product design and testing in four U.S.- and two India-based firms. A key finding is that engineers spend about one fourth of their day engaged in some type of information event, which was somewhat lower than the percentage identified in previous research. The explanation may be rooted in the significant change in the information environment and corporate expectations in the last 15 years, which is the time of the original study. Searching technology has improved, making searching less time consuming, and engineers are choosing the Internet as a primary source even though information may not be as focused, as timely, or as authoritative. The study extends our understanding of the engineering workplace, and the information environment in the workplace, and provides information useful for improving methods for accessing and using information, which could ultimately lead to better job performance, facilitate innovation, and encourage economic growth.

Introduction

On a daily basis, engineers are some of the heaviest users of information and innovative information technologies. Prior research has indicated that how engineers collect, communicate, and use information can vary greatly between different engineering environments (Tenopir & King, 2004). For example, in the private sector, engineers who deal with each step of the project (design, drawing, testing, etc.), coupled with tight product deadlines, are more likely to make use of information sources that are immediately available, even if those sources are not the best. This contrasts with engineers in academic or research settings, who are more likely to use documents or scholarly journals to satisfy their information needs (p. 58). In the past, our understanding of the habits of private-sector engineers mostly relied on self-reported data. This study extends our understanding of the private-sector engineer who is involved in the design, drawing, and testing of new products in the telecommunication, health devices, and hardware and software industries. The study collects extensive observational data about how design engineers and technical professionals (i.e., engineers) in innovative, high-tech firms in the United States and India communicate and use information in their daily work activities including research, development, and management.

Tenopir and King (2004) also noted that

> Engineers tend to be resistant to change, including adapting to new technologies and innovations. This characteristic reluctance to change extends to how they seek out or use information . . . . The tasks that design engineers do on a daily basis make them some of the heaviest users of information and innovative information technologies. (pp. 40 & 45)

This is an important problem since engineers' resistance to change and the variation in their information habits make it challenging for publishers, librarians, and other

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information providers to design better information delivery and communication systems, products, and services.

This study addresses that challenge by extending our understanding of the engineering workplace and the information environment within the workplace, and by providing a picture of information seeking methods engineers use daily in their normal work environments. The researchers conducted a series of daylong workplace observations with 103 design engineers and technical professionals (hereafter referred to as engineers) engaged in product design and testing in four U.S.- and two India-based firms. Firms in these two countries were chosen because the United States is established as a leader in product innovation in these areas and because India's reputation for work in these areas is rapidly increasing. Studying engineers in each environment, established and emerging, provided an opportunity to compare what is consistent across both environments and what may be different. Researchers used naturalistic observation techniques to record the actions of engineers in their workplace as they carried out their daily work rather than depending on gathering self-reported data. The results of this study provide a unique insight into the workings of high-tech engineers and an understanding of the manner in which they use and communicate information in the 21st-century workplace.

Prior Research About Engineers and Information

How engineers find and use information has been studied for at least 50 years. Tenopir and King (2004) summarized much of what we already know about engineers' information finding and use. Patterns of information use have been identified, and theories have been developed to explain these patterns. Two general themes have emerged from past research:

- Internal communication of any kind is more prevalent in engineering work than is communication with sources external to the organization. Furthermore, engineers tend to rely on their own information and on colleagues before the library and other internal sources (Bichteler & Ward, 1989; Bishop, 1994; Hertzum, 2002; King, Casto, & Jones, 1994; Pinelli, Bishop, Barclay, & Kennedy, 1993; Shuchman, 1982; Tenopir & King, 2004; VonSeggern & Jourdain, 1996).
- The cost associated with the use of an information source is an important determinant of its use, with cost being broadly defined to include ease of access (Bichteler & Ward, 1989; Bishop, 1994; Hertzum, 2002; King et al., 1994; Pinelli et al., 1993; Shuchman, 1982; VonSeggern & Jourdain, 1996).

Past research has shown that internal sources of communication are more frequently used than are external sources of communication. Engineers most frequently use internal sources including an individual's personal library, other information in the building, and a knowledgeable individual nearby (Rosenberg, 1967). In a study of industrial engineers, the top information sources were conversations with colleagues, consulting superiors, and in-house technical reports (Shuchman, 1982). In another study of scientists and engineers working in industrial R&D, it was found that work group, trade journals, handbooks, newspapers, and in-firm experts were the most frequently used sources of information (Chakrabarti, Feineman, & Fuentevilla, 1983). A study of aerospace engineers and scientists solving technical problems showed that the three most important sources of information were personal store of information, a colleague inside the organization, and someone outside of the organization (Von Seggern & Jourdain, 1996).

Some commonalities among engineers' use of internal information sources emerge (Court, 1997). They are:

- There are common access paths undertaken by all designers; those most frequently accessed being colleagues, employees, internal reports, existing drawings, supplier catalogs, and suppliers themselves. These all focused on local sources and verbal communications.
- The size (small, medium, large) of the enterprise did not significantly influence the information accessing path, with each using the same sources with approximately the same frequencies.
- The type of design activity undertaken did not significantly influence external information accessing and sourcing any more than internal information accessing, with each type of design making extensive use of verbal contact with suppliers and personal contacts.

