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INFORMATION SHARING WITHIN A DISTRIBUTED, COLLABORATIVE DESIGN PROCESS: A CASE STUDY

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ABSTRACT

A current research project at the University of Strathclyde is introduced which aims to better understand the role of distributed engineering design in industry and address present problems. The first major industrial case study of the project, completed within a multinational in the oil and gas industry, is then described together with the main research questions. This multinational will be described in the text as *company A*. The findings are split into three areas depending on the data collection method employed. The main case study issues are investigated through interviews while a profile of current activities and perceptions comes from completed questionnaires. Sampling and analysis of distributed activity over time is served by the completion of daily diaries and direct observation. These combine to increase the understanding of information sharing and collaborative design in a distributed organization. Interviews show the importance of design reuse within the organization contrasting with the pressures of formalizing all parts of a design project. The preponderance of variant design activity is also highlighted along with concerns of continued practice. The questionnaires show that 34% of engineers' time is spent sourcing relevant information and knowledge and that the most popular sources are company systems followed by personal contact. 18% of work is found to be distributed while colleagues from another location and another floor/department *know more* 51% and 57% of the time respectively. The detail design phase of a distributed design project is analysed over time which finds that most collaborative work consists of simple information exchange *supplementary* to the main design activity. Furthermore, concentrated periods of collaborative design are

found to follow these information exchange 'cycles'. Distributed problems are also discussed in the paper, ranging from difficulties with unfamiliar terminology to a lack of visibility at worldwide sites.

INTRODUCTION

The use of globally distributed engineering design teams continues to increase as companies aim to boost profits and decrease lead times by effectively leveraging knowledge and communication from dispersed locations. However, the benefits offered by distributed design are often marginalized by the problems that are inherent in the process [1]. The following problems have been communicated from recent pilot studies [2]:

- Knowledge bases or Domains (KB) are "confused" and "fragmented";
- KB 'islands' exist internally within organizations and externally within projects;
- There is a lack of common understanding between departments and problems with other project partners;
- An additional issue regards awareness. In order to effectively re-use knowledge from past experiences people have to know that it exists.

Currently, for the purposes of this research the manifestation of these problems have been termed *inconsistencies*. This seems to be the most appropriate term for factors that cause disruption to the smooth running and understanding of the design process. They arise, and are most abundant when knowledge and communication are not utilized

correctly. These beliefs are re-enforced by the current industrial climate worldwide. Continual technological advancement is set against a backdrop of international mergers, take-overs and partnerships, resulting in a distinct lack of consistency on an organizational and design project level. There is a definite need for measures that will ensure a satisfactory level of continuity across all levels and particularly within distributed working scenarios. These problems have been re-enforced by the findings in the literature. The two main study domains of the project, Computer Supported Co-operative Work (CSCW) and Knowledge Management, detail the present shortcomings in working at a distance and maximizing the use of knowledge as a company asset.

A set of industrial case studies is required in order to focus the many issues in the field and to give adequate focus to problem areas to be addressed. The overall aim of these case studies is to investigate the distributed design activity within a large multinational that designs complex technical products. Particular attention is to be placed on the role of knowledge in supporting this distributed activity and any supporting knowledge or information systems that the companies use. The first case study, discussed here, was carried out within Company A, a company which supplies pressure control and drilling equipment for the oil and gas industry. It is primarily a descriptive case study which aims to provide a snapshot of a part of the distributed design process.

BACKGROUND AND MOTIVATION

KITE – Knowledge Integration and Transfer for Engineering design

KITE is a three-year research project based in the fields of Computer Supported Co-operative Work (CSCW) and knowledge management. The main aim of the project is to investigate methods of safeguarding against inconsistencies in the distributed design process, by the effective integration and transfer of knowledge. This will be achieved through investigating a number of issues and encapsulating these findings in a Knowledge Integration and Transfer environment for Engineering design (KITE). It is envisaged that continuous consistency will be a key requirement for real progress to be made in future distributed engineering design projects. This will be addressed through investigating the following objectives:

- appropriate knowledge that can be used to enhance the design process;
- the most efficient and useful methods of integrating and transferring knowledge;
- types, levels and location of inconsistencies within the design process;
- the needs of various distributed design teams and required modes of communication.

