DIGITAL COMMUNICATION TECHNOLOGY: CONNECTING DESIGN, ENGINEERING AND MANUFACTURING

MARCIO ZUKIN

Dept. of Industrial Engineering, PUC-Rio.
Rio de Janeiro, BRAZIL
e-mail: marzukin@rdc.puc-rio.br

HUGO FUKS

e-mail: hugo@inf.puc-rio.br
http://www.inf.puc-rio.br/~hugo/

PAULO R. T. DALCOL

Dept. of Industrial Engineering, PUC-Rio.
Rio de Janeiro, BRAZIL
e-mail: prtd@rdc.puc-rio.br

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Abstract: Companies increasingly need to reduce lead times in product development as a way to get products onto the market faster and more efficiently. Digital communication integrating design, engineering and manufacturing can greatly improve the product development process through concurrent engineering and overlapping activities. This paper presents a case study on how digital communication can overcome temporal and geographical barriers in the exchange of information, enhancing a collaborative and cooperative environment. The project studied was a vacuum cleaner developed in Electrolux-Italy, in which the first author of the paper participated as Senior Product Designer. In this paper, the authors describe and analyze the process, and then elaborate a scenario that contemplates networks for digital communication, and a technology infra-structure for the process highlighted.

Keywords: Digital Communication, Concurrent Engineering, Industrial Design, Engineering, Manufacturing.

Resumo: As empresas necessitam crescentemente reduzir o *lead time* no desenvolvimento de produtos de modo a lançar produtos no mercado mais rapidamente e eficientemente. A comunicação digital, integrando o *Design*, a Engenharia e a Manufatura, pode representar uma grande melhoria no processo de desenvolvimento de produtos, por meio de engenharia simultânea e atividades sobrepostas. Esse artigo apresenta um estudo de caso de como a comunicação digital pode superar barreiras temporais e geográficas no intercâmbio de informações, criando um ambiente colaborativo e cooperativo. O projeto estudado foi um aspirador de pó desenvolvido na Electrolux -- Itália, no qual o primeiro autor do artigo participou como *designer* de produto sênior. Nesse artigo, os autores descrevem a analizam o processo, e então elaboram um cenário que contempla redes para um sistema de comunicação digital e uma infra-estrutura de tecnologia para o processo em questão.

Palavras-chave: Comunicação Digital, Engenharia Simultânea, Desenho Industrial, Engenharia, Manufatura.

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1. INTRODUCTION

This paper addresses the analysis and construction of a digital working space focusing on the communication process. The analysis concentrates on the relationship between the functions of design, engineering and manufacturing in the production of high quality products, developed in very short lead times.

Digital communication is a computer-based support for concurrent engineering that can overcome temporal and geographical barriers in the exchange of information. Digital communication can link large groups of physically separated people, enhancing a collaborative and cooperative environment for the design, engineering and manufacturing of a product. In this paper, digital communication is designed to be applied at the final stages of a product development process, that started at the strategic planning stage.

First the product development process was studied in its general aspects. Then a specific case was chosen that presented a product with a complex and high quality design. The process selected was a project developed in Electrolux-Italy, in which the first author of the paper participated as Senior Product Designer.

Later, the product development process chosen was described and analyzed. The research then focused on application software that could be used for digital communication. Finally, we elaborated scenarios that contemplated networks for the digital communication process, and a technology infra-structure for the process highlighted. These scenarios were analyzed in terms of cost, software packages, training, and process deployment.

This digital communication system was designed specifically for the organizational culture and product development approach of the Electrolux Corporation, in Milan - Italy. However, since product development has a certain degree of generality, we believe it is possible to apply this particular system to many other cases. The recommended solution for the

Electrolux case was to purchase software outside the company and not develop an in-house integration system, as happened in Toyota for its CAD/CAM system (Ohara 1988). The solution to purchase software off-the-shelf was highly enforced due to reduced costs and good quality service. Once software has been purchased outside the company, the in-house Systems Engineer should be responsible for integrating it to the company's culture and routines.

The research delineated in this paper treated the product development process in Electrolux-Italy as an object of study, aiming at the creation of digital communication solutions for improvement and new functionality in this process. The result of this research was not proposed for implementation, and it will likely need more testing and refinement.

2. COMMUNICATION AND INTEGRATION SYSTEMS

The digital mechanisms that integrate design with engineering and manufacturing, must adapt to the design activity and its complexity, matching the product's need of range and flexibility, quality, and so on. The most highly integrated digital systems are warranted only when there are high design task coordination requirements (Liker et al. 1992).

Low design task coordination requirements are attributed to projects where: the information processing requirements are low, and the product designed is a minor variant of an existing product, consisting of few components. Thus, it is possible to delegate the design of the components to different designers, with low communication necessity. In contrast, high design task coordination requirements refer to projects that require high information processing, have complex shapes, their tasks' uncertainty is high, and design decisions are interdependent.

In a design activity with low design task coordination requirements it is possible to use a courier service to mail blueprints, or data files on tape or disk. When there are medium

design task coordination requirements it is possible to use a computer, modem and a telephone line, to transmit files that require translation or to transmit files between compatible systems. When there are high design task coordination requirements it is possible to use a computer, modem, telephone line and a network, for asynchronous use of a common database. It is also possible to work concurrently on the same database, thus communicating in real time.

As well as the digital mechanisms, the organizational integration mechanisms must fit the design activity and its complexity. Similarly, design tasks with high design task coordination requirements will benefit from higher levels of integration (Liker et al. 1992). The organizational integration mechanisms will also influence the requirements of digital communication.

In a design activity with low design task coordination requirements it is possible to use design rules, or *ad hoc* communication, with low organizational integration. Systems based on design rules have some fixed paths of reasoning that do not match with design reasoning.

When there are medium design task coordination requirements it is possible to use cross-functional teams, or job rotation, with medium organizational integration. In cross-functional teams, group decision making may be difficult, there is a limitation on the team member's knowledge and there are the increasing costs of maintaining a team (O'Grady and Young 1991). These difficulties occur especially when there is no digital communication integrating the people involved in different geographic locations.

When there are high design task coordination requirements it is possible to use co-location, or combined roles and organizational structure changes for horizontal processes, with high organizational integration. The need of co-location, or other physical change in the

organization for high complexity design activity, diminishes when there is an efficient computer network in function.