Several studies (i.e., Cave & Noble, 1986; Culley, Court, & McMachon, 1992; Puttré, 1991) have found that design engineers spend approximately 30% of their time searching for and using design information to complete their work. One explanation (Court, 1997) is that engineers tend to use internal, nearby information because it is considered to be a time-saving methodology. It would be expected that if colleagues could not provide the necessary information that the engineer would look to other sources of information within the organization, both individuals and printed materials. This failure to use existing information may be due to the difficulty in locating it and may be a detriment to the success of the project.

Context plays a significant role in choice of information source. Engineers use two types of information as they perform their jobs: technical information and contextual information. Technical information includes documentation on technical solutions and results. This type of information often is included in company archives where it is indexed, and may be searchable. Contextual information includes data on the context of the design process. This type of information is either not documented or if it is retained, it has far less detail than does technical information. Further, contextual information often includes details about why a certain solution was selected over another. Colleagues are often considered the best source for this information since there frequently is no official way to document it (Hertzum & Pejtersen, 2000).

Research has suggested that colleagues play an important role as information sources not only as sources of verbal information but also as facilitators in finding relevant document sources. Among design engineers, several reasons for the important role that colleagues play in the engineers' information-seeking habits were identified: Colleagues

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served as a source of feedback for ideas and designs because the engineers felt their opinions were trustworthy; because the document-storage system was inadequate, often a colleague's recollection of a document was the only easy way, apart from looking through all the files, to find a relevant document; and colleagues were a good source of direction in choosing a person, based on personal knowledge of a person, or solution to a problem (Zipperer, 1993).

There are many factors influencing information-source choice. Several of these factors influence the preference for internal versus external sources of information.

Cost

Cost does not refer to monetary outlay but to the economic definition of the word: the amount of effort expended to obtain information and accessibility of the information. The more experience an engineer has with an information source, the greater the perceived accessibility it has (Rosenberg, 1967). Although these are older studies, they have established a foundation for considering cost since it is still studied in terms of effort and still considered an important factor.

Quality of Information

The relationship between quality of the source and its use is more ambiguous than the relationship between cost and use. While a study found that there is a slight correlation between the technical quality of the source and its use, accessibility still is a major influence (Allen, 1977; Hertzum, 2002).

Trustworthiness of Source

Until recently, it has been assumed that cost was the most important factor affecting the choice of information; however, trustworthiness of the source also influences information-source decisions (Hertzum, 2002). For example, when choosing people-related information sources, engineers prefer people who with hands-on knowledge and experience, especially when they have worked on similar projects (Hertzum, 2002). Individuals with hands-on experience are valued over appointed experts (Nochur & Allen, 1992).

Many important themes, such as the prevalence of internal communication; the tendency of engineers to rely on their own information and that of colleagues; and the role of the cost of information, including ease of access; have emerged in the last 50 years. In that time, new technologies that influence the cost, quality, and trustworthiness of information have been introduced to the engineering workplace. These technologies make it easier to access information from outside the firm and to make contact with those who are not traditional workplace colleagues. These new technologies also influence the ability to assess the quality and trustworthiness of information. This leads to the question "How do design engineers collect and use information in today's high-tech workplace?"

Study Description

Research Participants: Companies

Four U.S. companies and two India companies provided access to a total of 103 engineers. Table 1 describes

TABLE 1. Company descriptions.

Company	Country	Industry	Brief descriptive facts
A	United States	Semiconductors	• Based in the Southwestern United States • Designs and manufactures semiconductors with applications in automotive and consumer electronics, industrial control, motor control, networking, and wireless industries • Design, research, manufacturing, and/or sales operations in more than 32 countries and nearly 25,000 employees worldwide
B	United States	Microcomputer processing chips	• Based on the West Coast of the United States • Manufacturer of microcomputer processing chips, and computer networking and communications products • Employs nearly 100,000 in 294 offices and facilities worldwide
C	United States	Medical devices	• Based in Midwestern United States • Designs, develops, manufactures, and distributes medical products • Employs more than 12,000 people in the United States and Europe
D	United States	Information technology	• Based in New England, observations at Southeastern U.S. offices • Specializes in the production and development of information technologies, including computer systems, software, and networking • Employs more than 300,000 in North America, Asia, and Europe
E	India	Communication technologies	• Based in Central India, observations at Southern India offices • Operations in many areas of business including information systems and communications, engineering, materials, services, energy, consumer products, and chemicals • Employs more than 200,000, with operations in more than 40 countries worldwide
F	India	Information technology services	• Based in Southern India • Produces new business models and solutions as well as leveraging technology and software • Employs more than 39,000 worldwide. Maintains offices in North America, Asia, and Europe

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TABLE 2. Observation numbers by company.

Company	Country	Industry	Engineers Total	Engineers Male	Engineers Female	Observation Mins	Observation Hrs
A	United States	Semiconductors	22	18	4	8,440	140.7
B	United States	Microcomputer processing chips	29	24	5	9,031	150.5
C	United States	Medical devices	9	9	0	3,720	62
D	United States	Information technology	9	7	2	3,190	53.2
E	India	Communication technologies	22	19	3	7,456	124.3
F	India	Information technology services	12	10	2	3,766	62.8
Total	United States		69	58	11	24,381	406.4
Total	India		34	29	5	11,222	187.1
Total	Full Study		103	77	16	35,603	593.5

the companies and establishes the range of industries and products included in this study.