These will result in the following actions:

- Definition of the requirements of KITE and production of a specification;
- Prototype of KITE environment.

The following propositions are the result of project work to date and help to frame the strategy behind the case study.

- The creation of distributed design teams has potentially major benefits for an organization which decides to implement them. Benefits include the sourcing of expert knowledge from different sources and the sharing of resources available worldwide.
- However, the potential of distributed design teams is not fully realized due to problems inherent in the process. These problems cause disruption to the smooth running and progression of the design process and are termed here, inconsistencies.
- By minimizing the level of inconsistencies we can improve the effectiveness and efficiency of distributed design projects.
- A key component in improving the communication in the distributed design process and minimizing the level of inconsistencies is to effectively use knowledge as the basis for leveraging the potential benefits.
- In order to do this we must first identify the level, location and types of inconsistencies in the design process and identify useful knowledge that engineers use in the design process.
- Full benefits will be realized if we can effectively integrate and transfer knowledge, which will, in turn minimize the level of inconsistencies.

Four main research questions, reflective of the aims and objectives of the project, exist:

- What are the needs of various distributed design teams and their required modes of communication?
- What are types, levels and location of inconsistencies within the design process?
- What is appropriate knowledge that can be used to enhance the design process?
- What are the most efficient and useful methods of integrating and transferring knowledge?

Although these questions were not asked directly during the case study they were at the center of all data collection method development as they maintain a strong link between the overall aims of the research and the case study findings.

CASE STUDY METHODOLOGY

Rationale

Company A are worldwide market leaders in the production of pressure control and drilling equipment for the

oil and gas industry. The main case study site is in Aberdeen, Scotland. Aberdeen is the head office of the Eastern region of Company A, a region which includes the UK, Europe, Africa and Russia. The two other main sites are in Houston, USA and Singapore. The company represented an ideal opportunity for investigating a collaborative, distributed design process. Firstly, the company is widely distributed. With regional headquarters in Aberdeen, Houston and Singapore many issues within the CSCW field will be present, including those of distance, time-zones, cultures and the resultant knowledge, information and data which exists within three widely dispersed regional headquarters of the organization. In addition to these three regional headquarters Company A has engineering and manufacturing centres, and sales/service offices in 59 locations and 24 countries around the world. Secondly, in designing and engineering pressure control and deep sea drilling equipment for the oil and gas industry, the work that engineers do is necessarily complex. This technical complexity adds another challenging dimension to the company's distribution and necessitates the optimal use of knowledge. If knowledge is used optimally then the technical complexity of the work may not cause as many problems between engineers.

Overall methodology

A core team of ten engineers were involved in the case study while informal discussions took place with other employees. The core team was requested to take part in semi-structured interviews, complete questionnaires and keep a daily diary of five short questions for a period of thirty days. These data collection methods were supplemented by other informal discussions and direct on-site observation. All research subjects were either involved in the design process or some level of distributed engineering work. The case study lasted for a period of ten weeks. Record sheets were completed for significant events, interactions or studies. The types of records and their codes are shown below:

- A - Informal staff meetings or interactions (e.g. discussion at lunch, in corridor)
- B - Data collection methods
 - a Interviews
 - b Questionnaires
 - c Diaries
- C - Documentation analysis notes
- D - Significant events (e.g. presentations)
- E - Observation notes
- F - Impressions and interpretation notes

A significant effort was made to record all relevant data, to create a sizeable and searchable case study database and separate actual events and facts from interpretation and opinion. These initiatives are in line with recommendations from the appropriate literature [3]. In total 21 interviews and 19 incidental interactions took place. This included the core

research group of 10 plus other employees at managerial level. This totaled over 130 record sheets and nearly 12 hours of interaction. 24 completed questionnaires and 174 days worth of activity was recorded through daily diaries. This equated to a response rate of 87% for the diaries.

