

Creating Shared Information Spaces to Support Collaborative Design Work

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Abstract

The provision of computer support for collaborative work is a central concern for Information Systems (IS) research and practice. In this paper we present the details of an information flow study undertaken in the household division of a large European design and manufacturing company (Delta) with the goal of eliciting and refining the user requirements for designing a computer system to facilitate the collaborative work of new product design teams. These requirements form the basis for the design and development of a Web-based LIRÉ (Living Repository) prototype system, the functionalities, features, and rationale of which are discussed. A re-implemented production version based on the prototype using commercially available software is currently in use by the New Product Development group at Delta. We also present the results of the evaluation of LIRÉ by the users at Delta and our observations on enhancing the sophistication and usefulness of this class of systems.

Keywords: Workflow systems, collaborative work, repositories, information flow studies.

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1.0 Introduction

Over the past decade, there has been a pronounced shift in the focus for designing and implementing support systems and related artifacts from individual decision makers to groups engaged in collaborative work. While some of the early research reflecting this trend addressed questions relating to group problem solving and work in the context of electronic meetings, a growing stream of research has targeted the problem of providing computer support for both co-located and distributed work. There is some evidence that with the emerging developments in information technology (IT) in general and the internet and the world wide web (WWW) in particular, the effectiveness and sophistication of such system solutions are improving. However, significant problems still remain (Schmidt, 1998b). Concomitantly, changes in the structure of contemporary organizations resulting from trends such as greater competition and globalization have intensified the demands for higher levels of support for distributed, collaborative work (Barnatt, 1997).

In this paper we build on the major concepts, theories, and debates in the areas of computer support for cooperative work (CSCW) and workflow management systems (WFMS) to motivate and advance research in the area of design, implementation, and testing of computer systems to support (primarily) asynchronous, distributed, collaborative work. We explore and attempt to extend the notion of shared information spaces in the context of defining, building and testing the LIRÉ (Living Repository) system to assist a group of product designers in the household division (Delta) of a large European design and manufacturing company. This work was done from 1996 through 1999. Some of the major methodological challenges in this endeavor are outlined and the information flow analysis method employed to elicit and refine the user requirements is presented. We also provide a description of the resulting LIRÉ system in terms of its functionalities and features, along with its links to user requirements. Some of the key problems encountered in on-site implementation of the system are discussed. LIRÉ system is currently in use at Delta following a re-implementation of the prototype to meet the scale and robustness requirements.¹ The results of the evaluation of the system by the first group of users will be presented in summary form.

The rest of the paper is divided into six sections. The background and a review of the relevant literature are presented in section 2. The information flow study details and the process of refining the user requirements are discussed in the third section. Section 4 is devoted to a description of the LIRÉ system in terms of its critical features and user interface. The results of the evaluation of the LIRÉ system are summarized in section 5. Section 6 provides a brief comparison of LIRÉ with other document-centric collaboration systems. The final section

¹ The system in its original and newer versions is also in use at other places, including at Carnegie Mellon University, where is it used in Product Design courses.

includes a brief outline of ongoing work on extending LIRÉ into a composable collaborative system architecture and conclusion.

2.0 Background

A significant body of IS research has examined a range of questions dealing with the provision of synchronous support for electronic meetings, negotiations, and related group work. However, it is only with the emergence and flowering of the area of inquiry that come to be known as ‘computer supported cooperative work’ (CSCW) that research attention shifted to developing a comprehensive understanding of the complexities of collaborative work. CSCW research grew out of what was perceived to be some of the critical limitations of the office automation research program with its emphasis on automating office processes and procedures. The thrust of much of this research has been on developing an in-depth understanding of the practical contingencies of work practices. This body of work argues that such an understanding is indispensable to the design of effective system that bears on cooperative group work. The social and organizational contexts in which such systems are embedded are also brought under close scrutiny.

In contrast, the workflow management systems research has its origins in the business process reengineering (BPR) school with its focus on developing models of business processes and the associated workflows in order to design the systems needed to effectively manage these processes (Hammer and Champy, 1993; Barua et al. 1996). The processes may be intra- or inter-organizational and typically cut across multiple functions such as purchasing, inventory control, manufacturing, sales, and accounting. The specific set of tasks, resources, and information elements involved in the fulfillment of a business process such as order fulfillment or new product introduction constitutes a formal definition of a workflow (Basu and Blanning, 2000). Implicit in the workflow logic is the assumption that all possible exceptions and contingencies associated with the process can be modeled and that the systems designed to facilitate the workflow can be sufficiently adaptive.

It is not surprising that the above two rather divergent perspectives on modeling work and designing computer systems to support work processes have contributed to an as yet unresolved debate. Proponents from either camp have argued over the merits of the ‘map’ approach (shared information spaces that provide contextual guidance and support) and the ‘script’ tradition (automated workflow systems with the ability to deal with contingencies that script a set of sequential and parallel tasks) (Schmidt, 1997). The former tends to be skeptical of the status and value of formal constructs and representations such as plans, process models, and workflow specifications and their efficacy in coordinating a set of pre-determined tasks to enable groups to function more effectively. Based on insights from the interpretive tradition in sociology and anthropology, CSCW researchers seem to concur with the ‘situated action’ perspective articulated by Suchman according to which plans and process models are best thought of as “...resources for situated action but do not in any strong sense determine its course. While plans presuppose the embodied practices and circumstances of situated action, the efficiency of plans as representations comes precisely from the fact that they do not represent those practices in all their concrete detail.” (Suchman, 1984, p.52). The somewhat minimalist design guidelines

emanating from this school of thought emphasize the creation of shared maps and the crucial role of mutual awareness as the work process unfolds over time.

The script view embodies a relatively mechanistic representation of work practices according to which a process model and a computer system based on the model will and should form the basis for the efficient execution of work processes. Furthermore, it suggests that such an approach is unavoidable to ensure smooth workflows when dealing with large-scale cooperative work arrangements in which significant interactions and inter-dependencies between subsystems are likely to be present.

