A multi-level process based investigation of distributed design

S P MACGREGOR, A I THOMSON, and **N P JUSTER**
Design, Manufacture, and Engineering Management, University of Strathclyde, Glasgow, UK

ABSTRACT

Nearly all published models of the design process fail to explicitly consider the impact of design being conducted by team members who are geographically dispersed. Such global design teams are becoming increasingly common. This paper presents the preliminary findings of two in-depth investigations of the distributed design process in two multinational companies. One company is primarily involved in original design whilst the other is involved in adaptive/variant design. The paper introduces some descriptive models of the micro and macro distributive and collaborative design processes observed in the companies. These descriptive processes should enable researchers to gain a better understanding of the distributed design process and thus begin to prescribe processes and associated tools to support new and improved distributed design processes.

1 INTRODUCTION

Previous studies of distributed design have concentrated on creating *tools* to support the design process [1-3]. These approaches assume that existing design processes [4,5] are satisfactory for distribution. However previous research [6] has shown that there are significant differences between distributed and 'traditional' design processes. For example, in distributed design there are lower levels of awareness of other people and work, fewer interactions and an increased difficulty in knowledge transfer. The research reported in this paper is part of a wider project aiming to achieve a greater understanding of distributed design – processes and failures – so as to best create supporting process structures for increased distributed design performance. This paper presents the preliminary findings of an eight-month industrial study of two multinational companies, Company A and Company B, who practice mainly variant/adaptive design and original design respectively. This allows comparisons to be made between these two types of design. The paper introduces some descriptive models of the micro and macro distributive and collaborative design processes observed in the companies. These descriptive processes should enable researchers to gain a better understanding of the distributed design process and thus begin to prescribe processes and associated tools to support new and improved distributed design processes. The paper is structured as follows – Section 2 introduces the industrial case studies in terms of the data collection methods used and gives a brief profile of the two companies studied. Section 3 outlines the research methodology adopted in the work. The main findings of the paper are presented in Section 4 where main issues and a description of original and variant/adaptive design environments are discussed for both micro and macro processes. Section 5 summarises the main findings and discusses implications for supporting distributed design work. Section 6 concludes the paper and indicates areas where future work is required.

2 INDUSTRIAL BACKGROUND

Two four-month studies of distributed design were carried out sequentially in UK industry. The work was split into three areas: an identification of current practices; an understanding of present problems or challenges associated with distributed design; and an investigation of possible solutions. Distribution was studied in terms of work organisation, communication modes and activities undertaken. The management of Knowledge, Information and Data (KID) (with particular emphasis on integration and transfer) was examined within each of the companies, due to a belief that the success of a distributed design process is directly attributable to the efficiency of KID management. The two case studies were different in the types of design involved – one case study involved mainly original design whilst the other involved adaptive/variant design. A variety of data collection methods were used: daily e-mail diaries were used to investigate engineers' day-to-day work in the distributed space; questionnaires were used to chart the current perceptions and activities of the engineers; semi-structured interviews helped to detail experiences; while document analysis and direct observation completed the method set. The data collection methodology was based on the work of Yin [7] and is described in more detail in [8].

Company A practises mainly variant/adaptive design. The company is manufacturing/quality driven and although design processes (based on Pugh's Total Design [4]) are preached, these are often ignored when engineers are required to schedule and work backwards from a contract end date. The design environment is highly technical and complex with design re-use predominant. Conventional communication tools are available with the addition of video and audio conferencing suites. Information and knowledge management tools are sophisticated and widely used.

Company B, is a Fast Moving Consumer Goods (FMCG) organisation and is marketing driven. Design is essentially a subset of marketing with the design process proceeding through a set of gates and split into three stages – idea, feasibility and capability. The designs observed in this company were primarily original designs. The company is required to innovate continuously but the product complexity is low. Communication tools are similar to Company A but the systems available for storing information/knowledge are poor.

3 RESEARCH METHODOLOGY

Table 1 shows a three-step approach to the overall body of research that is one of description and prescription with part of the description the focus of this paper. Firstly the existing processes are observed and described, and then any perceived failures are mapped to the existing processes. This then leads to the prescription of a process for supporting distributed design. This paper only discusses the first phase (describing the process). Future papers will report on the other two stages.