Data collection methodology

Interviews. The use of interviews helped to lay the foundations for the case and gain an overview of the company in addition to highlighting issues for further investigation. Topics such as working habits, philosophy, distribution, communication, knowledge and information within Company A were investigated. Furthermore, the core research group of ten engineers came from a variety of backgrounds. Although the study was based within Research and Development (R&D), only five of the group worked for R&D. The five consisted of the R&D manager, the principal analysis engineer, a component specialist and two engineers. Other departments represented included UK Operations (UK Ops) which dealt with day-to-day engineering project work and the bid group of Subsea Production Equipment (SSPE). Members of the research group possessed backgrounds in, and were responsible for:

- the company's knowledge and information systems;
- the potential of current technology for future use;
- the qualification of new products and systems, and;
- workflow management.

Years of experience ranged from under 5 to over 30.

Questionnaires. Questionnaires were used to profile the overall distributed design and knowledge sharing activity within Company A. These were distributed after the semi-structured interviews and focused on particular issues, including those raised in the interviews. For most of the questions the respondents were presented with 'range' questions. These consisted of 10cm lines with opposite ends of the appropriate scale (see figures 1 and 2). For example the range may be 0-100% or *very satisfied* and *very unsatisfied*. This allowed qualitative issues to be quantified by measurement.

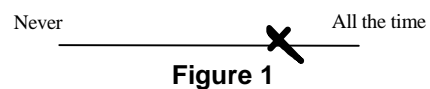


Figure 1

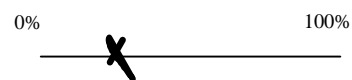


Figure 2

Diaries. The use of daily diaries afforded the opportunity to analyze the engineering design activity over a period of time

without having to utilize observation techniques, although observation augmented the findings in the diaries. The diary consisted of five short questions. An e-mail message, comprising the questions, was sent from the research base each evening, allowing the engineers to complete the diary each morning, on opening their mail client (Lotus Notes). This was the best available method, decided in conjunction with the research group. As such the response rate for the diaries (30 days data for ten engineers) was 87%. Each of the engineers completed the diaries with varying levels of detail. The diary questions together with a typical response are shown below:

1. Did you take part in any distributed activity (yesterday)?

If YES, what was it?

Further attempts to gain information about subsea connectors, eventually being passed on to the correct person, still awaiting details. Received Pro/E simplified model of Company A's template, onto which our tree fits. In exchange, sent them drawings of our tree with dimensions in inches and mm.

2. Did you encounter any problems from this distributed activity? If YES, what were they?

Getting hold of the correct person to get the required information. Company A's Pro/E template model was created in mm, which did not convert very well to inches. the geometry converted, but all reference entities stayed at the original size.

3. Did you take part in any activity which involved the use or exchange of data/information/knowledge? If YES, what was it?

Pro/E model and Engineering bid drawings.

4. Did you encounter any problems with this data/information/knowledge activity? If YES, what were they?

As above.

5. Was there any particular piece of knowledge that proved useful yesterday? Details please

The template model was very useful.

The 30 days (6 weeks) of data available for this scenario concerned distributed collaboration between the engineer on site (Aberdeen, Scotland) and a sister company in Norway. The teams were working together on a major bid for an upcoming Invitation to Tender (ITT) for a major oil and gas company based in France. The work carried out could be equated to the detail design phase in light of the level of complexity. The data collection period coincided with the start of the project and continued through to a relatively advanced stage. Initial emphasis was placed on the interactions which took place over the six weeks. Essentially, this information sharing supported

the collaborative design activity between Scotland and Norway. Interactions were identified as being one of five types:

Information Out (IO): Information was sent to the collaborating party in support of ongoing work;

Information In (II): Information was received from the collaborating party;

Request Out (RO): A request for information was sent to a collaborator. In most cases this information was required to progress the design activity;

Request In (RI): A request for information was received, and;

Information Exchange (IE): A congested activity where numerous pieces of information were sent and received over a short period of time.