Given the nature of the asynchronous collaborative design work that we attempt to support in this project, the shared information space approach based on the 'map' metaphor appears more appropriate. The process supported involves the development of new products or redesign of existing products and it typically involves small groups of 15-20 designers and support staff working in cooperative ensembles for periods ranging from 9 to 18 months. Processes of this nature do not lend themselves to rigid process modeling and detailed specifications of workflows and information inputs. Bannon and Bodker (1999) have examined some of the key features of shared information spaces to facilitate sharing of information and collaboration in groups of this ilk. Similar to the idea of 'design space' articulated by Sharrock and Anderson (1996), shared information space is an analytical conception in which actors create the shared space over time by storing a variety of inter-connected 'documents' and then explore it by searching for, reading, and managing the information available. It should, however, be noted that shared information spaces may by themselves be not sufficient to meet the support needs of certain collaborating groups. Our own experiences from other similar field studies in the past indicate that in some situations, shared information spaces may be needed as supplements to workflow systems so as to effectively handle critical contingencies and exceptions that arise in collaborative work over time (Subrahmanian and Jellum, 1998).

A related stream of research has addressed the problem of actually building systems to support collaborative work. Descriptions of a number of such system prototypes have appeared in the literature. Examples include gIBIS (Conklin, 1989) and Answer Garden (Ackerman and Malone, 1990) for capturing design rationale and maintaining organizational memory, Collaborative Work Environment (CVE) to facilitate real time group work with shared objects and artifacts (Hindmarsh et al., 1998), Oval, a tailorable system for cooperative work (Malone et al., 1992) and EGRET to assist in exploratory settings (Johnson, 1992).

2.1 Methodological Issues

From a methodological standpoint, workplace studies typically employing ethnographic methodologies have played a major role in CSCW research. Schmidt (1998a) and Plowman et al. (1995) provide analyses of a cross section of such studies. Some of the more influential workplace studies in recent years include:

- The comprehensive Lancaster study of group work supported by system artifacts in an air traffic control room in the United Kingdom (Hughes et al. 1988; Harper et al., 1991) and the

study of the London Underground Railway Control Room by Heath and Luff (Heath and Luff, 1992, 1996): The rich case data presented in these studies highlighted the complex interplay of the individual and group activities and the critical role of the production of “awareness” at both these levels in the course of the unfolding of the work over time. They also pointed to the need for the seamless meshing of both individual and group cooperative work.

- The studies of the role of organizational plans and procedures by Suchman and her colleagues: They have attempted to show through rich case data that plans, procedures, and process models play a far weaker role of providing limited guidance for situated action in contrast to the received notion of these as detailed prescriptions for how work should proceed. This view leads to them to argue that the procedural structure of such protocols can be thought of as the result of orderly work in offices rather than its determinant. In this sense, plans and procedures are analogous to maps that assist actors to traverse the space of work rather than complete scripts for micro-level activities (Suchman, 1982; 1983; 1987; Schmidt, 1997)
- Bucciarelli’s studies of collaborative engineering design work in building photovoltaic cells for solar energy: He has underscored the social dimension of such work and illustrated the plasticity and malleability of much of the organizational constructs and artifacts such as critical path charts in this work (Bucciarelli, 1984; 1988).
- The study of the operation of the *kanban* system in manufacturing by Schmidt and Simone (1996): The main idea of the *kanban* just-in-time production control protocol is that of coordinating loosely inter-dependent activities through the exchange of cards between actors. Each card signifies the instruction to initiate the production of a particular part or subassembly and specifies all the information required by a recipient to complete the job and forward the output downstream. Schmidt and Simone reported that this mechanism of group coordination worked well as long as demand was steady. Under conditions of fluctuating demand, a strict adherence to the *kanban* protocol led to delays and bottlenecks in overall production. They documented several instances in which workers improvised by not sticking strictly to the *kanban* protocol to achieve better results.

The foregoing discussion is not intended to be a comprehensive overview of the significant array of insights and findings that have emerged from a growing collection of workplace studies. Our goal is primarily to motivate the discussion of an important methodological issue these studies have spawned which have implications for the choice of a design method and our conceptualization of the shared information spaces for Delta.

Ethnographical methods were originally proposed as a counter to the reductionism involved in the more traditional information systems requirements elicitation techniques for the design of collaborative systems. These techniques were found to be “leaky” in that they were unsatisfactory for representing dense knowledge about the individuals, inter-personal and collaborative aspects of work, the explicit and implicit coordination mechanisms, as well as the explicit and tacit work practices (Heath and Luff, 1992). However, the contributions of ethnographic workplace studies from the point of view of providing design guidelines for system design have been seriously challenged (Shapiro, 1994; Schmidt, 1998a; Plowman et al. 1995;). The latter has alluded to the paucity of specific design guidelines and attributed this to the ‘... lack of reported research which has developed to the stage of a systems prototype’ (Plowman et

al., 1995, p.321). Anderson (1994; 1997) has gone further to suggest that ethnography represents an inadequate or at times, a downright erroneous method of specifying end user requirements for systems and may sometimes be a barrier to achieving the goals of designers. The information flow method described in the next section is presented as an alternative approach for analyzing work with the goal of generating specific user requirements that can inform system design. This method builds on aspects of ethnographic methodology in attempting to understand and document the context in which collaborative work takes place while focusing on existing and idealized information flows. This focus enables us to identify specific problems and bottlenecks in work design, to elaborate on the implications of these problems, and to propose relatively specific requirements a collaborative work support system should satisfy in order for it to be useful and effective.