Table 1 Research methodology

Phase	Step	Definition
Descriptive	(describing) PROCESS	Existing multi-level processes (detailed below) within industrial case studies
Descriptive	(describing) FAILURE	Failures/problems arising from processes above
Prescriptive	(prescribing) PROCESS	New processes to help counteract failure modes identified above

Table 2 Process definitions

Level	Definition
Micro	day-to-day working practices of designers in a distributed environment
Macro	longer-term working practices evident from designers work, usually within the context of tackling a project
Preached	on a macro level but different from above as designers rarely replicate exactly what is considered policy from the company. Academic processes from the design field are also considered

The process findings are presented on three levels (as shown in Table 2): micro-processes detail the day-to-day working practices of designers in a distributed environment; macro-processes detail longer-term work patterns within the context of a project; and preached processes detail company processes which designers are expected to follow. An examination of these levels should indicate the suitability or otherwise of company policy and provide clues as to what types of processes might be implemented to improve distributed work. An important point to make is that certain areas of a designer’s work are open to change whereas other areas are part of *natural* human behaviour and therefore impossible to change. Both areas should be acknowledged and catered for in any implemented process.

4 MULTI-LEVEL PROCESS DESCRIPTION AND CROSS CASE ANALYSIS

4.1 Micro-processes

4.1.1 Adaptive/variant design environment

Observations of the working processes of Company A showed the importance of switching or changing between different types of work in a distributed design project. The main work types were simple information exchange/searching and collaborative design. Information exchange is defined as interaction with any distributed colleague who may be internal or external to the organisation and has no interest or stake in the final design, e.g. a sub-supplier who provides a specification for a component that may be used in the final design. Collaborative design is distinguished from information exchange by the fact that, although the collaborators may exchange information, they have a common interest in developing the design. The engineers were found to go through a cyclic process of long periods of simple information exchange, and short intense periods of collaborative design. These interactions were found to occur in a ratio of approximately 5:1. Information exchange was characterised by asynchronous interaction, primarily through e-mail and often included low levels of problems (with the notable exception of *external* collaboration which was fraught with difficulty, especially concerning remote availability) while collaborative design was usually conducted in a synchronous fashion using any tools at the engineers' disposal. Collaborative design was characterised by a much higher level of difficulty, including unachievable design details and miscommunication of specifications. Distribution appears to exacerbate problems found in both information exchange and collaborative design in a collocated environment.

At the micro level, the process of collaborative design can be represented simply as a black box process where a period of collaborative design transforms some information into a new set of, hopefully useful, information. It was observed that a *critical mass* of information is needed before collaborative design can commence. In some circumstances the collaborative design phase is initiated, due to time constraints, before the critical mass of information has been reached. This usually gives rise to a greater number of problems. The information produced by a period of collaborative design is then used as input for another period of collaborative design, shown by the cyclic process modelled at the bottom of Figure 1. It was evident from the case study that that some level of common understanding and individual work is required before collaborative phases can commence.

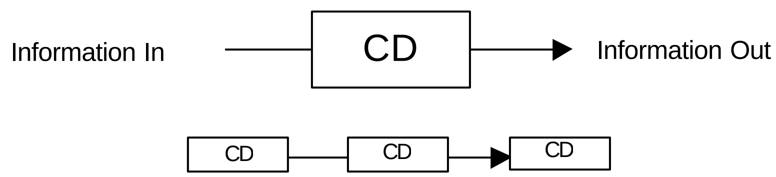

Figure 1: IE/CD cyclic model

Another micro-pattern discovered in the adaptive/variant design environment, outlined in Figure 2, centred on basic information exchange with little or no distributed collaborative design. The first stage in this work pattern is the discussion of a work problem or need. This is usually carried out synchronously and centres on some abstract representation of the problem/need. At this stage the designers only possess mental models of the work in question. Through discussion the abstract representations become more concrete and information exchange becomes asynchronous. Finally, some level of synchronous review and discussion takes place in order to clarify or develop the representation.