Each of the above identifiers were specialized by the tool adopted. For example, IOe would signify sending something out by e-mail while IIt would signify receiving some information by telephone. Distributed activity identified in the diaries took the form of either simple information exchange (for example, with a supplier) or collaborative design, as supported by information exchange (for example, a level of discussion and trade-off in agreeing an aspect of a design).

CASE STUDY FINDINGS

Investigating the main case study issues – interviews

Although a variety of backgrounds and job functions were represented in the interviews it became clear that a common company approach would emerge for certain areas of work. The contrast between the engineering design activity as it is preached in academia and practiced in industry was a main output of the work by Hales [4]. Although a set of 'Golden Rules' abounds through the company, much of the work was said to be about prioritization and "responding to pressing requirements." Rules, such as specification generation and materials selection are often completed after the core work is finished, informally or from limited past solution spaces. With regards to fully documenting project work for future re-use the metaphor of a 'trail of debris', is used to describe the occurrence of unformalised parts of the project left on completion. This factor takes on significant importance in light of the nature of design work completed within the company. Each of the core research group mentioned most design work as being reworking or reuse of past projects (referred to by engineers as 'tweaking') as opposed to utilization of all parts of the design process. If parts of past projects are left unformalized, it follows that engineers will design without the complete set of knowledge gained in the previous project. Reworking of past projects can be identified as variant design – the most prevalent within the company. Other types of design are adaptive – taking the same design and adapting to new applications, and original design. However, concerns were raised with continual variant design activity in that some

projects of detailed complexity have a “limited change capability.”

Each member of the research group could see the benefits in distributed design, citing the following:

- being able to respond to a global customer base;
- pooling resources, and;
- leveraging experience and knowledge from branches worldwide.

However, many distributed problems existed including:

- Distributed team members without sufficient background knowledge and a full grasp of the issues to make informed decisions on work;
- Problems with nomenclature and terminology with distributed team members frequently using abbreviations and acronyms unfamiliar to the rest of the distributed team;
- Duplication of effort worldwide due to a lack of visibility of projects at the other sites;
- Cultural differences.

In line with the aims of the KITE project and other past and present research initiatives [5-8], the use of specialized design knowledge has the potential to address many of these distributed problems. It follows that, the way in which Company A carries out its distributed activity has to be viewed along with the above distributed issues. Distributed work is said to be ‘split-up’ for distributed partners to progress. The use of discrete work packages for distributed personnel is practiced within the company. This would seem to illustrate a different perspective on distributed work – where less support is required for day-to-day work but where extra care is required when merging or combining these packages or interfaces. Examination of *interface* design is conducted later in the paper.

The study of knowledge and information and how this is used within engineering design work is inextricably linked to the study of distribution. In recent years, Company A has implemented several company systems which purport to manage knowledge within the organization. Research in the recent past commented on the need for such systems [9] and an evaluation of these systems must now take place for progress to continue. Interviewees commented on types of documentation which helped transfer knowledge. Drawings were said to be the best method complemented by specifications and bills of materials. However, some engineers commented that a higher level or rationale is still missing and that too much reliance is still placed on more experienced members of the organization (referred to by engineers as ‘the old heads’). Problems, as noted in the KITE project, of inconsistency and islands of knowledge were subsequently communicated.

Profiling current activity and perceptions - questionnaires

Much of the questionnaire addressed the basic concepts of distributed activity and knowledge sharing and how these related to the design process. The following average figures resulted from questioning the engineers how they spend their time:

- 17.8% of their work is distributed;
- 36.7% of their time is spent working as part of a team, and;
- 23.3% is spent working with someone from a different discipline.

These figures are relatively high and when allied to similarly high levels of perceived *complexity* and *importance* in distributed decision making, call for adequate systems to be put in place. Furthermore, when asked how often people outwith their personal space know more about a particular problem,

- geographically distributed colleagues know more than a collocated colleague 51% of the time, and;
- colleagues from another floor or department know more 57% of the time.