3.0 Information Flow Analysis

As suggested earlier, the general focus of ethnographic workplace studies is not requirements generation. They attempt to develop descriptions of work situations and artifacts surrounding a particular arrangement of cooperative work. We have adopted a somewhat different approach in our study. Our fundamental premise is that people receive, organize, create, and structure information from a personal and group perspective and are members of different cooperative ensembles concurrently and over time. Each of these cooperative ensembles whether derived from a project or functional structure will operate with its own logic of co-ordination and interaction patterns among the participants in a given context. A person caught in this web structure may be part of different sets of co-ordination modes. The role of our information flow studies is to uncover the different modes of co-ordination and information exchange. Our study can also identify the causes and consequences of information flow breakdowns which enable us to sharply focus on the important user requirements and the related functional specifications for system design.

3.1 Information Flow Study: The Method

The method of data collection employed in conducting the information flow study at Delta comprised of a questionnaire survey and follow-up interviews. Six development engineers possessing varying levels of experience in several product development projects along with eight personnel from engineering support departments such as costing, technology management, and engineering drawing responded to the survey and were interviewed.

The questionnaire used for data gathering is in Appendix 1. A free flowing format was used in the interview in order to elicit problems in information exchange as well as to understand information needs and the characterizations of time-consuming tasks. . The interviews were recorded both on audiotape as well as with the use of a technique called mind map (Buzen and Buzen, 1993). Mind map is a technique for recording open-ended interview data to capture both the inter-relationships among the responses to different questions and the temporal connections between the actions described. The primary object of the mind map technique is to cluster related ideas and concepts even though they may arise out of sequence during the interview. We have used the mind map method as a means for recording data in conjunction with linear notes.

The data thus gathered was used initially to create information flow maps of the relevant domain. There are two main caveats to this method of creating information flow maps:

- i) In performing a study of information flow and use, it is important to emphasize that such a study cannot be done outside the workplace of the design and manufacturing organization. The reason for this is that the individuals involved in the design and development process maintain the information for their work in and around their workplace. This allows them to point to and show types and structures of information around them. This aspect is consistent with the approach employed in the workplace studies referred to in the previous section.
- ii) Not every individual in the design organization was interviewed. The choice of individuals was based on their functional and project roles. An attempt was made to cover as many levels, functional areas, and roles in the organization as possible. In terms of coverage, achieving breadth was given preference over depth in a functional area. This approach is employed to attain maximum coverage of the information flow along the horizontal or lateral dimension.

In order to ensure the correctness of the information flow maps, they were reviewed and verified by the participants in the study.

Results of the Analysis

Delta is part of a large European engineering company with a number of products. The focus of the study was on new product development groups in the household tools division. Based on the responses to the questionnaire and the interview data, we prepared several maps of information flows that depict the tasks performed by the development engineers and functional support personnel and the information exchanged by them in the form of reports, messages, drawings, prototypes, simulation results, costings etc. were prepared. The maps also include the types of archives consulted and the medium of exchange (paper, email, phone/voice mail, fax etc.). These maps help us better understand the space and scope of interactions of personnel in different departments. We will present the results from two maps, one of the product development department and the other of the Development and Research Support (D&R Support) department to illustrate the key issues and requirements that surface during the analysis.

Information Flow Map: Product Development Department

Figure 1 depicts an information flow map created by consolidating the information provided by the product development engineers and the engineers from the other service departments. The figure illustrates the inflows and outflows of document types, modes of transferring and sharing, location of archives (paper and electronic) and their accessibility. The information flow map is distinct from other approaches as the issue is not data flow but interaction that takes place among the participants around specific views of information. The documents represented in the map are viewed to be at the center of interaction among those that originate and receive the documents. The directionality of the arrows in the map represent the origin to destination flow of the document type in final form. However in the map, the interpretation of the directionality is

limited as the document serves as the focus and protocol around which the collaborative interactions between the originator and the recipients take place rather than as the finished product that is passed along a sequential work process. For many of the paths in the figure, detailed data was also gathered as to how an engineer accesses, for example, a part drawing from the archive for the product he is redesigning. At Delta, at the time of this study, in one location it took over 2 hours to access a drawing because the engineer had to search through three indexes, one electronic and two more card and microfiche based catalogues before he could get to the part drawing. Another finding from that can be seen in Figure 1 is that part lists are handwritten and sent to the Engineering Services for entry into the parts system for release and future use. These examples provide an insight into the time taken to perform a task in terms of information access and the repetition of task at different information entry points. Figure 1 is a consolidated map and it belies some of the variations that were found in the way the interactions were handled by different product development groups and their comparative efficacy. The map for each product line was slightly different in terms of standardization of documents, access times and task allocation due to differences in practices across departments arising from their geographic distribution across Europe and the United States.