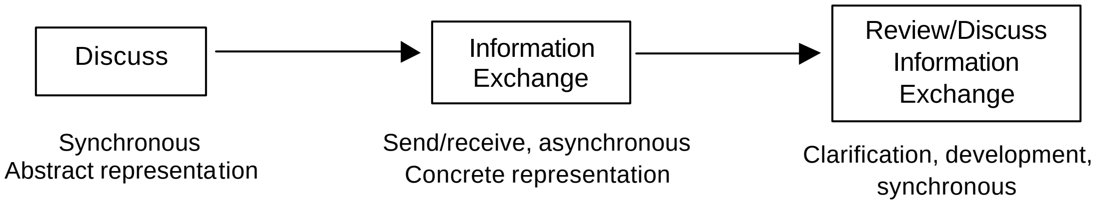

Figure 2: Basic IE model

4.1.2 Original design environment

Although each of the above micro-processes was discovered initially in the variant/adaptive design environment the same general patterns were observed in the original design environment of Company B, but with a few key differences. Firstly, a very low amount of distributed, collaborative design took place. Although it was observed that a critical mass of information was required before collaborative design could take place, the design sessions were often collocated rather than distributed. Collaborators would often travel or key individuals were collocated for the duration of the project. It is assumed that due to the decreased complexity of the product (with respect to Company A) the possibility of having all necessary interactions in a small, collocated team is greater. Also current technologies do not make it easy to transfer creative, innovative design work between distributed individuals, therefore collocated sessions are more effective. The original design environment required more iterations and a greater percentage of the time actually spent designing. However, much of this design was done on an individual basis and then shared – there was very little synchronous, co-operative design. The observed micro-process is shown in Figure 3, which is, in essence, a combination of the processes shown in Figures 1 and 2.

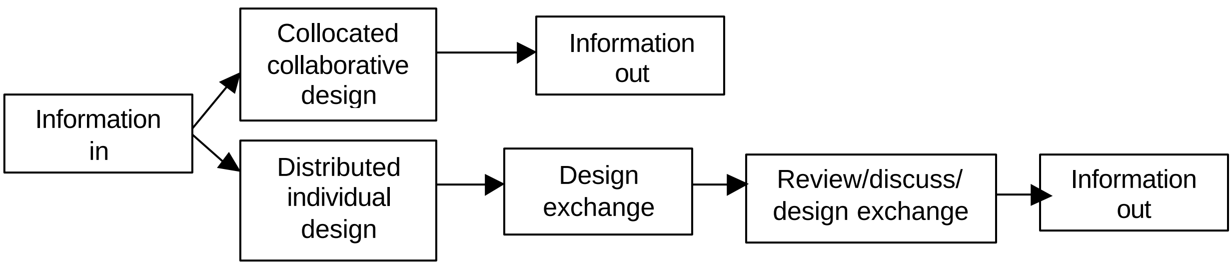

Figure 3: Original design process

Another defining feature of this environment in Company B was the continual need for feedback from physical models and prototypes. These were used at all stages of the design process and were valuable in a knowledge transfer sense but were time-consuming in a distributed environment to the need for conventional mail, while the electronic transfer of virtual models did not prove as informative.

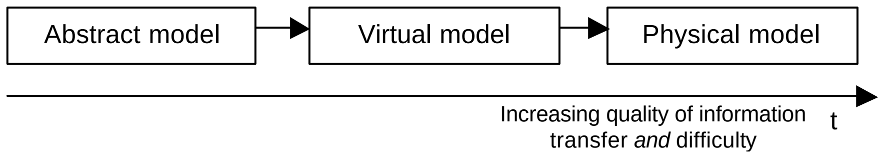

Figure 4: Representation stages

4.1.3 Issues

Observation in Company A indicated a high level of problems in the collaborative design phase. This may also be the case in collocated design – when collaborating, individual work is open to question more immediately by the rest of the team. However, it is clear that some of the problems were exacerbated by distributive factors – many were related to the concept of information, having timely transfer and a critical mass necessary for collaboration. All could be linked to the need for having a greater awareness of the different types of people and their activities at different locations. The original design environment of Company B involved low levels of distributed, collaborative design. Simple tools such as shared workspaces may be able to facilitate higher levels of collaboration. Both companies used well established tools such as e-mail, telephone and fax to facilitate distributed work. Other tools such as audio and video conferencing *were* available but design teams tended not to use them on a daily basis, if at all. Greenberg claims the reluctance of people to use such tools is due to the significant extra start-up effort that is required [9]. It is clear, therefore that a greater examination of processes and human factors associated with distribution has to be carried out in tandem with a continual improvement in tools.