Participating companies were identified by the granting agency and were classified as innovative, high-tech firms in the software, hardware, medical device, and telecommunications industries. The granting agency contacted the targeted companies, provided details of the study, assured them of confidentiality, and asked them to participate. Nondisclosure agreements were signed with all firms that agreed to participate in the study. Once a part of the study, management within each firm designated which engineers would be included as participants, and further contact and observation were conducted by the researchers.

Research Participants: Individuals

At each company, the engineers were responsible for innovative work on products or product platforms. Two thirds (67%) of the sample were engineers at U.S.-based companies, and the remaining third were at India-based companies (Table 2). These engineers were observed for a total of 593.5 working hr (406.4 working hr in the United States, 187.1 working hr in India). The term *working hr* is used because our observations include multitasking minutes in which the engineer may be engaging in two or more activities at one time.

The individuals who participated in the study were active members of a design and development team for a product, service, or system; however, within these criteria, the participants held a variety of project roles and responsibilities, and their tenure at the firms ranged from new hires to experienced senior staff. Examples of participant job titles were Senior Component Design Engineer, Micro-Architecture and Logic Design Manager, Principal Electronic Engineer, Computer Scientist and Project Manager, Software Engineer, Advisory Programmer, Validation and Testing Engineer, and Technical Lead (Table 3).

Departmental staff members and those providing administrative support or lower level project-team support were not included in the study. Men and women of all ethnicities were eligible for participation. The participants were selected by the organization being studied; the researchers had no input into which employees would be observed.

Methods

This study used two methods to gather data in the workplace setting: naturalistic observation and structured interviews. Naturalistic observation, also known as "shadowing," has been used in a number of information studies, including those that have observed the information behaviors of security analysts (Baldwin & Rice, 1997), psychology academics (Eager & Oppenheim, 1996), and social services departments (Wilson & Streatfield, 1981). It also has been used to study use of the electronic environment among music students (Notess, 2004) and use of Web interfaces by test participants (Thompson, 2003). Naturalistic observation also has been successfully used to study information behaviors of Microsoft engineers (Fidel, Pejtersen, Clean, & Bruce, 2004). However, this is the first study to use naturalistic observation to study the communication and information-seeking habits of engineers at multiple organizations and in multiple countries.

Some studies that have used naturalistic observation required the observer to maintain a socially acceptable distance from the person being observed and also that the observer not interfere with the tasks or habits of the worker (Eager & Oppenheim, 1996; Thompson, 2003); however, those studies focused on information-seeking behavior (Fidel et al., 2004; Notess, 2004; Wilson & Streatfield, 1981) and allowed the observer to interact with the participant to clarify issues related to the information or communication event.

For this study, engineers were observed in their workplace as they conducted their daily responsibilities. The events of an entire workday were captured (including lunch, meetings, etc.). Data collected included observations about the physical work environment, the nature of communication, the use of information, and the type of technology used. Coding sheets were developed specifically for this study prior to initial observations based on an analysis of prior research and the types of activities that were reported. Additional activities were added to reflect the new technologies in the workplace.

TABLE 3. Examples of participant engineers' job titles.

Design Engineer	Technical Architect
Integration Design Engineer	Research Associate
Design Lead Engineer	Senior Consultant
Verification Engineer	Principal Architect
Design & Verification Engineer	Marketing Manager
Intellectual Property (IP) Design Manager	Software Engineer
Design Project Leader	Senior Research Associate
Senior Design Engineer	Principal Electronic Engineer
Design Manager	Analog Engineering Team Lead
Physical Verification Engineer	Advisory Programmer
Principal Engineer	Computer Scientist and Project Manager
Senior Design Engineer	Software Engineer/Quality Test Team Lead
Senior Staff Component Design Engineer	Advisory Software Engineer
Second-Level Manager	Senior Specialist
Senior Component Design Engineer (Validation)	Staff Engineer
Principal Design Engineer	Senior Staff Engineer
Design Engineer	Senior Staff Design Engineer
Validation & Testing Engineer	Principal Engineer
Senior Electronics Engineer	Validation Engineer (Architecture)
Software Engineer	Micro-Architecture and Logic Design Manager
Manager	Technical Lead
Specialist/Project Leader	Senior Software Engineer
Manager	Specialist
Engineer	Project Manager
Research Management Specialist	Senior Project Leader
Senior Engineer	Project Leader
Specialist in Networking	Software Team Leader
DSP Multimedia Specialist	Senior Specialist

After observations were completed at the first company, the team reviewed the performance of the coding sheet and made revisions to the observation instrument. We also added a special form for organizational meetings specifically designed to capture the context, activities, and key events that occurred during these interactions. These changes did not result in new or different data being collected at the later firms but it did improve data collection and coding. Three activities were conducted to increase intercoder reliability. First, prior to any observations, all research team members received training to learn how to properly assign what they were seeing to coding sheet categories and how to properly identify the time devoted to each activity. Second, after each day of observation, researchers met to review the work of the day and discuss any questions. Third, data entry from the coding sheets was reviewed by a research team member who had not done observations.