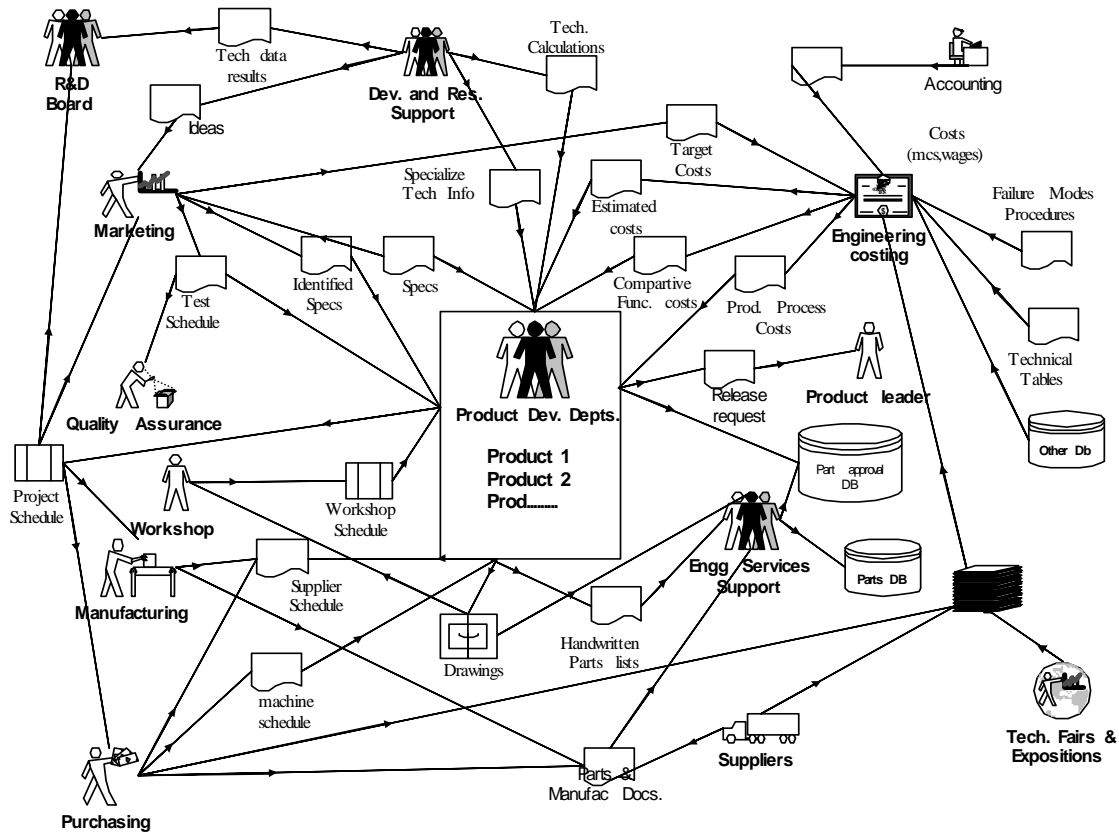


Figure 1. A consolidated information flow map centered on the Product Development department.

In all of these documents and processes, we did not find a well defined work flow process that was based on task based or logical organization of work. The primary work co-ordination mechanism for a given product line was the Project Schedule document that is shown on the far

left in the middle in Figure 1. This project schedule document is laid out as a Gantt chart including milestones for marketing review, design release, pre-production series production and manufacturing release. The chart is more of a map model rather than a script model of workflow. However, within a product line a task list had recently been introduced to link milestones with dates. The tasks in the task lists provide a broad and not detailed task descriptions and it was introduced to get an idea of where delays were taking place rather than as a task control mechanism.

All other interaction among the project team took place through pushing (providing) and pulling information during the design period through phone calls and visits to each others' locations in the case of distributed design. All physical documents were exchanged through Delta's internal surface mail system with delays of up to 2-4 days. At the time of the study the organization did not have e-mail facilities across all departments and geographical locations.

For any given product and a given model of the product the information on the products design is scattered across different departments in different archives such as CAD archives and, personal archives in service departments. While there are personal archives of the individual development engineers, they are not accessible or standardized enough that knowledge is exchangeable across product models and lines. This pose problems especially when the engineering goal is to minimize variations in design across models especially in a global market. Process knowledge related to the somewhat similar product lines was not captured let alone shared. Further, different product leaders used their own personal organizations for many of the design documents and followed policies of versioning and processes that were idiosyncratic. However, in our interviews the design engineers expressed a preference for an open system in the company across product lines for they felt they had a lot to gain from this. They expressed a preference for universal access to view all information across the firm with controls on updates and modifications.

In summary, information exchanges between the functional department and the product department personnel took place on a one-on-one basis. The people within the design team communicate through design reviews and were governed by a project time line. The work of the engineers both at the product development level and functional level were not scripted. Development tasks such as sketching of parts, testing of components etc. are carried out by the actors based on information that was either provided (pushed) to them or they pulled from internal or external sources. Most functional departments were co-located at Delta's main facility. Marketing and Manufacturing departments were distributed globally, which complicated design co-ordination.

Information Flow Map: Development and Research (D&R) Support Department

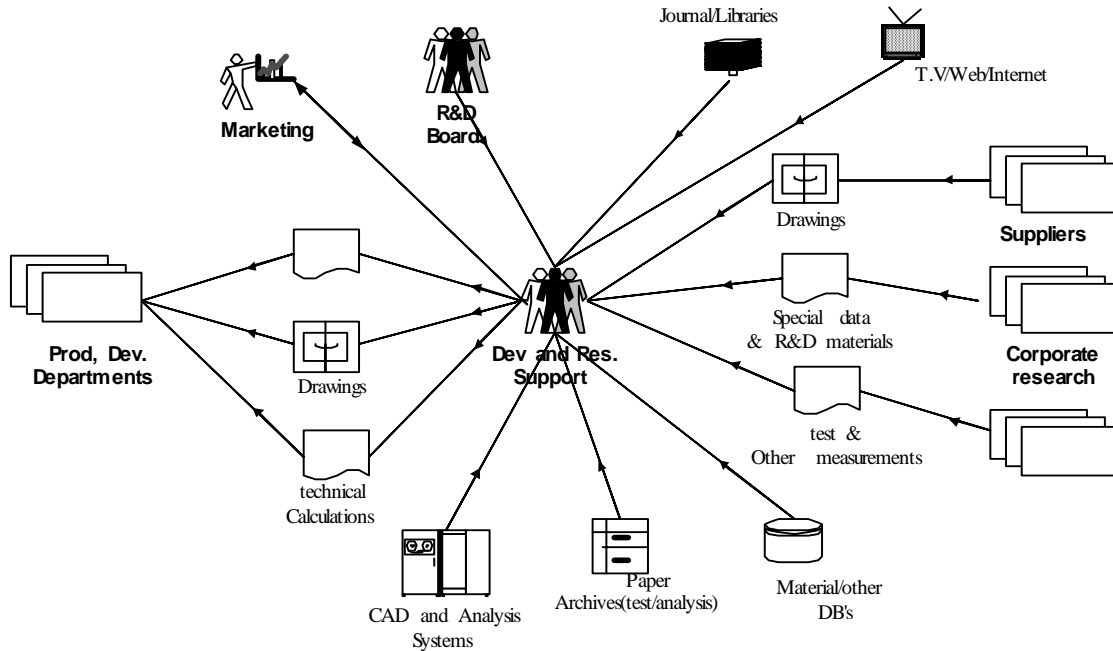


Figure 2: An Information Flow Map centered on Development and Research Support department.