If distributed colleagues know more about certain topics it is important to examine how colleagues *interact* and increase their design knowledge. Poltrock and Engelbeck [10] cite that the preponderance of interactions are opportunistic, their frequency generally decreasing as physical distance increases. Furthermore, Kraut et al. [11] found that 52% of all conversations involved people located within the same corridor and 87% involved people located on the same floor of a building. It follows that, if distributed colleagues know more about certain areas of work and these are *not* the people who engineers are interacting with on a regular basis then there has to be some system or procedure put in place which will make up for this apparent shortfall in knowledge transfer. These figures also re-enforce the belief that distributed design not only occurs across countries and time-zones but also within the same site. Indeed, one engineer commented that communication is more efficient with colleagues of a similar background in a different country, than collocated colleagues with a different engineering background.

With respect to communication tool utilization, telephone and e-mail are by far the most popular, followed by fax, videoconference and lastly, conventional mail. Mode of communication is perceived as being 53% asynchronous, 47% synchronous, although a large range of answers were forthcoming depending on job description.

The engineers were also questioned on **how** they find relevant information. Figure 3 shows the average responses.

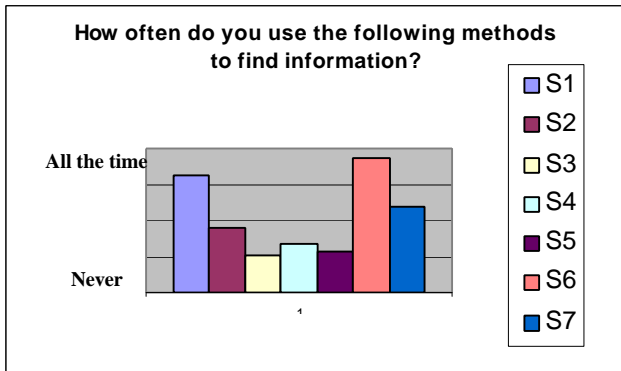


Figure 3

KEY: S1 – Colleague in the same office;
 S2 – Colleague in a different office;
 S3 – Colleague from another company;
 S4 – Internet;
 S5 – Intranet;
 S6 – Company systems;
 S7 – Library/catalogues.

Encouragingly for the company, the most popular methods were using company systems or asking a colleague in the same office. These methods have the lowest overhead in terms of time, however, it is imperative that the systems are effective. In his study of 1996 Marsh [9] found that personal contact was the most frequently used source of finding information, and that 78% of this was provided by memory. Formally recorded information was comparatively infrequently used and was rarely obtained from formal, maintained repositories. This shows that Company A at least, have addressed some of these information management issues of a few years ago. Personal contact is still a main source of information but company systems were shown to be the most popular source by all methods in the case. However, satisfying the next level, of knowledge management still seems to be unfulfilled. Data collection methods indicated that company systems would satisfy the first level of information query but would not suffice. In most cases, engineers would then seek a relevant point of contact who would fill in the *gaps* left. These gaps took the form of rationale or justification – in essence a higher level of design knowledge. Investigating the systems that the company has in place, the most frequently used system contained information on past projects with associated drawings and reports. This was followed by a system which contained standard design theory and the company’s operating policies and procedures. By examining the content of these systems we can begin to hypothesize on one of the projects research questions – that of appropriate knowledge for engineering designers. As the most popular system contains information on past projects this would seem to confirm the crucial role of experience in engineering design as detailed by

Marsh [9] as well as re-iterating the preponderance of variant design activity within company A. Policies and procedures are very useful, looking at the level of use for the second most popular system.

Again, the *level* of use of these systems is encouraging from a company perspective although a level of criticism of these systems was communicated throughout the case. The questionnaires also showed that on average, 2.64 sources of information were required to be consulted to satisfy a works query (4 being the highest) and that the engineers perceived 34% of their time to be taken up sourcing or locating relevant information and knowledge. This compares with a figure of 24% as shown by Marsh [9]. Other studies have shown that as much as 85% of engineers’ time is spent on non-analytical tasks including locating and structuring information [12, 13]. Furthermore, employee satisfaction is generally high. Figures of 5.8/10 and 5.6/10 resulted for confidence and satisfaction of company systems. 10/10 equated to very confident and very satisfied and 0/10 equated to slightly confident and not satisfied.