This study allowed research team members to directly communicate with the participants at various points throughout the workday. These discussions were used for clarification of what they were observing to get detailed explanations about information resources and communication processes being utilized. These conversations also aided the ability to build a sufficient level of trust and comfort with the participant. In addition, this communication also allowed the engineers being observed to communicate their feelings or thoughts about certain types of software or communications methods. Observed engineers also could respond to events observers may have witnessed in the structured interview.

To protect the proprietary nature of the work being observed, observations were recorded at a general level of granularity. For example, the data did not include specific product and personnel names, activities, or proprietary information, and the specifics of a communication event (e.g., name of the other participant) were not recorded. Observations were classified as either communication events or information events.

All but one of the observations were conducted from 9 A.M. to 5 P.M., although many of the observed employees arrived before and/or stayed past these times. One observation began at 7:00 A.M. so that the observer could be present for a virtual staff meeting with employees from offices throughout the United States, Europe, India, and China.

Data were monitored and recorded in 10-min increments (Table 4). After each 10-min period, the observer began entering data on a new coding sheet. Both the duration of the event within the 10-min increments as well as the total duration of each event were recorded. For example, if a phone call started 5 min into a 10-min observation period and lasted for 10 min, it would be recorded for 5 min in the first observation point and 5 min in the second observation point, and that the call lasted for a total of 10 min.

After the data were collected, a dataset was developed to standardize terminology and to provide a consistent way to handle data collected in each communication and information-event type. For each event, the time, duration, total time, type of event, technological medium, description, and an explanation of the event were coded and entered into

TABLE 4. Overview of Coded Event categories.

Communication events	Information events
PHONE: Cell/land; recd'/made; duration	JOURNAL/MAG/BOOK: Browse/ purposeful search Type: hard copy, electronic copy, facsimile, Publisher,
F2F: scheduled/casual; type; partner; duration	Title, Content Reason for use, Length of time
MEETING: same office/other office Meeting sheet; Duration	INTERNET: supplied link/search product, publisher/site, Title, Content, Duration
WRITING: Report; Notes; Content; Purpose	SOFTWARE TOOLS: word processing, Web browser spreadsheet, CAD, database Other:
E-MAIL/IM/PAGER read/ written, duration purpose	Visualization/No. of windows open

the data file. Research team members coded their own data for each person they observed. Information from the observation sheets was collected by the data manager, and a master file was constructed.

Researchers also used a project-designed drawing form to sketch the participant's office/cubicle to capture the physical layout of the workspace. These sketches included notations about desk space, shelf space, and the presence of information containers such as books or journals.

While the naturalistic observation component of the study allowed observers to collect actual incidents regarding communication and information events, such as intranet searching or e-mail use, the structured interview allowed observers to collect feedback from the engineers themselves on the structures and methods currently in place to facilitate communication and information needs. At a mutually agreed time during the observation, the researcher conducted a short, structured interview. If the respondent gave permission, the interview was recorded. In all interviews, the team member took brief notes. The interview lasted no more than 45 min, and demographic data and information about the participant's work roles and responsibilities as well as questions about preferences and opinions of information resources were collected. The interviews also explored how technical professionals believed work patterns and information use might change in the future. Team members transcribed interviews that were recorded and wrote field notes on those that were not recorded. All of the observed employees agreed to the interview.

To ensure participants' anonymity, all tapes on which interviews were recorded were destroyed after transcription. Moreover, the participants' names were not used on the data-collection instruments. To protect the participants' identities, each participant was assigned a code number which was used to label all the data instruments. The participant's name was associated only with this code number on the Principal Investigator's master sheet.

The overall study examined information and communication events as well as meeting and multitasking behavior, and the cultural components that influence each of these. However, this article focuses on information events, which we defined as activities involved in the search for knowledge. We identified three major categories for information events: (a) the use of software tools, (b) the use of the Internet, and (c) the use of print documents (i.e., reading a journal, magazine, or book). E-mail and instant messaging, which were found to be important conduits of information sharing, are discussed in another article. *Software tools* included, but was not limited to, applications for word processing, Web browsing, spreadsheets, databases, and computer-aided design (CAD). Observers recorded the use of the tools and, when possible, the type of tool. *The Internet* included all activities that made use of the Internet, such as using search engines, linking to sites for work-related information, finding information for personal use, and accessing Web e-mail accounts. When possible, observers noted if the engineer was using a supplied link (e.g., a link embedded in an e-mail) versus a site that was visited after a search. Intranet usage also was identified and recorded. *Reading* included recording the format of the item (e.g., a hard copy either directly from a publisher or printed off the Internet, an electronic copy, or a facsimile). The content of the item was recorded in terms of the nature of the information (i.e., scientific, technical, business, etc.). If possible, the identity of the item (e.g., publisher or title) was recorded. Observers noted whether journals, magazines, and books were browsed or purposefully searched and whether the copy was electronic or hard. Observers also tried to capture the reason for using this item. The length of time an item was used also was noted.

Information events are characterized in terms of the number of incidents and the number of minutes spent on each information event. An incident is counted each time an engineer engages in an information event, no matter how long the duration. The minutes record the amount of time the engineer spends on that information event, regardless of whether that time represents one continuous use or multiple short uses.