In the case of the product development process at Electrolux-Italy, there was high design task coordination requirements. This paper is focused only on the digital integration and communication of that process, therefore, excluding the influence of the complexity of the design activity on the company's organization. In the next section we give a description of one specific communication process.

3. THE PRESENT COMMUNICATION PROCESS

An ontology of the collaborative work domain was built, in terms of a conceptual framework for interpreting the domain in terms of recurrent communication and transportation actions (Denning and Dargan 1996). First, a communication structure (Figure 1) was elaborated, mapping the present communication process and trying to find possibilities for improvement and new functionality through digital communication.

In the case to be described, the engineering management outsourced the design activity to Unitec-Milan, an external office that has worked for Electrolux in Italy[1] since its foundation. Therefore, Unitec had an easy interaction with the firm organization and its interlocutors. Electrolux also subcontracted: the model and prototype makers, the materials supplier, and some manufacturing processes specified in the design. The product developed was to be sold globally. After Italy, the first countries to place this new product on the market were to be England, France and Australia, where Electrolux also has factories. Nevertheless, only the engineering department of the Italian branch of Electrolux participated in the product

[1] In the late 80's the Swedish corporation Electrolux acquired the Italian company Alfatec which was the leading Italian vacuum cleaner manufacturing company.

development process. There was great difficulty in coordinating it globally, mainly because of problems and handicaps in the conventional modes of communication.

The product to be developed was the Global New Vacuum Cleaner, that deals with spills and floods and also performs carpet shampooing, without the need of a motorized water and shampoo pump. In the following description, the departments were collapsed into the manager person of each function. In this case, the richness of the communication is in the inter-departmental relationship and not between the workers of the same department.

3.1 AGENTS RESPONSIBILITIES

The mission statement of each function was also the criteria for the evaluation of each department's performance. All the departments' mission statements were general in what concerned the product's brief that was defined at the strategic planning stage. The mission statements were specific in the following terms:

DES Design: functionality, styling, manufacturability of the product designed, and model making management;

ENG Engineering: development of technological solutions, producibility of technical parts, and management of prototype making and tool design;

MAN Manufacturing: management of tool making, development of the facilities and the processes used to fabricate and assemble the product designed, quality control and dependability.

3.2 PROCESS INPUT AND OUTPUT

The input of this product development process was studied in terms: of material; equipment; physical communication devices; shared workspace and environment.

Material:

- A Contract Book was created that contained the project brief; the customers' needs; the details of the selected concept; the development schedule and deadlines; the product specifications; the economic analysis of the product; the project staffing and the budget (Ulrich and Eppinger 1995, p.19).
- Information came from: Electrolux; similar products; competitors; suppliers and customers. It was mostly printed information.
- Similar products on the market or competitors products were used for: evaluation; benchmarking and reversal engineering -- always in three-dimensional volumes.
- Files in the computer, containing drawings of other products and parts already developed by the company were studied. Drawings of parts already defined and chosen to feature in the product to be developed, such as: motor, filter, keys and buttons, wire and so on, were also studied.

Equipment:

- PC computers and workstations running CAD programs
- Workstations running CAM programs
- Conventional or CNC machine tools, not under DNC -- linked control

Physical communication devices:

These devices must support all the messages listed below, and common knowledge must be available about how they function correctly.

- Computer programs
- Fax machine
- Telephone machine
- Courier services for documents, drawings and models

Shared workspace:

In these workspaces, messages are transmitted and received, in an asynchronous mode, or in the case of face-to-face meetings, a synchronous mode.

- Telephone calls
- Document papers
- Drawings and blueprints
- Books and magazines
- *Facsimiles*
- Photos of models and products
- Other products (from the company, from competitors or similar products)
- Mock-ups, models, prototypes, and so on

Environment:

- Inside the organization: offices, laboratories and shop floor.
- Outside the organization: design office, model and prototype workshop, suppliers and customers places, Australian factory and so on.

The output of this particular product development process was basically two items:

- A pilot product and its complete specifications.
- Knowledge and experience to be recorded, and the development of project capability.

3.3 PROCESS DESCRIPTION

The project's brief and schedule were an input to the process. They stated that the lead time of the product development should be thirty days. A further thirty days should then be allocated for the prototyping, testing of the prototype, production of the pilot product and its final blueprints. The blueprints comprised all the conclusive product specifications for the

acquisition of molds and tools. Figure 1 shows how communication in the final stage of this particular product development process evolved, and it is described in detail below.

Electrolux sent ENG to the DES office. DES did not have professionals sufficiently skilled and with great technical experience in vacuum cleaner products. There was much information that had been generated inside Electrolux, which is known to be a technology excellence center in this field.

In this first stage, the communication process occurred mainly in three ways. DES worked with his own computer -- which was not connected to a network, in the same room as ENG, who used a drawing board for the detail design. Drawing boards were also used for sketching out new concepts and the exchange of ideas. That exchange occurred mainly through transfers of drawings on paper and, therefore, DES and ENG could not work concurrently on the same file. Each one developed an element mainly in sequence, and seldom in parallel. DES needed to plot its drawing file and, finally, ENG joined all the information in a final drawing on paper, that included various pieces of drawing by DES. There was also transfer of data files on disks, which occurred between the computers of the DES office.

Other exchange was oral, through face-to-face chat, and discussions about specific items. Face-to-face chat is different from telephone chat and face-to-face meetings. Unlike the telephone chat, it is done in the presence of both interlocutors. Communication is done mainly through chat not including presentation of materials, and conversation is conducted between two people whereas meetings are considered to be between at least three people.