A major problem within the original design environment regards representation. Physical models are required and used. Studies have shown collocated design work, particularly questioning, to change dramatically depending on whether concrete or abstract models are used [10]. Concrete models are shown to facilitate design progress at certain stages. However, this does not prove easy in distributed processes. In Company A where large scale, highly complex products are designed, it is not possible to build physical prototypes and the engineers must make do with virtual models most of the time. Problems arise in distribution when dealing with abstract representations and even non-physical models - collaborators do not know if the 'signal' is being transferred adequately, that is, is there sufficient understanding? More concrete representations, earlier in the process may help with these issues as well as an increased awareness of the situation and others' actions.

4.2 Macro-processes

4.2.1 Adaptive/variant design environment

Figure 5 models the observed distributed design process on a general level and is linked closely with the IE/CD micro pattern shown in Figure 1. The Collaborative Design (CD) 'stream' is ongoing in terms of the design being continually progressed while Information Exchange (IE) 'threads' exist. These pursue matters external to the main design development and often include others external to the core design team, but are nevertheless very important to overall development, for example, the electrical connection details from a sub-supplier and the name of a person from a sister company who worked on similar projects in the past.

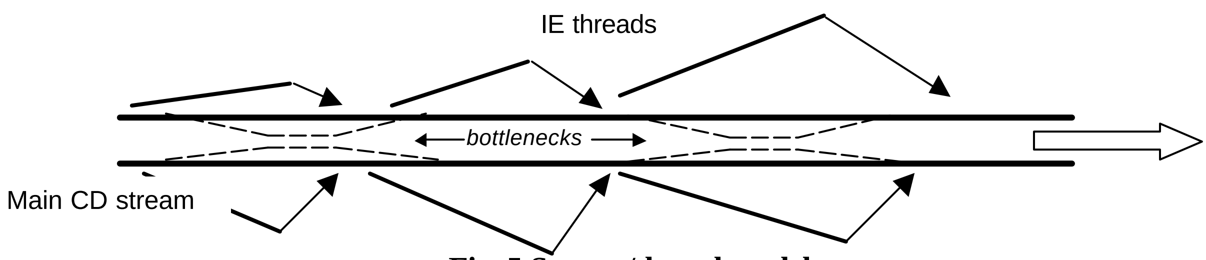

Fig. 5 Stream/thread model

However, the CD stream rarely proves to be without trouble. Frequent bottlenecks usually appear at stages of the main CD stream and sometimes only open up when output from one of the IE threads feeds back into the stream. In a distributed environment there is increased potential for these bottlenecks to cause disruption due to increased delay in information transfer. Engineers stated the importance of the right levels of constraints and resources at the beginning of the stream.

Figure 6 gives a graphical representation of the distributed design process and product structure in Company A. The process starts with a design need and a perceived solution to that need. In many instances this early stage of the design process is collocated. The overall perceived solution is then split into sub-systems. These parts of the solution are then tackled by distributed groups, according to resources and expertise. Few problems are realised within these groups but problems arise when attempting to integrate these sub-systems to form the overall solution.