Results

Information events account for one fourth (25.6%) of the engineers' minutes during the day (Table 5). Most companies (in both the United States and India) fell within a similar range in terms of percent of the day minutes spent on information events; however, Company D, which specializes in software information technology development, was markedly more engaged in information events than were the

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TABLE 5. Information Events as percent of minutes observed in the firm.

Company	Country	Industry	No. of engineers	Total no. min observed	Info events as % of total min of observations in *each* firm
A	United States	Semiconductors	22	8,440	24.8
B	United States	Microcomputer processing chips	29	9,031	21.4
C	United States	Medical devices	9	3,720	18.4
D	United States	Information technology	9	3,190	42.2
E	India	Communication technologies	22	7,456	27.0
F	India	Information technology services	12	3,766	27.8
	Total		103	35,603	25.6

other companies (42.2% of the observed minutes vs. an average of 23.9% for the other five companies). This suggests that there may be significant differences in the information needs or corporate culture of that firm. We believe that the high percentage of minutes engaged in information events reflects Company D's role as an innovator in information technology software development. What set Company D apart was that the focus was on building and testing new software that would be tailored for customers, rather than building customer-initiated software products (Company F) or hardware devices (Companies A, B, and C).

This analysis first will report the results for the three major information categories and then look at these categories on a company-by-company basis.

Software

The software category included the following applications: word processor, Web browser, spreadsheet, CAD, and databases. Using software was the most prevalent information event taking place at each company in terms of the number of incidents occurring and the number of minutes devoted to it. Nearly three fourths of all information incidents recorded at each firm related to software uses. In terms of information event minutes, software usage accounted for between 73 and 92% of minutes at each company.

There was a wide range of software in use. Engineers in both the United States and India used browsers to access the Internet and to access the intranet of several firms. Internet Explorer was the prevalent browser in use. Only a couple participants at Company D used Firefox. A more in-depth discussion of Internet usage follows this section.

The majority of operating systems were Windows based, although a few firms had some systems running on UNIX. The notable exception was in India, where one firm ran on a Solaris system.

The Microsoft Office Suite was used almost exclusively across all the firms for word processing (MS Word), presentations (MS PowerPoint), spreadsheets (MS Excel), and e-mail/calendar functions (MS Outlook). In India, we also saw the use of MS Project.

Adobe Acrobat reader was heavily used to read documents downloaded in that format; however, we did not observe any instance of the program being used to create a document or to make notations on an existing document.

In terms of writing code, we saw code being written in MS VC++ and JAVA. One of the India firms also used WinCVS, a free software distributed with the GNU General Public License that works on Windows operating systems for monitoring versioning of C++ code. At times, Notepad was used while working on building or debugging code.

Most of the database work was completed on proprietary systems, and it was not possible to determine the software being used.

CAD software was used extensively in two firms for running simulations, conducting tests, and printing out schematics. Determining the specific CAD programs was not possible, and Company A used proprietary CAD software.

Software usage among engineers was well below average in Company C, where medical devices were being designed and tested, often in a mechanical, lab setting. Software usage was above average at Company B, where hardware was being tested using several software programs. Software usage among engineers at Companies A, E, and F was slightly above average. This suggests that engineers at these firms all had responsibilities that were highly reliant on using software.

Internet

Internet usage was the second most common information activity at five of the six companies. Company C was the exception, where Internet usage was engaged in less frequently and for fewer minutes than was reading. As noted earlier, reading might be taking place using the Internet.

At each of the U.S. companies, the percentage of incidents of Internet usage was higher than the percentage of information minutes it accounted for. This was particularly true at Company A. This shows that contact with the Internet is frequent, but the duration of each interaction is not long. It also suggests that the India companies rely more heavily on the Internet for information provision and connectivity.

The Internet is used for a wide variety of activities, ranging from work-related Web searches to connecting to documents from links embedded in e-mail to occasionally gathering information for personal use. The Internet was used to find information that would help with work-related issues such

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TABLE 6. Comparison by firm of engineer participation in each type of information event.

Company	Country	No. engineers	Internet	Reading	Software
A	United States	22	Average	Slightly below average	Slightly above average
B	United States	29	Average	Below average	Above average
C	United States	9	Well below average	Above average	Well below average
D	United States	9	Average	Average	Average
E	India	22	Well above average	Well above average	Slightly above average
F	India	12	Slightly above average	Slightly below average	Slightly above average

as open source code (i.e., user-community repository), technical specifications (e.g., www.iso.org), coding information (e.g., rfidjournal.com), requirements for a conference-paper submission (ACM's proceedings), technical discussions (slashdot.org), reference (www.libraries.rutgers.edu), and definitions (mathwords.com). There also was interest in monitoring the industry via such sites as siliconvalley.com

Web searches were conducted for many reasons. These included looking for solutions to code problems that might be listed in online communities, finding information about conferences, looking for a specific article, or re-accessing a specific community that had been visited in the past. Google was the most used search engine, and only a few searches were recorded using any other search engine such as Yahoo or Vivismo. Google was seen as a way of finding materials that the engineer knows are there, but are hard to navigate to. For example, an engineer noted that "I went to an IEEE site first, and they didn't seem to have the information I wanted, so I just did a Google search and it was at some university website it seemed." Another engineer mentioned that the company set up a public library of documentation so that external customers could access documents, and that it was easier to use Google to find these articles than to go through the company's internal publishing system. Another engineer said he would like to create a Google for his company. Another noted that "If there's a paper I need to find, I can either go to the IEEE Explorer which is accessible to me, or I can try to find information directly in a Google kind of search."