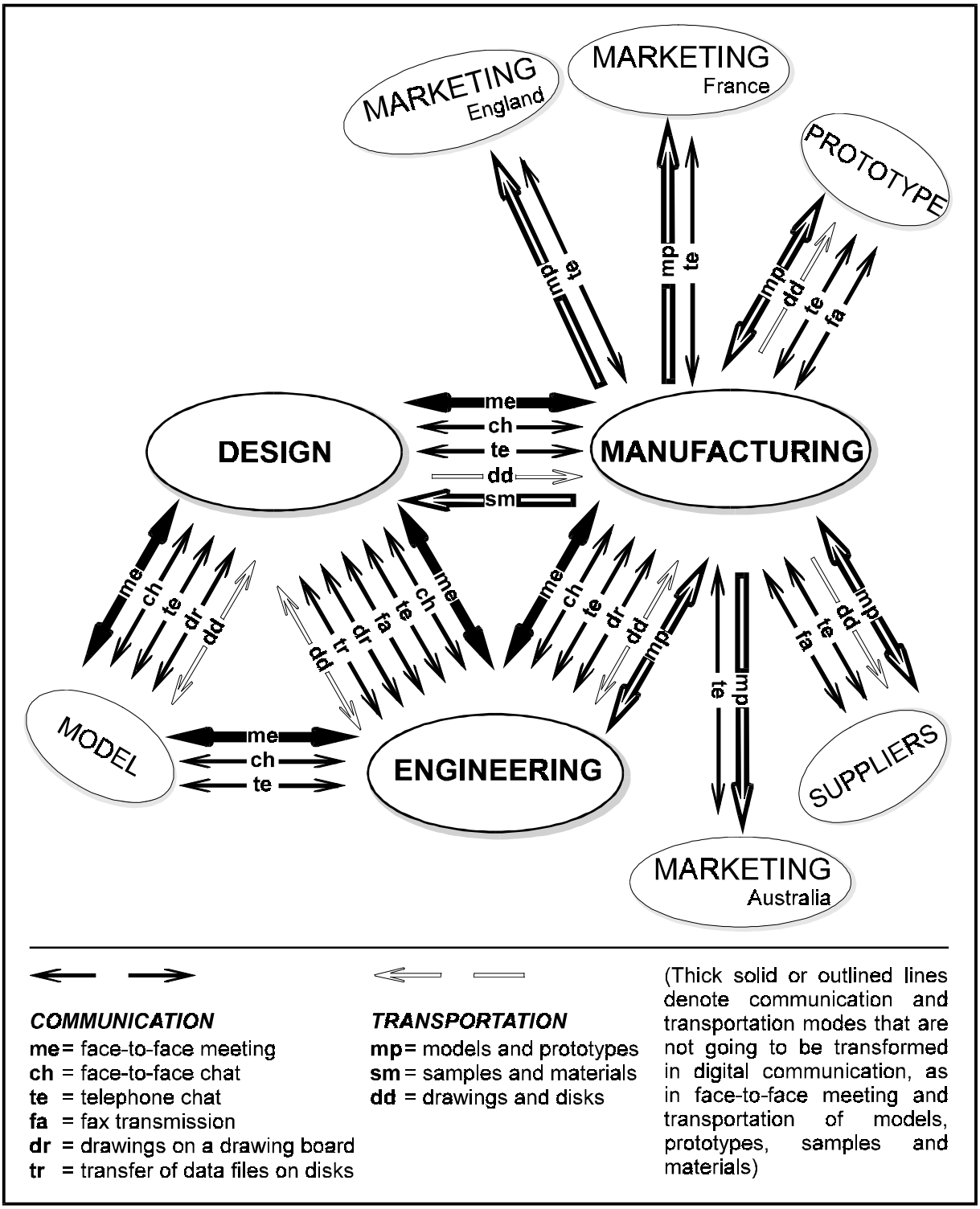

Figure 1 Communication in the final stage of a vacuum cleaner development process at Electrolux-Italy

The last mode of communication, at that stage, and perhaps the most important one, occurred in the model workshop, contiguous to the DES office. DES and ENG met there to observe and discuss the product's last volumetric results. DES generated the drawings that ENG sequentially modified and transformed into optimal specifications for manufacturing. DES was then in charge of performing the changes in the drawings, in order to be understood by the model maker. The drawings were plotted and brought to the adjacent model workshop and, finally, the model maker prepared the model. The model maker called the ENG and the DES from time-to-time, to ask any questions that came up.

Once a day, MAN passed by the DES office in order to observe the project evolution, to make suggestions or clarify any manufacturing issue, and to control the schedule and deadlines. He would then report to the Electrolux chairperson. Occasionally, MAN also brought some information or objects necessary to the project, that could be found just in Electrolux, even if it was a courier service's task.

Communication also took place on the telephone, between DES, ENG, and MAN, to clarify any doubts and confirm any information that occasionally came up. The conversations occurred separately between the interlocutors, because it was not possible for more than two people to discuss on the telephone. The telephone was also used to arrange meetings, discuss any changes in the design document and explain details. Some meetings took place to present the models, either in the DES office, or on the Electrolux premises, although they were not very frequent due to the brevity of the project lead time. There was also a need to transmit some drawings and documents by fax (out of scale) to show some project issues.

In Figure 1, the communication by telephone between DES, ENG and MAN is represented by a thin solid black arrow with a symbol "te". The communication by fax between DES and ENG has the symbol "fa". The meetings that grouped the DES, ENG, MAN, and

sometimes the model maker, are represented by a thick solid black arrow with a symbol “me”. It differs from the other thin arrows because the meetings will continue to exist even after the implementation of the digital communication process.

After the presentation of the final model and the approval by the Italian Electrolux top management and Board of Directors, the operation moved to Electrolux. The ENG took back his workstation and developed the conclusive drawings for the prototype construction. ENG and MAN still exchanged important information, using transfers of drawings on paper, therefore not working concurrently. Once more, as occurred in the DES office, an important part of the work could not be done concurrently. This fact increased the lead-time of the process, and reduced the collaboration and cooperation between the people involved. Communication also occurred through brief meetings, in which the discussion needed the drawings on paper.

There was still some communication between ENG and DES: for confirmation of details, on the telephone, or through the transmission of drawings by fax, or through a courier service. Transportation took up much precious time. Finally, the drawings for the prototype construction were plotted, obtaining DES and ENG sign-off. Then, MAN approved the drawings, and released them to the firm selected by competitive bidding, to be in charge of constructing an accurate prototype of the product designed.

The product model traveled around the globe (England, France and Australia), to be accepted for local business. In the meantime, MAN made contact with subcontractors, especially for the fabrication of the shampoo and water recipient, which was the bottleneck. It required an innovative production technology that Electrolux did not want to develop in-house. MAN also searched for the production of other parts of the product. In the case of the recipient, for example, the high cost and scarcity of producers with technology of welding

process of the two halves by ultrasound, generated the need to search for an alternative technology, like the “hot blade”. This new technology required substantial alterations in the product project for those pieces and, by extension, to other parts.