In contrast to the product development department, the D&R support department was a service department. Figure 2 provides an information flow map for this department. It can be seen from this map that many of the information sources for the personnel involved were outside the boundaries of the product division as opposed to interactions that are largely bounded within the department for the product development department. The D&R support department pulled information from a large number of varied sources to both compile its archives and to push appropriate information to other internal departments. A large proportion of the information received by the Research and Development support personnel in this department was actually ‘pushed’ at them often resulting in low relevance and delays in the context of the work of the engineers. Design engineers could not easily ‘pull’ information based on their needs leading to frustration. Another problem they encountered was the existence of multiple archives using different classification schemes and media. For instance, an important archive that categorized manufacturing costs, production methods, country of manufacture based costing of parts was part of an individual engineer’s archive based on a highly idiosyncratic classification system. While this archive may seem personal it contained critical, catalogued synthesis of information that was not easily sharable or shared. This discussion points to the need for cross indexing, tolerance for multiple classifications, and uniformity of media to streamline the work of the design team.

The foregoing discussion presents exemplars of the information flow maps that we developed as part of the requirements elicitation and some related observations. Without reviewing every one of the maps that were created and the useful inferences derived from each, we will summarize our findings dealing with information generation, sharing, organization and management.

1. Company standards are not easily accessible and standardized formats are non-existent or flexible enough. An example of a company standard is the set of procedures for carrying out failure mode evaluation.
2. Extent of documentation varies from department to department. (e.g. documentation procedures in one product department is not the same as the next). A major impediment using information across departments and hence collaboration.
3. Product development documentation is scattered (e.g. drawings and text are distributed among several persons and locations). Historical information is either person- or part-centered and are not interconnected leading to time consuming access of information
4. Information flow across departments to external entities is very slow in some cases (e.g. Developer supplier, developer-marketing exchanges)
5. Organization of information and access to them are often opaque and time consuming.
6. Process knowledge is not recorded and managed.

The first two important findings needs to be kept mind in that the functional specifications that characterize the system for collaboration rely on the successful implementation of the organizational processes of standardization of documents across product lines for part description, project plans and other marketing and other information. However, one set of common functional requirements for collaborative support system emerged consistently from the above list across all the relevant departments at Delta. They are the need to:

1. Organize and access information under multiple classifications by multiple perspectives and granularity of creation – individual, project, company standard and other standards national and disciplinary classifications;
2. Multiple indexing schemes that facilitate accessing of information across the entire product information base– by part, by technology, by model, by product;
3. Be able to push and to pull information to and from collaborators or archives;
4. Accommodate changing ensembles of collaborators during a project.
5. Support map based workflow activity.

These primary requirements were taken from this study and refined through two cycles of design, mockup and review of the system. R&D personnel from Delta were part of the system design team. An end user team of development engineers was assigned to participate in the system design review process. From these phases of design we arrived at other functional requirements that the designers felt would enhance the usability of the system. These includes the following needs to:

1. Create networks of documents by inter-relating documents of multiple media and format;
2. Use and organize keywords and the ability to index and maintain the vocabulary of the products designed.
3. Use of annotations and versioning to critique and advise among collaborators and beyond.
4. View and read documents of different format without actually possessing the tools that generated it; and
5. Provide universal access to all documents while restricting the ability to modify the documents beyond the current product design team.

It is important to point out that Delta at the time of study was in the process of installing a company wide network and was issuing PC's to its engineers and other personnel while a number of legacy systems were still operational requiring that the system being designed will work across all platforms. The requirements of the LIRÉ system described in the next section are the end result of the prototyping phase of the project.