Sampling distributed activity - daily diaries

The highest level of activity took place with the main collaborating partner in Norway (see figure 4). This accounted for 62.5% of all activity. Next highest was collaboration with suppliers at 20%, followed by other parts of the Company A group at 10%. Sub-contractors and customers at 5% and 2.5% make up the rest of the activity.

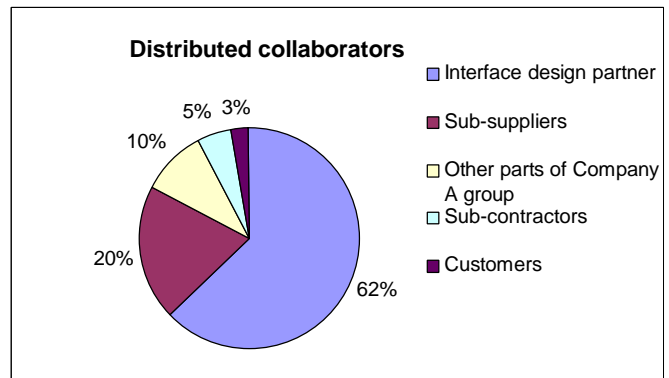


Figure 4

This variety of collaboration calls for measures to be adaptive to certain situations. Furthermore, activity with the Norwegian design team was by far the most prevalent in all groups with the notable exception of *Requests Out (RO)* which consisted of 70% interaction with suppliers. Further sections will discuss that certain types of distributed problems were prevalent in each of these interaction categories and collaborators. Examining these types of interactions in more detail (see figure 5), asynchronous communication tools are found to be significantly more prevalent than synchronous tools.

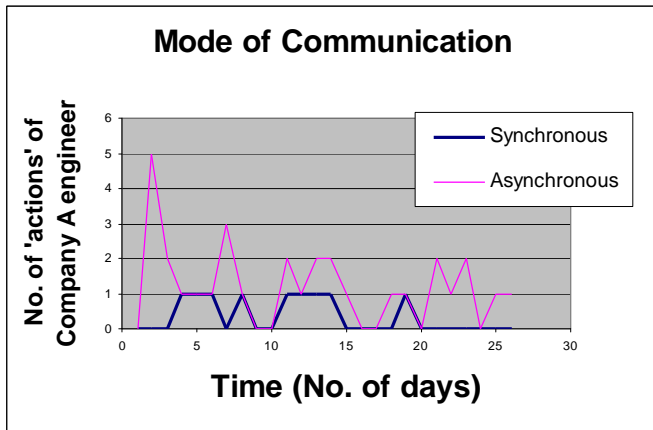


Figure 5

This concurs with other research in the field [14] and could be explained by the slight time difference and the difficulty inherent in the availability of dispersed colleagues. More significantly, it may be that the bulk of the subject of interaction is only supplementary to the ongoing design activity with only periods of core designing done distributively, especially in a synchronous mode. These cycles can be examined in more detail by charting the occurrence of each of the types of interactions (see figure 6).

Some distinct patterns emerge from the charts which comprise figure 6. A high level of activity in all information types is seen at the start of the project. *Requests Out* shows a high level of requests for information over the first 11 days. *Information Out* shows a consistent occurrence of information being sent out over the first 7 days while the amount of information being received is consistently high over the first 11 days and especially on day 2, as shown by *Information In*. This activity followed on from a meeting that called for a series of actions. Most of *Requests Out* occurred during the first two weeks and were sent to sub-suppliers. The rest of the information categories involved, on the most part, collaboration with the main design partner in Norway. *Requests Out*, *Information Out* and *Information In* all have their highest level of activity at the beginning and the end of the sample period. The middle phase is taken up by a focused period of *Information Exchange (IE)*. This indicates periods of simple information exchange followed by collaborative design with respect to the information shared, and then on to the next cycle. We propose that the results for the time period after 40 days would include another period of concentrated IE. Distributed activity is also *continual*. On very few days was there no distributed activity at all. It is important to note that the data collection period coincided with the beginning of the project and ended at about 65% completion. The most popular type of interactions week by week were as follows:

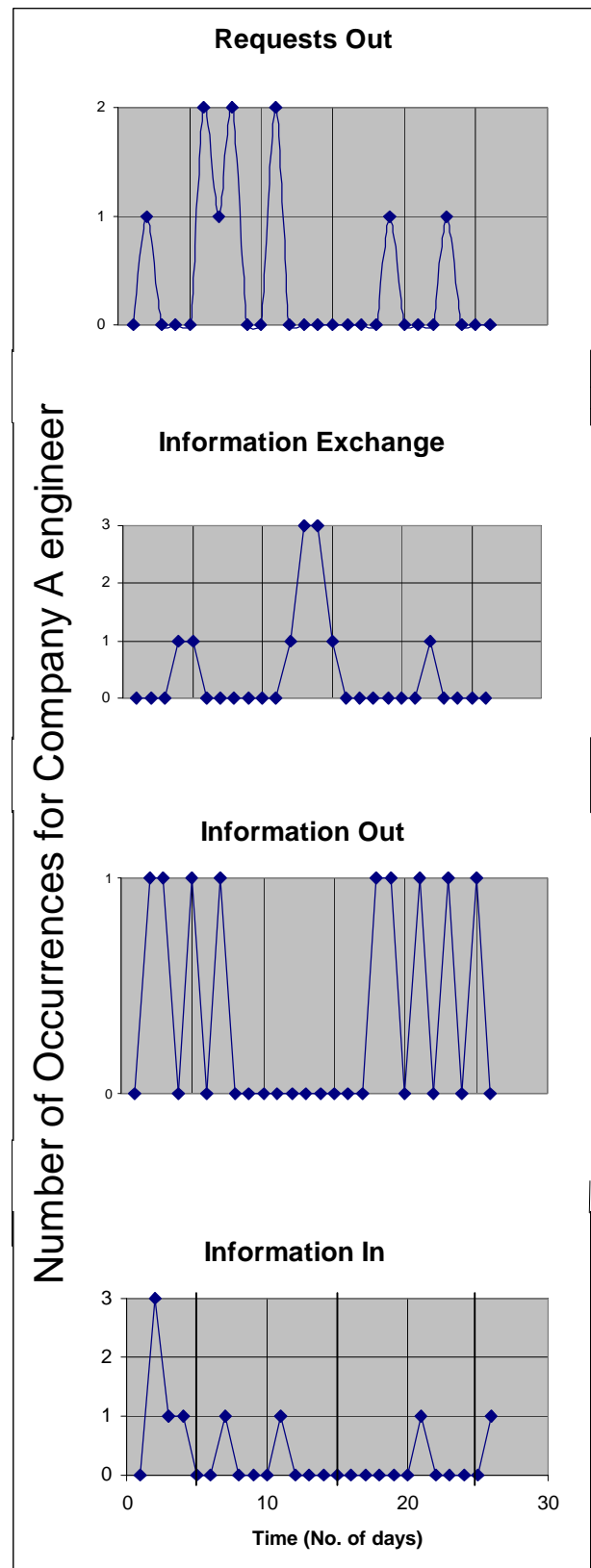


Figure 6

Requests In (RI) only occurred once throughout the thirty-day period on day 12.

- Week 1 – Information In;
- Week 2 – Requests Out;
- Week 3 – Information Exchange;
- Week 4 – Information Exchange;
- Week 5 – Information Out;
- Week 6 – Information Out.

Further studies are required to detect how each of these activities *combined* to make up the distributed design activity. Further investigation would also estimate the type of information interaction in the rest of the project, from week 7 onwards. A series of problems were also communicated during this sample activity.