ENG sent the changes needed by fax to DES, and he sent the drawings with the sketches of possible solutions to the problem that emerged, by courier service. He had to wait for the return of the model that was abroad, which was needed for the model construction of the new recipient. DES made three other models of the recipient, through orientation and drawings of ENG and MAN. They came to the workshop to speed up the approval of the best solution that fitted the requirements of the new technology employed. ENG (through interchange with MAN) developed new drawings. A courier service delivered the drawings, together with the new model, to the prototypist that was already in the final stages of the prototype construction.

The prototype was tested in the Electrolux laboratory (controlled by MAN). ENG required some minor changes that were carried out, and the Electrolux Board of Directors and C.E.O., together with DES, ENG, and MAN, approved it.

MAN searched for the construction of molds for the production of a pilot product. He kept touch by telephone with DES and ENG, every time a problem that harmed the project appeared in the manufacture. Later, MAN sent samples, by courier service, to the DES and the ENG. These samples were colors and injected pieces for the conclusive analysis, judgment and choice of the best solutions.

After the necessary decisions were taken, a pilot product was produced, the final detailed drawings of the product with all the specifications were drawn up, signed and authenticated. Printed copies of these drawings were archived in the ENG office and sent to

the DES. After the production of a pilot product, everything was brought together to see if it worked as planned, in a pilot run. As the pilot run was successful, it was followed by ramp-up that was the start-up of commercial production.

After the beginning of mass production, MAN detected some inevitable changes, and immediately communicated them to ENG. Some decisions of changes in the product were taken after many meetings, which implied in losses in terms of time and money, because many pieces had been already produced. This time lag in the detection of the problem was mainly due to the lack of, or difficulty in communication between the shop floor and MAN, ENG, and DES. They were all physically distant. After correcting the molds and re-starting mass production, the production batches ordered by the foreign branches of Electrolux were finally delivered.

It should be noted that one team designed the whole product. There were not different teams designing subassemblies, subject to common design goals and constraints. The coordination of different teams highly increases the process complexity and would benefit even more from digital communication technology. Once different component designs have been set in process, any further change to one of them should have a proper notification accompanying it to those in charge of all other component designs that the change could affect. Oversights of the changes lead to delays downstream when incompatibilities or conflicts are discovered. Through digital communication all affected parties may immediately be notified of any changes made to the design brief and subassemblies' design.

4. THE DIGITAL COMMUNICATION PROCESS

The digital communication process and computer networking are new communication technologies. These technologies will lead to long-term changes in the way that people work

together. They touch the most critical process in an organization: the way people communicate. Nevertheless, it is difficult to understand **how** computer technology will interact with ongoing routine practices and policies, in organizations. There are some experiments being carried out, but very few studies analyzing its real effects.

Sproull and Kiesler (1991) point out that this change in the way people communicate has first and second-level effects. First-level effects refer to efficiency changes consisting of productivity gains which conventional cost-displacement or value-added analysis often underestimates their calculations. Second-level effects refer to social and organizational changes, that they consider to be more important to the organization as employees cross barriers of space, time, and social category to share expertise, opinions and ideas:

> If an organization's business is stable or if it is operating within a placid environment with long lead times before predictable changes in markets, suppliers, or customers, then diverse dynamic group structures make little sense. An organization that is operating in a turbulent, unpredictable environment, however, will find that the network can become a powerful strategic tool for flexible management. (Sproull and Kiesler, 1991: 15)

De Meyer (1992) remarked that it is often argued that the greatest savings in the reduction of development times can be made in the interfaces between the different company functions involved in the development process. Digital communication improves the interfaces in the product development process through collaborative and cooperative work admitting mutual and constant consulting of the design, engineering and manufacturing departments and the sharing of knowledge. Therefore, it stimulates concurrent engineering, understood as: "a way to conduct the design work where the various activities related to the product realization process are integrated and performed as much as possible in parallel rather than in sequence"

(Naveiro and O'Grady 1995). It can then can be used to increase personal connections and affiliations.

Computers provoke intense communication that allows different aspects of a project to be carried out at the same time rather than sequentially, therefore, the project can proceed rapidly through overlapping and parallel activities. Clark, Chew, and Fujimoto (1987) showed, in their comparative study of automobile development projects in Japan, the United States and Western Europe, that Japan leads the United States and Europe in its ability to get products to the market faster and more efficiently. Japanese project teams use intense formal and informal information transfer both within R&D and between R&D and production, allowing for coordination while preventing too many surprises that could delay the project. Clark, Chew, and Fujimoto (1992) reveal that information moves less quickly between design engineering and the prototype unit in U.S. firms. On the other hand, when the product design changes during the prototype process in a typical Japanese company, design engineers instruct the shop technicians directly about the changes, without waiting for paperwork.

4.1 COMMUNICATION STRUCTURE

Communication will occur basically through computers connected to one another through an information transport medium that carries packages of information in a network. This network may be internal to the organization at the beginning, and afterwards external, connecting the organization with its suppliers, outsourcers and clients, converting them into partners in the development process.

The physical communication device will be just the computer with its software, network, and telephone line. The computer will incorporate the telephone and fax machine. The telephone line and a modem will be necessary mainly for the communication between the

worker's house and the firm. This communication will take place through the Internet. Besides the computer, courier services will continue to be used for delivering documents, drawings and various objects.

The transmission, the reception and also the shared workspace will all be in a digital format. The shared workspace may include: chats, documents and drawings, magazines, books, *facsimiles*, photos of the model and other products, and so on. The 3D models, the prototypes and other three-dimensional products will be delivered by courier service.

Digital communication will link the separate functions of design, engineering and manufacturing, in a horizontal cross-functional process of product development that reduces the conflicts and divisiveness between the organizational sub-units. The integration is attained through multiple group membership, promoting cooperation and cohesion between the separate departments.

Face-to-face meetings will continue to be held even when digital communication will be the main communication format. It would be necessary initially for the constitution of project teams to secure commitment to the team's goals and to decompose the tasks into parts. Later, each participant of this process stage will work in his office, in his department, connected internally to the organization and externally to the other participants, through a computer that will mediate the digital communication. People will be connected because of shared interest, rather than proximity, working in a decentralized way, even geographically, using the network to integrate the different professionals. Other face-to-face meetings can be held for a final design review or a decision such as the start-up of the commercial production. They will be more focused and rigorous because participants should exchange information digitally before the meetings, to clear up misunderstandings, prune away distractions, and identify the key issues.