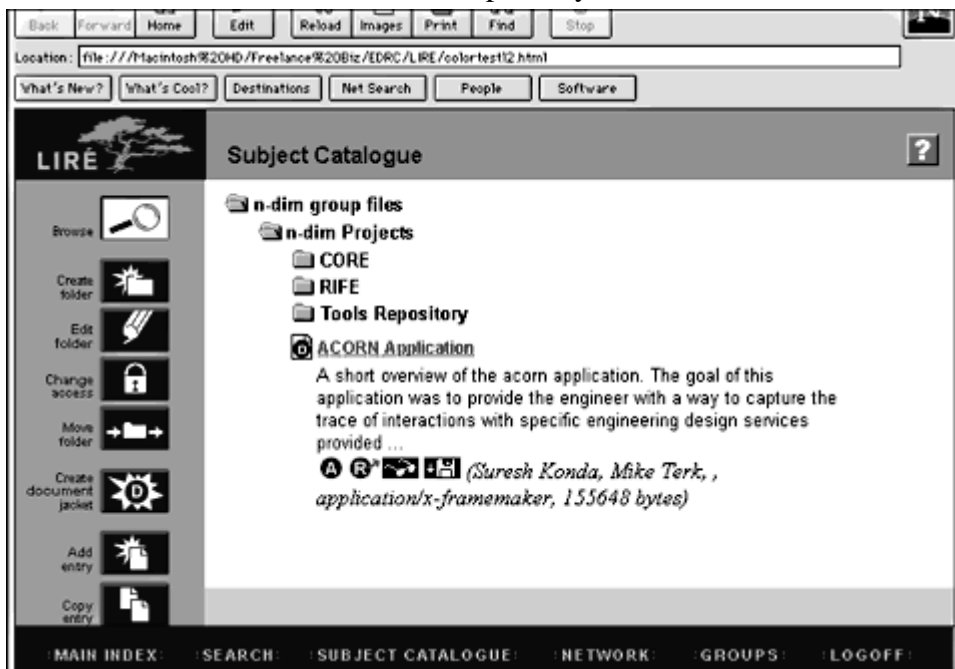
4.0 The LIRÉ System

Based on the requirements of the New Product Development group at Delta under the three categories of documentation, computational infrastructure, and information and knowledge organization discussed in the previous section, we designed the LIRÉ (Living Repository) prototype system, a Web-based information and document repository to support collaborative work. This is conceived of as an information space that can evolve, to be shared by the users. The basic unit of information in this space is the 'document' which we use in the broadest sense to include any intellectual object such as report, memo, letter, annotation, email message, spreadsheet, presentation material, drawing, sketch, image, audio tape, video, photograph etc. It is 'living' to the extent that it is capable of evolving organically with the changing needs of the group. Also, the users are primarily in charge of placing documents drafts and versions in LIRÉ during the course of their work to be shared by others in the group. This enables the group to examine, update, review, annotate, and extend the intermediate outputs of the group and in the process create shared cognitive maps of the work domain. Some of the major features of LIRÉ that facilitate this shared perspective follow below.

4.1 LIRÉ Features

a. Document Organization

All users can add documents to the repository. These documents can be classified in the Subject



Catalog in multiple ways using a hierarchical folder structure. This structure is modifiable to fit the changing needs of user groups. Despite the hierarchical folder structure, LIRÉ can maintain multiple classifications (with the same document being part of different folders) over the same set of documents. This provides the capability for different users to maintain separate classifications based on their divergent perspectives and viewpoints over the same document collections. Figure 3 presents a screen shot of the Subject Catalog page of LIRÉ.

Figure 3: Subject Catalogue in LIRÉ

b. References Between and Annotations to Documents

An interesting aspect of any library is the inter-relationship between documents that address similar or related subject matter. In a discovery process of searching for information an individual often identifies these inter-relationships for later reference. The purpose of this feature of the system was to allow development engineers to share the knowledge of inter-relationships between the different documents that have been read, used, or referred to by the group. In a similar vein, the purpose of providing the ability to annotate documents was to provide means for sharing thoughts, opinions, and remarks on the documents in the system.

c. Searching for Documents through Multiple Means (attributes, classification, keywords)

Most documents are characterized by a number of critical attributes. These include author, date, abstract, keywords and others. The attribute values for a particular document are shown on the document jacket (see Figure 4). These may include specific classificatory identification beyond the organization of these documents in several logical information collections. Some of the features required of the system are quick searches that use a small number of attributes and search over contents of the documents.

The system also provides a feature to browse through keywords and identify documents that are related to the chosen keywords. The keywords are required to be organized as a network of tokens along the generalization-specialization continuum so as to facilitate the browsing and searching of related documents. Each keyword comprises a word (token)- meaning pair to help reduce synonym and homonym problems.



Figure 4: A document jacket in LIRÉ

d. Delivery on Standard Hardware and Software Platforms

One of the most important parts of system development stems from the constraints imposed by the computing environment of the focal organization. At Delta the underlying IT infrastructure was to be developed and maintained by the IS department. Within this framework, the delivery software was defined to be a Netscape Browser on a Pentium PC running Windows 95. The LIRÉ repository server itself was restricted to a Silicon Graphics server. The Web-based interface enhanced the ability of users to have almost universal access to the repository from any client that runs a Web-browser. This is useful given the spatially distributed nature of much of the collaborative work being supported.

e. Document Formats and Translation

LIRÉ is designed to eliminate problems of document sharing arising from different versions of software packages and different document file formats such as MS-Word, postscript, RTF, Framemaker etc. LIRÉ's translation server, Babel, takes a given document in any format as input and translates it into a searchable file (ASCII text) and a viewable file (PDF). The searchable file permits full text search. Image, product data model, and geometry files are translated into universally viewable formats such as jpeg or VRML.

f. Groups, Ownership of Documents, and Access Control

Groups are used in LIRÉ for access management. The group a given user belongs to determines which document jackets and subject catalog folders that user has access to. All users of the LIRÉ repository belong to at least one group - the group "All." Other group membership is determined by the administrator(s) of a given group. Subsequently, any administrator of a group can nominate other administrators for that group.

All users also have a user profile. Much like a document jacket, the user profile stores attributes of the user. A user profile is accessed by clicking on the user's name link.

Access to documents by different users can be controlled at very fine levels of granularity such as "know about," "read," "download," "overwrite," and "delete". Delta users have generally been given the authority to check in and check out documents and to create new versions.

4.2. LIRÉ Architecture

LIRÉ has a standard three-tier architecture. The top layer is the user interface using html protocol. The middle layer is a web server that communicates with the web browser client and the lower storage layer comprising ORACLE DBMS and the file system. The other modules of LIRÉ include a text search module using off the shelf software and Babel, a document transformation system. The design of LIRÉ is extensible and designed to be continually modified to meet previously unanticipated requirements reflecting newer contingencies that arise over time.

5.0 Evaluation of LIRÉ

A modified version of the LIRÉ prototype described above is currently in use by the New Product Development group at Delta. The modifications had to be made for improved scalability and performance based on an initial testing of the prototype. We present some of the early results and lessons learnt from the ongoing evaluation work at Delta and our observations on the user feedback as well as issues arising from our discussions with the sponsors of the project.