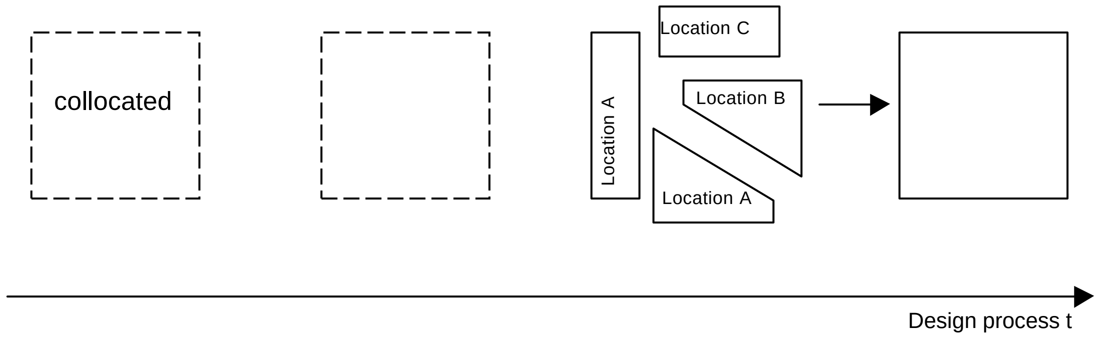

Figure 6: Sub-system model

The physical sub-systems can be considered as chunks of knowledge distributed between different locations and members of the design team. The overriding factor is the need to achieve sufficient integration of these disparate elements of the final design. This view of distributed design suggests that most distributed work is a collection of collocated teams, in essence a collocated-centric view of distribution. We propose that for distributed work to reach its full potential a distributed-centric view must be developed where the links between disparate chunks or sub-systems are optimised. This will involve optimising interfaces between sub-systems before optimising the content of those sub-systems. However, Figure 7 illustrates some of the problems when dealing with this. Often stages 2 and 3 of the process have to be conducted in parallel due to the different needs of the distributed collaborators. These 'interface' problems also exist in collocated design but are exacerbated by distribution.

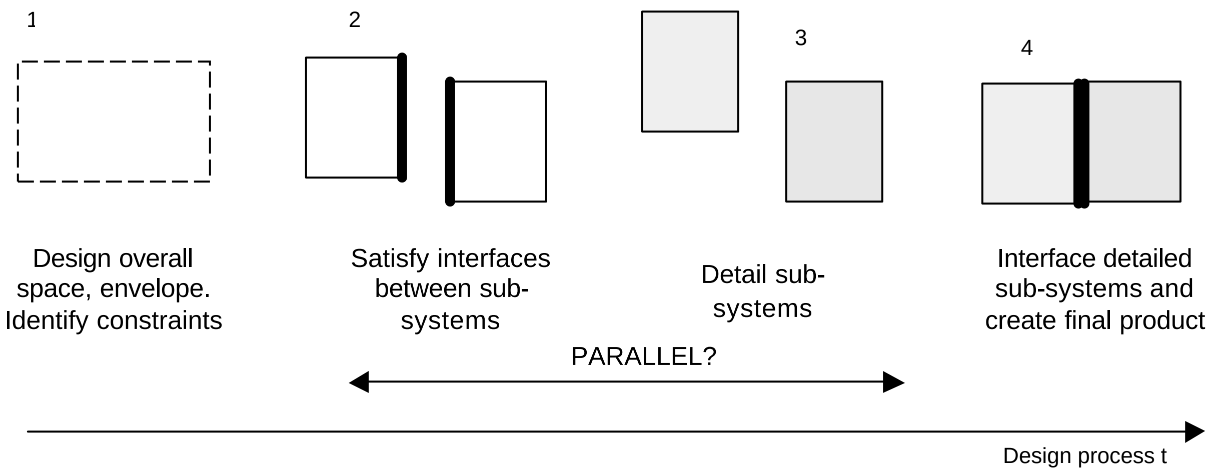

Figure 7: Dynamic sub-systems model

One possible solution to the interface problem could be to spend more time on a joint specification and set out a very accurate solution envelope. However in practice, due to time constraints, the envelope is usually defined quickly and briefly after which accuracy is achieved through iterations.

4.2.2 Original design environment

As with the micro-processes, general patterns observed in the original design environment were similar to the variant/adaptive design environment. The CD stream/IE thread model (Figure 5) also applies to this environment. However it was observed that collaborations out with the core design team/organisation were more efficient than those within the company. This increased efficiency appeared to be due to good relationships which were evident with external suppliers, and can be partly attributed to the lower complexity in product and therefore supply chain. Furthermore, this efficiency emphasises the importance of relationships and trust in distributed work. Difficulties encountered in the CD stream were attributed to the broad discipline base, each with a different perspective on the work and slightly different goals. The sub-system model of Figure 6 was also applicable but there were fewer sub-systems due to decreased product complexity. Furthermore, a broader discipline base is evident here resulting in a greater variety of inputs and different disciplines or organisations at each of the locations. The dynamic sub-system model of Figure 7 was also representative but on a smaller scale. The typical number of interfaces in the original design environment product was 2 or 3 but with variant/adaptive environment products the number of interfaces could be as high as 100.