The Internet will constitute the external communication network of the organization, and an intranet will be a corporate internal service. The intranet is like private *World Wide Web* servers (from now on just *Web*), that copy the Internet model, but offer access just to the authorized users of the local internal network of the organization. The intranet also offers the possibility of communicating with the Internet, because they are harmoniously complementary. There will still be other networks inside the intranet: separate local area networks for each of several functional sub-units, available for sectors, departments or projects. It will treat a specific subject with confidential information that must not go inadvertently to inappropriate people. Compartmentalizing the networks should help protect integrity and confidentiality of data.

The organization will need to hire a webmaster and technical staff to build and maintain the external and internal communication system. In the following delineation, the webmaster and staff were combined into the webmaster person, in the same way was done in the process description where the departments were combined into the manager person of each function.

The position of the webmaster is becoming a more senior-level position, with the person being responsible for managing the evolution and well-being of the *Web* work, as well as the more traditional HTML and other technical work. In some organizations the webmaster has a senior level position, which is expected to become more commonplace as the *Web* becomes critical to the success of a company's information environment.

4.2 COMMUNICATION REQUIREMENTS

The digital communication, external and internal, will be based on the *Web*, and the utilization of some Winsock application software (like Netscape Navigator, http://home. mcom.com/home/welcome.html and Eudora, http://www.qualcomm.com/ProdTech/quest/

products.html), that speaks the Internet language. The external and internal communication refers respectively to the Internet and the intranet. For communication between the worker's house and the firm, each computer should have a SLIP/PPP connection.

Requirements of connectivity are available on the TCP/IP network, and at the IP address. Requirements of hardware for Windows environment are: PC with 80486 processor or better; 256 colors (8-bit) video with 640x480 resolution, or better; 8-bits sound card full-duplex, with input to microphone and output to speaker (internal or external) and compatible to Windows; 8Mb memory; connection with IP network (Windows Socket compatible with TCP/IP architecture); QuickCam or FlexCam cameras, with microphone separated from the camera; speakers; printer; plotter; and scanner. For the house-firm communication a 28.8k modem, or faster will be needed, as well as the Windows Socket having 28.8 kb band or better, and being SLIP/PPP compatible.

4.3 SERVICES

Through the communication structure described above, with a client-server configuration, and using some application software, all participants of the product development process can be physically dispersed and with divided responsibilities. Some communication modes such as: face-to-face chat, telephone chat, fax transmission, drawings on a drawing board and transfer of data files on disks, besides the transportation of drawings and disks, will all be substituted by digital communication (Figures 1 and 2). The necessity of face-to-face meetings will be greatly reduced and will continue to occur, but only when really necessary, and they will be arranged through digital communication. In addition, digital communication will bring the marketing departments of Electrolux in Australia, England and France to the product development process. In the present process, the foreign marketing departments are

major clients of the project, but they are very distant and just buyers of the product. In the process integrated by digital communication, they will become major participants in the whole process.

In the process described, design and engineering could not work concurrently on the same drawing. Through digital communication, concurrent engineering may become the norm. The delays downstream that occurred when incompatibilities or conflicts were discovered, may not happen anymore as digital communication can immediately notify all the affected parties whenever a change is made. In the same way, the problems discovered downstream that required a lot of time until they are known upstream, can be fixed quickly when digital communication is established.

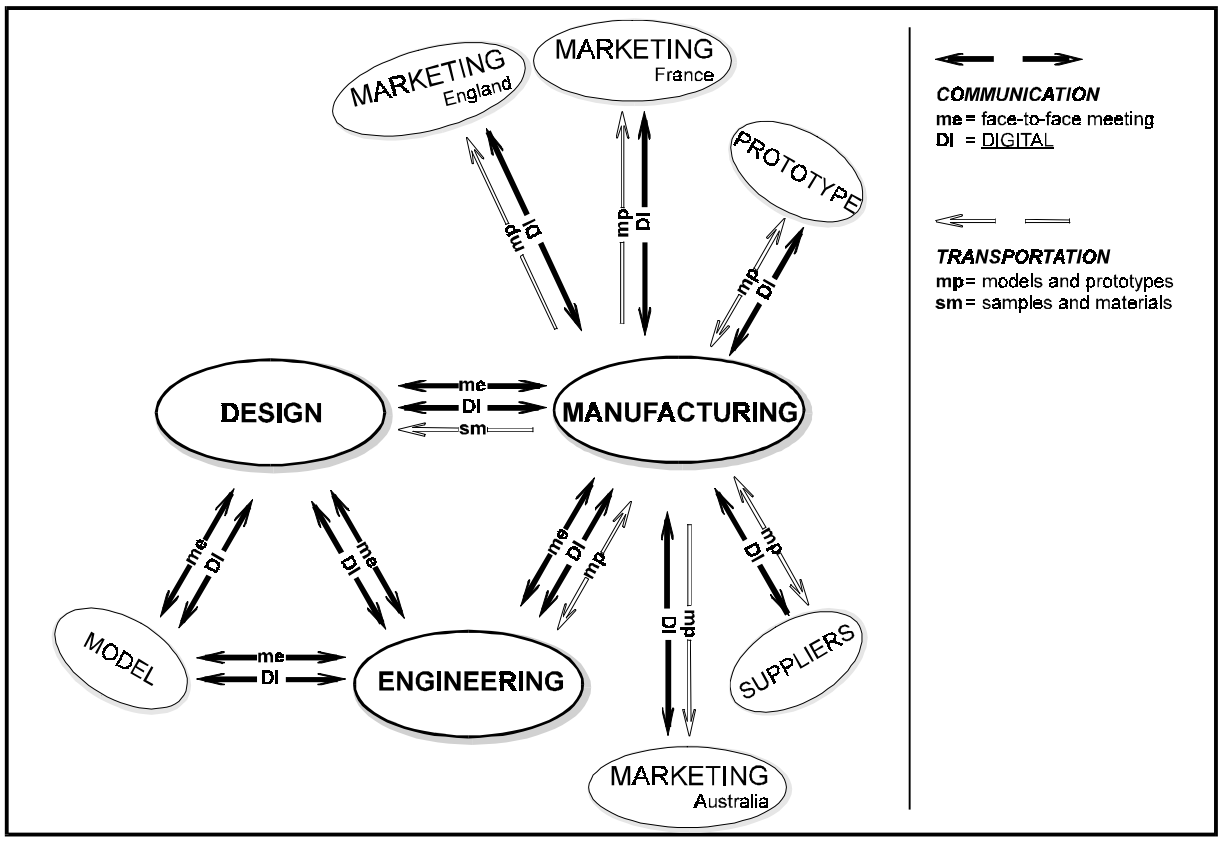

Figure 2 Digital communication improving the information flow in the product development process