While the use of Google was quite common, engineers did see limitations. One noted:

> I thought about going to Google, but I realized that it is not a silver bullet, and you have to sift through a lot of stuff, and I realized that I have this experience and I probably have documented it.

Other engineers preferred to bypass Google and turn to fellow workers to find the answer. For example, "People work differently. I know [coworker] loves to use google.com for just about everything. I don't directly go to Google. I tend to go to other people first or to the code directly." Engineers also noted using the intranet to find internal documents or hard-copy books provided by the company, although during the course of our observation, we only recorded two cases of a book being used.

The Internet also was used to gather personal information. For example, we observed people using embedded links from e-mail to visit financial sites (including e-trade) and scuba sites. We also saw people check their company stock quotes, real estate listings, news, and cricket scores (India). In India, one engineer also accessed www.telugupeople.com, which is a site that provides information for people of this particular language group. Engaging in behavior outside their prescribed work suggests that the engineers were behaving naturally while being observed and that the Hawthorne effect (discussed later) may not have been very strong during this study.

In terms of comparing engineer participation in Internet usage, only Company E had noticeably higher levels of engineer participation compared to the other firms. We believe this is because the team we observed was in a phase of the design cycle that required connectivity both within (intranet sources) and outside (Internet sources) the company. The other firms were involved in product development that was more localized within the firm. We also believe that the design cycle may explain the situation at the company with the lowest level of Internet usage. This team had only a few members engaged in designing a new product for the platform while most team members were working on testing in traditional lab settings.

Reading

The use of journals, books, and articles also was recorded, and it was the information activity that was least engaged in at all but one firm. The exception was the medical device company, where about 10% of the information-event minutes was spent on reading. Reading material included a small number of journal or professional articles, product specifications, and project documentation. Additionally, a small amount of reading contained general news and corporate news. Most reading took place with electronic files. There was one notable exception of an engineer who had boxes of printed-out materials throughout his working space; however, even then, the longest interaction we saw this engineer have a print document was about 4 min.

There were only two cases where we observed engineers using books. In one case, it was a book referred by a colleague (for 4 min); in another case, an engineer used a LINUX reference book to look up a command (for 17 min). Although 1 engineer commented "My textbooks from school—they're golden," and we did see some textbooks in workspaces, we never saw them in use.

The other type of "hard-copy" reading we observed was engineers referring back to their own notebooks of comments

DOI: 10.1002/asi

and observations. One company encouraged all engineers to keep handwritten journals that recorded all development and testing activities; however, these notebooks were being systematically digitized so the results would be in the corporate repository, and there was discussion of having the engineers keep these notebooks electronically in the future.

We did not observe the use of journals in the traditional article container; however, we did see some use of journal articles in the electronic environment, including from the IEEE DL, from the proceedings of the ACM SigGraph, and from professional journals. The range of topics included reengineering and developing products at their own and competitive firms. Electronic newsletters from professional societies and in-house also had some use.

The only specific mention of book titles was the O'Reilly series of technical books safari.oreilly.com; however, the search for an appropriate title was mentioned:

> Typically, I just go to Amazon and if there's a topic I'm searching for a book about, I go to Amazon and search for the topic and read the average customer reviews and try to get an idea whether it has the subject matter I'm specifically looking for.

Engineers also spent time reading PowerPoint presentations that they had received in their e-mail. These were usually presentations they had seen in a meeting or would be seeing in a scheduled meeting.

In terms of engineer participation in reading, only Company E was well above the average. This suggests that the company's focus on development was building on and extending existing knowledge in a manner that encourages the use of existing materials. It also may suggest that the corporate culture at the firm was patterned more directly from a research university, that the team we observed was headed by a someone with a PhD in physics who valued traditional research practices, or both. Companies A and B were both below average in their participation in reading.

Discussion

This study was conducted to answer the question "How do design engineers collect and use information in today's high-tech workplace? The results will be discussed within the framework established by the findings from the past 50 years: the prevalence of internal communication; the tendency of engineers to rely on information from their colleagues; the role of the cost of information, specifically regarding ease of access; and concerns for quality and trustworthiness. Additionally, we will discuss how engineers engage the overall information environment at their firms.

Prevalence of Internal Communication

Confirming previous research, we found that engineers are still depending heavily on gaining information from internal sources such as other colleagues and, to some degree, from institutional document repositories (e.g., internal reports) and existing drawings. Also confirming earlier studies, we observed many engineers contacting suppliers or vendors for further information, which is a natural extension from fully internal sources. However, we did record a change in engineer behavior, as they are regularly using the opportunities provided by the Internet to easily access information from outside resources. This information source was particularly useful for software developers, who used it to tap communities of developers for solutions to specific problems. The Internet also provided easy access to industry-related news, an information source that had value to many of the engineers we observed.