As part of the prototyping process we carried out a usability study of LIRÉ. We gathered data from all 20 users in the group using a usability survey instrument. This resulted in a number of modifications to LIRÉ primarily at the user interface level. Some concerns about the terminology used by the system were expressed. Part of this is attributable to the fact that the user interface is in English which is not the native language of most of the users but is one of the two "official" languages of Delta worldwide. Nevertheless, the exercise was helpful in identifying and correcting semantic problems, clarifying several homonyms and synonyms in use

at the user interface level and in developing previously unsupported functions. Modifications to the workspace window to improve the check in/check out (of documents) feature were carried out. Some of the key distinctions involved in the deleting of full folders comprising documents and links to and from the documents to other documents were made sharper and the users' ability to make the right choice based on their precise needs was enhanced. Improvements to the Edit menu to make it easier for users to create new groups and to amend existing ones were carried out. Additional visual clues were introduced into dialog boxes (eg. the box for specifying all the attributes of a document). Changes to the menu structure, help screens, and error messages were introduced in response to user comments and suggestions.

The more formal assessment of LIRÉ at Delta was performed in two phases. In the first, responses to a set of questions using a questionnaire to measure user acceptance of systems were collected and analyzed. The questionnaire had of two parts; the first dealt with computer system efficacy and the second with usability. The latter is a modified version of the validated instrument proposed by Davis et al.(1989) for measuring user acceptance of systems. In the second phase, semi-structured interviews based on a fixed set of questions with a select group of users and some of the group members who were not LIRÉ users (though they were trained to use it) were conducted. The small and non-random nature of the sample and the absence of a meaningful control group do not permit a rigorous, quantitative analysis of the numerical data based on a 7-point Likert-type scale. We can, however, present the commonly expressed qualitative responses in both the survey and the interviews and the major issues that emerged over the course of the implementation phase of LIRÉ at Delta.

1. There was near consensus that LIRÉ resulted in improved communications through easier sharing of a wide array of documents across both space and time. This was attributed to the facility for document search, ability to rapidly access virtually any document, version and access control mechanisms, and the structure for document organization, which served the role of an information map.

This finding is gratifying to the extent that it suggests that the baseline features of the system have met with ready acceptance. This also provides the foundation for building the evolving virtual edifice of shared documents.

2. Significant improvements in design cycle times were recorded primarily resulting from the enhanced ability to track and share information quickly and thereby speed up the flow of collaborative design work. Evidence to date suggests that there has been a reduction of approximately 40% in the design cycle time at Delta even though this figure cannot be attributed entirely to the use of LIRÉ. The system design and implementation was part of a corporate initiative to achieve a 50% reduction in cycle time and we can safely conclude that the system has contributed to increased efficiency in product development and redesign at Delta. Currently over 75 engineers are using the system and this number is expected to increase to 250 in 2001.
3. Significant improvement in the ability of users to manage the complexities associated with a variety of information at various stages of development leading to greater reuse of knowledge gleaned from them was reported. Statistical data on the number of new

documents being generated, referenced, used, and linked to other documents are being routinely monitored at Delta and have shown an increase over time.

4. The improvements in the user interface following the usability study have put the more experienced users at almost the same level as the casual users. Moreover, the familiar web-based interface renders easy access as well as provides the ability to open and work with non-LIRÉ documents on the World Wide Web.
5. The system has served as an invaluable learning tool for new designers who join the design team after specific project were started. Systematic access to all previous documents, correspondence, drawings and their versions and some of the discussions and design deliberations has been very helpful to newer participants.

Delta is currently using the experience in the household division and implementing their version of LIRÉ in other divisions of the company that have similar work patterns.

5.1 Caveats and Concerns

Several criticisms, concerns, and managerial issues emerged from the interview responses and ongoing discussions with the sponsors of this research. Some of the more significant ones are discussed below.

The creation and maintenance of the keyword network turned out to be the single most critical problem with the ongoing use of LIRÉ. The initial design principle of users having the freedom to select keywords (token-meaning pairs) and creating an evolving keyword network by specifying not just the keywords for each document but also the inter-relationships among them along the generalization-specialization continuum proved to be problematic. The job of specifying keywords turned out to be either difficult or time-consuming for most users. Bloomberg et al.(1997) has noted the same problem of lawyers not having the time to assign keywords to documents in their study of lawyers working with a document sharing system.

The proposed solution to this problem is the seeding of an initial keyword network to provide the users with a useful starting point. This collection can be used to suggest possible keywords from the seeded list from which the users can choose the appropriate ones or add new ones. This approach can serve to reduce the cognitive load on the user. This calls for analyzing a corpus of initial documents and developing a set of keywords that will constitute the initial base. LIRÉ architecture is being extended to develop and refine a software tool that partially automates this task using co-word analysis.

A related issue that arose in our discussions with our sponsors at Delta is the question of approved keywords and the danger of uncontrolled keyword proliferation if the users are assigned the role of furnishing keywords. The severity of the problem will become more acute as the number of folders, documents, and versions grow over time. Prompted by the concerns of the sponsors of the project, we investigated the problem and agreed to initiate an authorization system for keywords. Delta has established an organizational mechanism to review and approve or reject new keyword submissions. LIRÉ design has been modified to accommodate the new

policy. The provision for ongoing introduction of new keywords is very important for LIRÉ users at Delta because static and inflexible keyword structures can impede the effective sharing of the information space created by LIRÉ. There is, clearly, a tension between the need for flexibility on the one hand and the avoidance of uncontrolled proliferation of keywords on the other. This can only be resolved through the creation of mediating organizational processes. Recently released natural language-based tools such as Autonomy can be used to support the identification of keywords along with the organizational processes (Autonomy, 2000). However, for a multi-lingual, global organization like Delta, the problem is compounded by the lack of availability of such multi-lingual tools.