Through a *Web* browser interface and using: application software, a memory section, a project section, and a "rules and routines" section of the corporation, everyone involved in the product development process will have the capacity to do the following:

Browser:

- Access information through a *browser*, visualizing another computer through a *monitoring* program (when it has been authorized), transferring and retrieving files through a *FTP* client, visualizing and working on them through *viewers* and many *editors*, discussing information through *IRC*, or on the *Internet Phone*, transmitting it via *electronic mail*, and working concurrently on the same drawing through a *whiteboard*, or even a *video conference* program.
- Go across the net concurrently, for joint research about some fabrication process, or information on technologies and their experts, through the *search* instrument in a browser, managed by a chat program (http://www.tribal.com/powwow/).

Memory:

- Help produce one of the main outputs of the product development process, consisting of knowledge and experience to be recorded. The same group memory is available to every member of the group. Through electronic mail it is possible to archive the complete text of every message, and automatically document entire discussions, which are invaluable in the preparation of reference manuals. Through built-in external memory, electronic messages can be stored and later retrieved, thus encompassing a social memory; and organizational memory can ensure consistency across time and units.

Project:

- Find a problem downstream in the manufacturing process and fix it upstream quickly, saving a lot of time and money. Digital communication technology is very fast and accelerates the information flow (Sproull and Kiesler 1991).
- Share information about production issues, while dealing with different languages, cultures and time zones in the different product development and manufacturing locations. The advantage of the *Web's* documents ability to embed graphics and hyperlink references to other documents in these cases is powerful.
- Keep people up-to-date with the others' progress and problems in between meetings, through electronic mail reports of accomplished tasks.

Rules and routines:

- Hold meetings electronically rather than face-to-face, solving the problem of finding an available day for a meeting when all the relevant people can attend, because people are busy and in different locations.
- Publish something and wait for someone to draw or to work upon it after one stops working and goes home, without the need to bother the collaborators in improper hours, thus linking different time zones. This is possible because digital communication technology can be used in an asynchronous way, so that both parties to a communication do not have to be available simultaneously for it to occur. They can send and receive at their convenience. Nevertheless, as this technology is very fast, it can approximate real-time interaction.
- Put all meeting minutes, presentations, and project plans on the *Web*, where anyone can access them when they need to. It is also possible to disseminate information to groups such as departments through electronic distribution lists, without needing to distribute documents on paper or send e-mail with large attachments. This is possible because digital

communication technology makes one-to-many communication as easy as one-to-one communication. Even previously *ad hoc* communication can become routine.

- Order material, parts, prototypes, molds, products, and so on, directly from the desktop, possibly visualizing on the screen what is available in the stockroom, or how long it will take to arrive. It is also possible to make use of a global procurement organization.

5. ESTABLISHING THE COMMUNICATION PROCESS

The traditional communication modes in the product development process, by means of: face-to-face meetings, telephone calls, fax transmission, and exchanges through courier service, slow down product development and increase lead times in two fundamental ways. Firstly, communication takes a great deal of time, for the reasons outlined above, which include: conventional mailing delays, difficulty to arrange meetings, the need to translate different formats and scales, and so on. Secondly, communication is hindered by temporal and geographic distance of the participants in the process. The difficulty to communicate, leads to problems such as those described above. If a change is needed in the product design it is detected only after the pilot production run, whereas this could be avoided if the decisions upstream were communicated downstream before they were taken.

A digital communication process is outlined in order to solve these problems of delay in the product development process. Although the proposed use of this technology is relatively new, there is strong evidence in literature (Sproull and Kiesler 1991; Clark, Chew and Fujimoto 1992; De Meyer 1992), and in its application in corporations such as AT&T, Olivetti, and others, that digital communication integrating design, engineering and manufacturing can greatly reduce lead times in the product development process, through concurrent engineering and overlapping activity.

AT&T (http://home.netscape.com/comprod/at_work/customer_profiles/att. html) uses digital communication and the *Web* for countless internal applications. These applications include an interface to: accessing library services; doing internal research; receiving external news feeds; accessing database; ordering supplies; putting papers available to be browsed; authenticating internal projects and so on. It has enabled AT&T employees to collaborate more effectively, even on complex projects, and it has improved the efficiency of research and development by helping people work together.

Olivetti (http://home.netscape.com/comprod/at_work/customer_profiles/ olivetti.html) uses a browser-based intranet to create a single "virtual laboratory" that links together Olivetti's research laboratories located throughout Italy and abroad. Researchers use the intranet to access product development information, debate topics in dedicated "discussion areas", and share experiences and projects' results with their colleagues regardless of their location. The product development can be done in teams, and the project leader has instantly administrative data on his project such as expenses, work hours spent, and status of procurement requests. This communication technology allows project teams to focus more on technical problems than on administrative issues, increasing the productivity and efficiency of operations.

5.1 THE *WEB* ENVIRONMENT

It is essential that people spend their time at work on the product development: designing, engineering, manufacturing the product, and even just communicating. People should not waste time struggling to learn how to use the computer and the tools available.

We believe that the *Web* browser interface is becoming standard, and a culture of using this interface is in the process of being molded. The operating systems and their services will

disappear and the browser interface will be common to everyone, although it will be customized to every particular use and user. For these reasons, the main interface between the user and the work he wants to do will be the *Web* browser. In this way, the user will not need to learn a different interface every time he simply wants to do some work.

Every participant in the product development process may sit at his work station, turn on his computer on his desktop, and be able to work directly on his project, as the one in the working space presented in Figure 3. The user's working space will encompass all the interfaces needed for the product development and its communication process. The first window, with its initial page, shows the project being developed in a CAD session where, for example, the designer may need to ask the engineer which plastic section would be needed for the 3D model in case.

The *Web* browser is placed at the top of the window, and functions as an integrative program. The "search" and "search in group" commands are placed just below it. They are useful for researching the Internet and the intranet. These instruments also enable joint research about some fabrication process, for example, when design and manufacturing may search for different qualities in the process. This kind of research, group work, is fundamental when it involves crossfunctional teams, and workers in different locations that produce more and better products when integrated. The communication process in Electrolux-Italy, did not stimulate the group work for researching and collecting information.