Relying on Information From Their Colleagues

Once again, confirming prior research, we found that engineers continue to follow the traditional path of seeking needed information from colleagues. However, what we found that differs from the past is that engineers often make another stop before consulting colleagues: They frequently are making the Internet the first stop, particularly to use a favorite search engine such as Google. If this does not produce the answer, then the engineer follows the more traditional path of contacting colleagues as an information resource both as providers of particular items of information and as facilitators for finding relevant sources.

Although engineers often first consult the Internet, we still observed engineer information seeking and use behavior that confirmed the three key reasons for using colleagues noted by Zipperer (1993). First, colleagues were regarded as trustworthy providers of feedback for ideas and designs. At each of the firms, we saw examples of engineers going to a teammate to discuss development and design issues. Second, there were some engineers who used a colleague's recollection of a document or of where to find a document rather than relying on an information system that they found inadequate. For example, at Company C when an engineer could not find a blueprint of a component in the corporate document repository, he asked colleagues to help him recall the information and find the document. This suggests that if an engineer at the firm is thoroughly trained in the information-seeking skills or products, his knowledge may be disseminated to others through naturally occurring events in the course of a workday.

Third, colleagues were regarded as a good reference for choosing a person, based on personal knowledge of a person, or as a solution to a problem. Engineers were clearly comfortable with a very inclusive definition of colleague. For example, the software engineers at Company D felt comfortable going to an online development community, although they would not fit the traditional definition of colleague.

We did find that communication paths (e.g., face-to-face interaction) varied considerably between firms, and it appears that this may be linked to company size among those firms observed.

Role of the Cost of Information: Access

Confirming earlier research, we found that cost, in terms of the principle of least effort, continues to be an important

DOI: 10.1002/asi

consideration, particularly in regards to ease of access. Interestingly, as new technologies introduce different cost-effective options, engineer behavior is changing. For example, while internal sources were generally preferred, several engineers noted that using search engines such as Google was much easier than working through corporate information systems that accessed external documents. This created a point of dissonance for the engineers because they found the internal sources more trustworthy, but they preferred the low cost of access provided by Google. This point was highlighted by the comments that several engineers made that they would prefer for the internal systems to have interfaces that were as easy to use as Google.

Quality and Trustworthiness of Information

The quality of information in terms of the quality of its content is important to engineers because they want to be sure that what they are building is based on something technically reliable. This is the one area that aligned with the past in terms of using internal resources since the cutting-edge work often required the use of internal sources because there was no external information available on specific items. However, cost was still important. An engineer might choose between finding the hard-copy document and using the electronic system by calculating which retrieval task would cost the least effort.

The trustworthiness of the resource is perhaps more important than it has been in the past since some engineers seemed to recognize that the Web sources they are using are not of a guaranteed trustworthiness. They seem to address this by working with online communities that they know (e.g., a developers' group).

Interestingly, we also recorded many instances of the use of contextual information, which engineers trusted because it was "born" within their environment. In the past, this type of information was often undocumented, or vague if it was recorded. We found that this has changed considerably with the use of current information and communication technologies that allow for this information to be captured in a way that makes it more trustworthy. For example, e-mail is being used to document the design process and to create an archive that explains decisions. Some systems of instant messaging have an archival capability, and these are being used in a similar manner. While this means that contextual information is being captured, it also is clear that there are weaknesses in how this information is being organized and accessed. These technologies were created for communication, and the way engineers are now using them as information technologies raises new challenges in creating tools to deal with these unique information containers.

Engineers in Their Information Environments

Our finding that engineers spend one fourth of their day engaged in some type of information event was somewhat lower than the percentage identified in previous research for the amount of time engineers spend searching and using information. We feel that the explanation is rooted in the significant change in the information environment and corporate expectations in the last 15 years, which is the time of the original study. For example, information is more readily accessible, so a search is less likely to be as time consuming as it was in the past. As noted earlier, the path for information seeking has a new first stop: the Internet. Firms also are asking their engineers to stay ahead of the competition, and the press of competition in the engineering field has increased in this time frame. Engineers are less likely to feel that they have as much time to spend on information-seeking tasks. This could have huge implications for the innovation process in terms of losing time on projects that might have pertinent research published, but not easily accessible through the engineer's first stop: Google.

This situation seems to be prevalent at all the companies we visited. The amount of time spent on information events was relatively consistent among five of the six firms. The one exception was Company D, a software firm. The observed employees at Company D spent 42% of their day engaged in information events, significantly more than at any of the hardware firms. One possible explanation for this difference was detailed in the research findings, as one difference between hardware and software creation is that once a software problem or feature has been created, it is often shared with others so that time reinventing the application is not wasted. Therefore, software engineers spend substantial amounts of time determining if the problem has ever been addressed. If the research is fruitless, they know that they must engage in the development of the solution. Thus, we believe that the high percentage of minutes engaged in information events reflects Company D's role as an innovator in information technology software development.