4.2.3 Issues

The stream/thread model again emphasises the importance of the timeliness and quality of information transfer when faced with the prospect of bottlenecks in the main design stream. Further, it highlights the importance of the extended design team. Problems are evident with external collaborators in the variant/adaptive design environment with its associated complex supply chain. Although previous designs may be re-used, areas of these extended collaborations may be new, and open to difficulty, partly due to the high volatility of staff movement in today's marketplace. Ensuring common goals is a necessity within the extended design team. Conversely, more problems were evident in the main design stream within the original design environment; problems were evident due to the presence of different disciplines and their varying perspectives on the design. Figure 6 highlights the importance of distributed sub-systems in a product and their integration and interactions. Collaborators need a clearer idea of the distributed space and how that fits with the product. The original design environment is less complex and is less troubled by such challenges but they remain relevant partly due to the diversity of disciplines involved, resulting in difficult interactions. The dynamic sub-system model takes the distribution/product structure theme further. Again, there is less of an issue in the original design environment but the importance of interfaces on a physical, information and 'distributed space' level cannot be underestimated.

5 SUMMARY AND IMPLICATIONS

A description of multi-level processes in original and variant design environments has begun to highlight important factors which must be taken into consideration when creating new process support structures. The importance of having a critical mass of information as well as timely transfer of it has emerged, while also validating the examination of knowledge management in the overall body of research. The importance of representation as a deciding factor in the success of communication is clear with a focus on the type as opposed to content which is an ongoing challenge in design communication. The theme of awareness runs through each of the issues as an important pre-requisite to success and is investigated widely within the CSCW domain. Finally the importance of the design team and interactions – the distributed design 'space' and the product with it's related complexity, scale, sub-systems and interfaces is crucial and demonstrates the significant challenges of providing support within this diverse field. A distributed design 'ecosystem' which will describe the overall environment and help to define boundary conditions for each case is currently being developed.

Any new process support has to take account of existing practices within the organisation. Problems arise when trying to integrate processes from distributed collaborators/organisations [11] while too many processes within an organisation are sure to do more harm than good. Although both case environments described here deal with the design of products the organisations are vastly different, although similar in that preached processes as covered briefly in section 2 are rarely used. It is hoped that a description of distributed design, which has begun to be developed in this paper, may help to establish an understanding of core needs, and result in supporting processes which may be used in conjunction with existing processes and models. In many cases, existing processes tell us how to design but not how to communicate or collaborate. The ultimate aim is to create support structures which may fit *onto* existing processes, thereby addressing the problems of process overkill and integration.

Present and future development of this support will centre on the collaboration domain from CSCW. An *awareness and switching* framework, based on existing CSCW literature and developed in light of distributed design has been created [12]. This caters for the general needs of flexibility and diversity, partly through a translation of distributed design needs to address needs related to sub-systems, interactions and interfaces, from the team and product domains. Awareness is defined here as an up to the moment understanding of a situation that a designer is working in. Switching takes account of the different realities that a designer changes between such as, synchronous and asynchronous, or individual and co-operative work. Additionally, existing design processes are being examined in light of the main issues above and may result in changes in process stages to take account of distribution, and issues such as the increased difficulty in achieving common ground, the importance of interfaces as a stage in their own right and a re-examination of the place of the design specification. Finally, the metaphors of a distributed design *space*, in light of the importance of resources and interactions, and a distributed design *journey*, due to designers' awareness and switching needs and their characteristics will be investigated.

6 CONCLUSIONS AND FUTURE WORK

The paper has introduced a research methodology which aims to address a significant challenge in distributed design – the shear scope and diversity of the problem. Two case studies have been discussed on a multi-process level, showing some of the main issues which confront engineering designers in day to day distributed work while future development has been discussed, revolving around a process based approach and the value of addressing various fields involved in distributed work.

The case studies also examined the failure modes apparent in the distributed design processes, however space constraints have necessitated their omission from this paper. A full listing and classification of all failures in the cases is completed and will eventually feed into an FMEA exercise to detail their impact on the distributed design process. Value in the overall research also lies in the presentation of industrial findings as a series of cases or stories so as to enable the efficient transfer of findings.

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