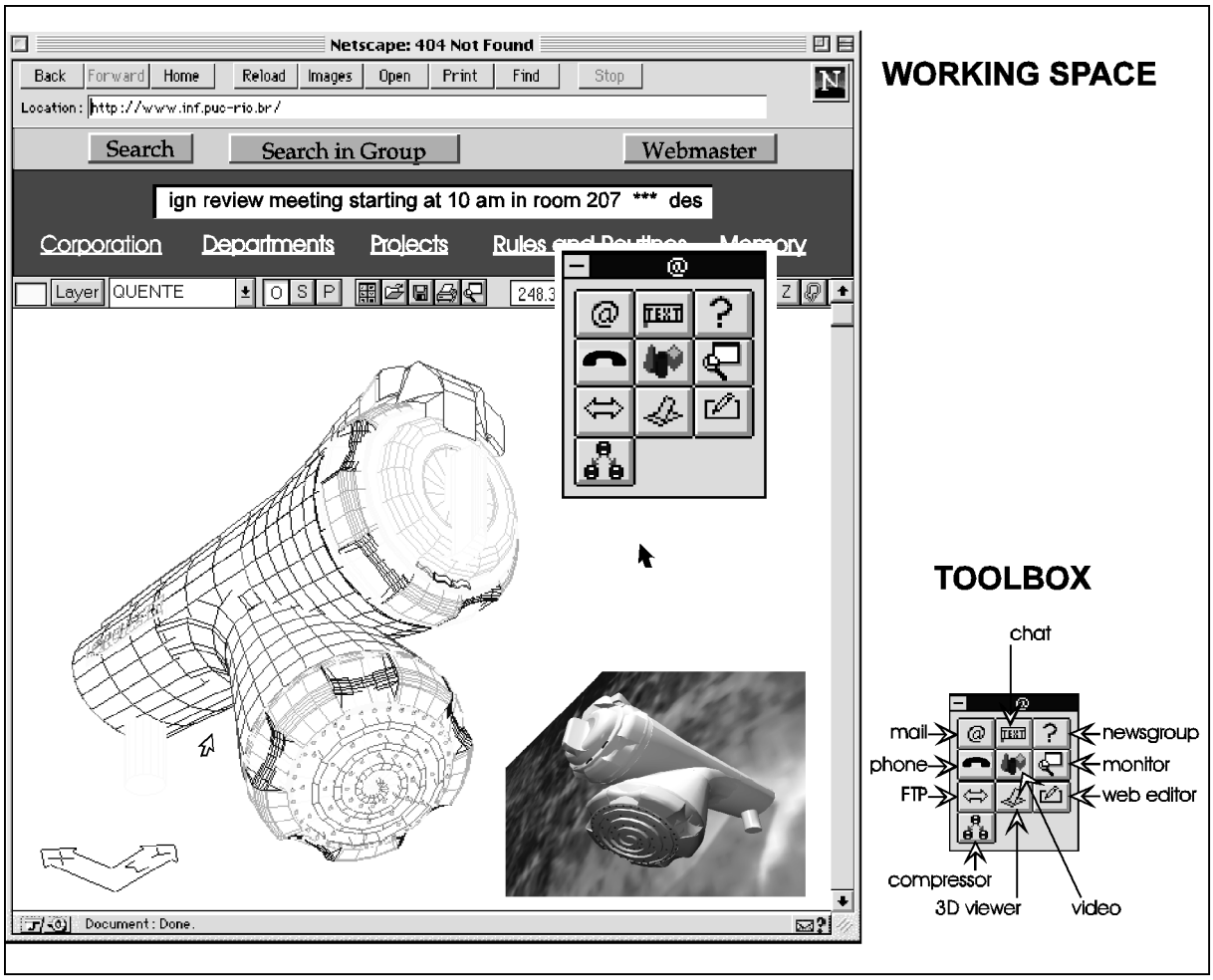

Figure 3 The Working Space window during a CAD session, and the Toolbox for digital communication

Next to the "search" keys, there is a special key that provides immediate contact with the webmaster and staff. As explained above, the users should do the work they are interested in doing. Therefore, they may need to contact the webmaster for help and to solve any problem that may appear, which disturbs the work development. The other communication modes, through the software applications, are easily accessed through a toolbox that can be placed anywhere in the window as well as in any program in use. The toolbox functionality is independent of the current program in use. The user may be working in a spreadsheet and use the toolbox to talk to someone, in the same way he would do if he was working in a CAM program. The interface will always function in the same way, to avoid constant re-adaptation.

5.2 THE WORKING SPACE

Figure 3 shows a window with a working space example that epitomizes how the digital communication process is established. Work in the digital space begins with immediate access to the *Web*. It is the primary interface between the user and the work he wants to do.

There are two keys related to the search instruments of the *Web* browser. The designer may want to learn a specification of a product section from a plastic producer, thus searching for his home page with the "search" command. He may also search for other producers together with other members of the team, using the "search in group" command. It can be used to go across the net in group, as well as to search for files inside the user's computer and every database in the organization.

The user may want to reach the webmaster frequently, as he may need help to continue work on the project, which is the most important process. Another user may have written a report on a new product and edited the report in HTML through the editor in the toolbox, wanting the webmaster to make it available on the *Web* server, and so on. Therefore, a special key that signifies a "hotline" to the webmaster is provided.

Recent and important news is broadcasted for those people who may be interested in reading it, such as: "the design review meeting is starting in room X". The news is frequently fed into this window, and messages such as "you have new mail" may be shown in this space as well. The designer may receive a note broadcasted to him that an important meeting that requires his presence is being held in the meeting room. He may use the electronic mail from the toolbox to send the drawing with a 3D model attached to a message, to another member of the project team in another place. In this message he may ask to continue the drawing and to search for the information needed, while he is out at a meeting.

The largest working space is addressed to every program of interest to the user, such as the CAD program in Figure 3, or a word processor and so on. Each user may have one cursor for concurrent use and communication. The user should not need to use other programs to mediate the access to the real programs he may want to use for his work, or for the documents he is working on.