Further details on the information events that define the engineers' environment include that the use of software by these engineers was similar to that used in most offices and included a word processor, Web browser, spreadsheets, CAD, and databases. Software usage accounted for between 73 and 92% of all minutes at each firm. Internet usage was the second most common information activity at five of the six companies. One interesting finding was that the percentage of incidents of Internet usage was higher than the percentage of information minutes it accounted for. The Internet is used for a wide variety of activities, ranging from work-related Web searches to connecting to documents from links embedded in e-mail to occasionally gathering information for personal use. Further, the Internet search engine Google was heavily used to find information that would help with work-related issues. The use of journals, books, and articles also was recorded, and it was a distant third in terms of information activities at five of the six firms. The only exception is Company D, the medical-device firm where about 10% of the information-event minutes were spent on reading. Reading material included a small number of journal or professional articles, product specifications, and project documentation as well as a small amount of reading about general

DOI: 10.1002/asi

news and corporate news. Most reading took place with electronic files.

Insights Gained From This Study

As in earlier studies, we found that context played a role in the engineers' choice of information sources. We recorded significant use of technical information. For example, the use of corporate document repositories at Company C to review prior designs and other platforms as well as details of products being designed for this platform. Another example was the way engineers at Company D referred to specifications and software communities for solutions. However, Company D did suggest that there is a new twist on the use of this type of information. Traditionally, this information has been found in company archives and is searchable through structured records. However, the pattern of use at Company D suggested that engineers are now seeking technical information outside the domain of their own company and that they are relying on search engine technology to access it. While this may not yet be pervasive, or it may be mostly confined to software development, it is an important consideration for corporate information system design.

We did gain new insights about how engineers use information. For example, we found that engineers are not as dependent on published research as much as would be expected from earlier research; however, they are very dependent on the information being produced by team members, especially if they can uncover it quickly. Thus, e-mail and instant messaging have taken on an important role in the everyday work of many engineers. These have particularly enhanced an engineer's ability to improve domain-specific knowledge through instant connection to designers working with similar items. It also helps with the timely transfer of procedural knowledge between contacts both within and outside the company.

We also discovered that the teams we observed were constructed in two different ways, and this affected their information needs and information seeking. Using Vincenti's (1990) categories of engineering knowledge was useful in making these distinctions. One team structure focused on a very limited number of these categories and had most team members engaged in activities related to this category. For example, at Company B, engineers were particularly focused on testing processes which would be classified as falling in the criteria and specifications category. The other team structure addressed many of the engineering-knowledge categories, and work in these categories was spread out among the different team members. For example, at Company C, the team was composed of a design engineer who was concerned with theoretical tools and fundamental design concepts and another member who was concerned primarily with testing, which falls in the criteria and specifications category. These team structures may provide a framework for understanding the differences we found in the number of engineers engaged in different information activities since the team structure helps define the tasks and responsibilities of each member.

Limitations

This research was conducted rigorously, but there are some limitations that relate to the following areas:

- Terminology: Acronyms were heavily used in each work environment. Observers would note when an acronym was used and would ask the participant to define it at a time that would not interrupt the engineer's workflow.
- Observer position: On some occasions, data collection was limited because the observer was positioned to be unobtrusive.
- Phone calls: On some occasions, data collection for phone calls was limited because it was difficult to determine what was happening with the mediated partners.
- Incomplete data capture of interviews: This happened infrequently, but occurred because of recording equipment failure, permission not granted by the participant, or it was difficult to hear everything on the tapes.
- Proprietary limitations or limited access: There were times when we were asked *not* to record data because of its proprietary nature, or were not admitted to a meeting because some meeting attendee was concerned about privacy (only one occasion).
- Hawthorne effect: An observational study of this nature always raises questions related to the Hawthorne effect, and the concern that the participant's behavior may have changed as a result of being observed. The members of the research team attempted to minimize this effect by taking every precaution to be as unobtrusive as possible and to fit into the workday as seamlessly as possible.
- Respondent biases: As noted earlier, the companies and dates of observations were arranged by a third party, and the observees were selected by their superiors. Thus, the observees may have stronger relations with management, may be considered to be the best workers, and may have been overly eager to participate. Thus, the researchers may not have received total pictures of the working environment.
- Product-development cycle: While all the firms were engaged in engineering activities, the timing within the product cycle was different at each organization. Prior research has demonstrated that in the early part of the product-development lifecycle, there would be more brainstorming and information-dissemination meetings; however, during testing and verification, there are fewer meetings as the workers need to complete these tasks individually.

Conclusion

Engineers are contributors to the economic engine of a nation, and their work relies heavily on the ability to find, use, and share information. Over the last 50 years, the study of engineers' information-seeking habits has produced a significant body of research. Findings from this research identified several recurring themes: the prevalence of internal communication; the tendency of engineers to rely on information from their colleagues; the role of the cost of information, specifically regarding ease of access; and concerns for quality and trustworthiness. This study adds to that literature by offering insight into how engineers work in today's high-tech workplace. Most significantly, while engineers maintain many of the traditional attitudes toward information in terms of the themes noted earlier, we recorded evidence that

DOI: 10.1002/asi

information technology, primarily Web search engines, is creating a shift in engineer information-seeking behavior. This shift towards using an Internet search engine before asking a colleague suggests that engineers are changing their values from a focus on ease of access *and* quality towards only considering ease of access. This suggests that engineers would benefit from tools that help them assess the quality of the information they are finding on the Web since they cannot count on it being filtered by their colleagues. Future research should concentrate on how this change is affecting workplace systems and workflows, and how information quality can be addressed so that the preferred style of access also can provide trustworthy access.

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