The level of active collaboration among the users using document versions and annotations in the information space was somewhat lower than we expected in the period following the system implementation. The annotation feature was used only sparingly. Two reasons were suggested for this. First, the existing user interface features in LIRÉ were perceived to be clumsy to use and second, a mechanism was needed to distinguish between global annotation that refers to the whole document and local ones that apply to specific locations in the a document. We are exploring several alternatives to deal with this problem. As well, the culture of engaging in virtual discussions over the contents of document versions was yet to take to root. More common was the practice of jointly preparing documents evidenced by the large number of versions of some of the reports and papers. We plan to monitor the ongoing use of the annotation feature to understand the extent to which this is influenced by the work culture at Delta as opposed to serious difficulties in using LIRÉ to carry out threaded electronic discussions using the annotation feature recursively.

Almost all users surveyed stressed the importance of ongoing customization and enhancements to LIRÉ. From the design standpoint, interactions of the users with the system and the range, type, and contents of the documents placed in the repository are continuously being recorded. Systematic analysis and review of these data will provide some of the information for refining and fine-tuning the system. It is in this sense that LIRÉ can be viewed as furnishing an evolving, shared information space for supporting collaborative work. The full value of the built-in features of LIRÉ to adapt to the improvisations in work practices by its users (Ciborra, 1996) will only be known over a longer period of time.

6.0 LIRÉ and Other Document-Centric Collaboration Systems

At the time of design of LIRÉ in 1997 there were almost no commercially available systems of this type other than Lotus Notes in the market. A detailed comparison of LIRÉ with other similar systems is beyond the scope of this paper. However, some of the major differences between them are apparent based on the scope of these systems. The commercial systems can be categorized into: a) Document management systems such as Live Link and Documentum; and b) Collaboration systems such as Lotus Notes, BSCW, and E-room and others. Live Link and Documentum started as document management system creation tool kits that contained a document repository, a script based workflow engine, version control and operated within homogenous hardware/software environment (Documentum, 2000, Live Link, 2000). These tools kits could be customized with their own user interface tool kit. More recently, the tool kits have been extended to facilitate web-based development. These systems require a thorough

understanding of the work environment before they can be customized. In fact, Delta's R&D Department used its developmental experience on the LIRÉ project and the specifications developed to customize Documentum-based collaboration system. The key point here is that information flow studies are critical in uncovering the nature of the work environment and the needs of workflow irrespective of the choice of implementation schemes and tools.

Collaboration systems such as Lotus Notes and BSCW provide basic facilities for exchanging documents among collaborating groups and provide some amount of notification capability (Appelt, 1999, Lotus, 2000). However, more recent versions of BSCW have incorporated some of the features of LIRÉ discussed above. The important distinction between LIRÉ and many of these systems is that they do not have *all* of the integrated set of features such multi-format exchange facilitated by standardized delivery of documents, multiple classification schemes, search over attributes meta-data and content, document relationship network and keyword network. Furthermore, LIRÉ is based on the specific needs of the design team at Delta identified through elaborate information flow analyses and is fine-tuned to meet the information flow and workflow needs of the end users. The eventual system prototype is tailored to conform to the designers' view of the workflow collaboration, something that is very difficult to achieve by customizing generic collaboration tools.

Our experience is that a systematic approach is required to uncover the complex requirements (technical and organizational) from a global perspective of information flow and workflow management in an organization for effective acceptance and use of IT tools in an organization. Besides, the final production system implementation may be accomplished in a variety of ways. The prototyping process provided us with a means for creating continuous participation of the end users in refining the requirements before the production system was implemented.

7.0 Conclusions

We have presented an approach to understanding end user requirements for collaborative repository systems based on the analyses of information flows among the members of a target work group. The architecture and important features of the LIRÉ system that facilitates the creation of a shared information space for the new product design team at Delta are described. Since our transfer of technology to Delta, we have continued the work on our version of LIRÉ in the university environment for use in product design classes over the last 3 years. Based on these experiences we are currently working on several extensions to this architecture to make it a composable and tailorable one with which contextually adaptive and sensitive collaborative systems can be generated. One of the additional modules under test is the inclusion of a notification server to deal with the problem of creating optimal 'awareness' levels across the group through the propagation of changes to the work situation in an orderly fashion. Another extension that is currently used is the Babel translation server. Currently LIRÉ is designed to perform a number of translation-type conversions from, say, a particular version of Microsoft Word to any number of alternative formats such as postscript, PDF, RTF, or text. This is being extended to translations across different compression formats and even translations from one natural language to another such as Japanese to English. A third proposal is for integrating a

tools-repository to the LIRÉ server to facilitate collaboration over the use of analytical tools during design.

A qualitative analysis of the data gathered for assessing the effectiveness of the system at Delta and some of our observations on the key problems and issues encountered during implementation and evolution of LIRÉ prototype have been presented. The first phase of implementation is now complete and the continuing use of the system by Delta users offers encouragement. However, many of the challenges that may arise as the user group moves through the different stages of their design work life cycle is currently under investigation.

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Appendix 1

Information Flow Analysis Questionnaire

Which tasks do you perform in relation to the product development process? Give a brief listing.

For each of the tasks; which documents or other information do you need/use? (Ex: specifications, contracts, orders, invoices, procedures, standards etc.)

For each of the above: where/who do you get this information from (Ex: customers, colleagues, other departments, databases, archives etc.)

Which format is the information in? (Ex: text/letters, spreadsheets, drawings, photos, database-data, sound recordings, video etc.)

How is the information transferred to you? (Ex: collected, post, fax, email, oral/ phone, fileserver etc.)

How do you sort and/or store this information?

What kind of results do you produce? (Ex: different kinds of documents, approvals/controls, physical products etc.)

Who uses the results of your work? (Ex: customer, subcontractor, supplier, colleagues, archives etc.)

How are the results passed on? (Ex: automatically or on request)

Who checks the results/what kind of feedback do you get?

Which tools do you use for your tasks? (Computer assisted and/or manual ones)

Which of your tasks seem most time-consuming or inefficient?

Wishes (tools/new functionalities etc.) or other comments