The communication will be accomplished through a toolbox comprising software of the following applications: electronic mail, browser, chat, newsgroup, videoconference, monitoring, FTP client, VRML viewer, HTML editor, and a compressor. The toolbox will be displayed not only on the first page but also in every program window in use in the computer. The user will access the software directly through ten commands that are available for immediate use. He will use it to communicate internally in the organization and externally to every participant in the project. From inside the program, through the toolbox, the designer may compress the file with the drawing of the product part he made in the CAD program, then opening the FTP dialog box and sending the drawing to the manufacturing department. He may later call, through the phone program, to ask if the extraction angle in the drawing is right. He may finally send a mail to the project's electronic distribution list, informing the other people of the changes he made to the drawing of part "B", and where it is available for concurrent work.

The user may need quick research or information from some important sections. Therefore, there is a frame containing the five main sections that are essential for the product development process. In every page of the *Web*, there will be a horizontal frame at the top of the page, with immediate access to any one of these five main sections. The designer may consider visiting the "memory" section to see if a problem like the one mentioned above has

ever happened in the corporation. He may learn the solution recorded before bothering the engineer with his question.

The following sections are available for immediate access, from any program in use:

Corporation: In the corporation section, corporate applications that are loaded in HTML (Hypertext Markup Language) are available from SQL (Structured Query Language) applications of relational databases, or from UNIX applications, and are multiplatform compatibles. This way, distributed database and data processing systems, resident in one computer, are available to people at a distance and other computers via network.

The applications constructed in HTML are truly interoperable solutions, capable of allowing different kinds of machines to easily share the same data (it does not matter if they are PCs, Macs, workstations UNIX, etc.). There is environment compatibility and, through *Web* technology, it is possible to load an application in a *Web* server and later each desktop with a *Web* browser can access this application through the existing network.

Departments: In the departments' section, each division or department in the organization has a page where current projects, services, processes and guidelines are described. Besides that, every worker has an e-mail address, and even a home page, depending on his or her function in the organization. When the information is available in any department, it is shown in the department's section. Otherwise, it is sent, by electronic distribution lists, to whom it is of interest, helping to accelerate the product development process. Information will also be broadcast and discussed in electronic interacting groups.

Projects: The section relative to the product project being developed contains all the information that the people involved in this process will share. This information may be: product brief with design goals and constraints, project schedule and time deadlines, project

budget, stages of the product development process and benchmarks. As the project advances, new pertinent information becomes available such as: prototype tests and marketing research results, bugs in the manufacturing, date of the first batch production, lists of the work in progress, and so on. This information is constantly updated and reformulated, like a big and distributed database where everyone can access it and contribute to it. This is particularly valuable when, for example, the design group is located in Brazil and the engineering group in Sweden.

When the design project is finished, the engineering has access to its final results, as well as the manufacturing, when the specifications of the product are concluded. Everyone that is part of the project team, or related to it, can follow the product development process. Each department does not have to wait until the end of each stage to give its opinion and contribution, or show any concern.

The two-dimensional materials related to the project must already be in a digital mode, such as the design document, the project budget, the project schedule and time deadlines, and general information that is written, edited, signed and authenticated electronically. It may also be scanned, like photos and product catalogs. The drawings must be in a CAD program format, to make it possible to rework and make changes that the scanned image does not allow.

3D Models and three-dimensional products can be video-taped and made available through animation or image files; to be visualized by a 3D *viewer*, or showed directly through a video conference program, in real time.

Rules and routines: This section comprises all the design rules and works routine files that are standard to the organization and available to everyone related to each particular rule and routine. It is appropriate that all parties involved in the development process have equal access

to a database regarding materials, processes, equipment, tools, market data, and other relevant information. These files may also include forms for material requirements, for part ordering, for prototypes, authorizations, and so on.

Memory: This section refers to the corporation's memory. It presents everything related to the communication and product development process that should be recorded and transmitted to participants for future projects. The organization's memory represents one of the main outputs of the product development process. It may be transformed into knowledge and experience that may compose the core competence of the manufacturing organization. The following examples are presented in the memory section: every discussion about an essential issue in the product development, recorded in the electronic mail; articles in a newsgroup that were important to solve a problem; a voice conference where a breakdown in the process was solved, and so on. This knowledge about the process may help to avoid the same mistakes occurring in another project, or speed up joining a solution to a problem previously solved.

6. CONCLUSION

Digital communication provides means to effect fast decision-making and bring action to where the competence is. It gives instruments to the users that enable them to go to the resources they want, rather than having information pushed at them. It also allows project leaders to focus more on technical problems than on administrative issues.

The results of establishing digital communication can be a more effective collaboration, even on complex projects, because it stimulates the group work. It establishes a unified approach to product development and at the same time leads to creativity. It fosters the knowledge of what the "others" are doing, sharing relevant knowledge through the organization and recognizing employees participation.

Design, engineering and manufacturing do not need to work on the same site. They can be geographically separate and nevertheless work concurrently on the same project using digital communication. Neither do they need to work at the same time. A designer may stop work to go home and send the drawing he was working on to another member of the project's team.

Digital communication may improve the product development process through concurrent engineering and overlapping activities. It is then possible to reduce the lead time of the process, facilitating clear and direct communication in product development groups. It also accelerates learning and getting products onto the market, thus being more competitive.

The product development process in Electrolux-Italy is presently using computers mainly for isolated work and not for communication, as described in this paper. There are some differences from the time of the project process analyzed in this paper, to the way the product is developed currently. The detail design is done using computers and CAD programs. Design, engineering and manufacturing each have their own computer, but are not connected to a network. The exchange occurs mainly through file transfer on disk, therefore, design and engineering can not yet work concurrently on the same file. Each one develops an element in sequence, or in parallel, joining all the information in a final file created by engineering, which includes various pieces of drawing by the design and the engineering. Information between engineering and manufacturing is exchanged using data file transfer on disk, without working concurrently, in the same way as happens between design and engineering.

Companies such as AT&T (http://home.netscape.com/comprod/at_work/customer_profiles/att.html), 3M, Silicon Graphics (http://home.netscape.com/comprod/at_work/customer_profiles/sgi.html), Olivetti (http://home.netscape.com/comprod/at_work/customer_profiles/olivetti.html), Motorola, National Semiconductor (http://home.netscape.com/

comprod/at_work/customer_profiles/semicond.html), Allen-Bradley, McDonnell Douglas (http://home.netscape.com/comprod/at_work/customer_profiles/ mcdonnell.html) and Sandia National Labs. (http://home.netscape.com/comprod/at_work/customer_profiles/ sandia.html) are employing several modes of digital communication for the development of various products.

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