Week 1

Design indecision;
Use of unfamiliar abbreviations and acronyms;
Not knowing who to contact for information;
Unachievable design detail.

Week 2

Misunderstanding during call;
No reply/response (2 instances);
Getting hold of correct person for information;
Geometry conversions from metric to imperial.

Week 3

Ill informed design changes;
Poor distribution of information;
Misinterpretation of e-mails.

Week 5

Describing and interpreting;
Poor distribution of information;
Ambiguities.

Week 6

Disagreement;
No reply/response;
Colleague with important information absent.

Some problems are human based and will occur during any collaborative or work activity, regardless of distribution. However others such as the problems with abbreviations and ambiguities may be solved through the aims of the KITE project, by making best use of the design knowledge abundant in the work activity. Others such as disagreement with the design are compounded with distribution, making it harder to come to an agreement. Taking the framework proposed by Gutwin and Greenberg [15] some of these problems may be

associated with the *taskwork* and others, the *teamwork* or the work of working together.

SUMMARY

The findings

The findings so far from the case study increase the understanding of distributed engineering design within the modern day workplace, giving an overall perspective of the role of collaborative design and distribution. The **interviews** aided in the initial investigation of the main case study issues as well as gaining an important overview of how the company operates. Some points concur with areas of the literature while other points are company specific and equally valuable. The most important points include:

- The value of design knowledge re-use contrasting with the time pressures of formalizing all parts of a project;
- The preponderance of variant design within the organization and concerns of continued practice for the future.

A list of problems associated with distribution help with a general understanding, including:

- Distributed colleagues with insufficient background knowledge;
- Problems with unfamiliar terminology;
- Lack of awareness or visibility at distributed sites;
- Cultural differences.

The distributed activity within Company A is also said to be split up into discrete work packages placing extra onus on the interfaces between different parts of the design.

Information is found to be transferred adequately but engineers voiced concerns over the lack of rationale in company information, resulting in a lack of working design knowledge. Too much reliance is still placed on the 'old heads' of the company, while some of the initial problems found in the project and communicated in the introduction were confirmed.

The **questionnaires** found relatively high levels (to be expected in a modern day workplace) of engineers' work associated with distributed activity, team working and multidisciplinary:

- 17.8% distributed;
- 36.7% team working, and;
- 23.3% working with another discipline.

The questionnaires also confirmed the importance of being aware of distributed design existing on various high and low levels. Collaboration with another floor or department can be just as important as another country. Figures 1 and 2 show that engineers source information from company systems and

collocated colleagues. These areas come with the lowest time overhead, and will be taken into account when catering for the needs of distributed engineers in the research project. Furthermore, this shows that if any implemented system actually works, then engineers will make the change in working practices. Only a few years previously, the main source of information in the company was the old engineering handbook. 34% of engineers' time is perceived to be taken up sourcing information, compared to a figure of 24% in a previous study based on observation [9].

Time series analysis is an important facet of any case study investigation. **Daily diaries** were the main method in this case as opposed to direct observation. Valuable results for level of work with different partners came from analyzing the diaries. The analysis of one engineer's diary gave the following figures:

- 62.5% of distributed activity with main design partner;
- 20% with sub-suppliers
- 10% with other parts of Company A's group;
- 5% with sub-contractors, and;
- 2.5% with customers.

Adaptability of any implemented systems is a must. Cycles of information exchange and collaborative design are also apparent from figures 7-10. Significantly at this stage, for this type of *interface* design the bulk of distributed activity is supplementary or in support of the design, rather than collaborative design itself, which only occurs in concentrated periods. Furthermore, the identification and analysis of this type of activity may be reflective of much collaboration in the modern marketplace where companies concentrate on their own specialisation, which is interdependent on other companies and functions.

Project progression

The findings, in general, have confirmed the results of the pilot studies undertaken during the initial stages of the research project, while adding significantly to the problem domain. Specifically the following points have been confirmed:

- KB 'islands' exist internally within organisations and externally within projects – *issues of this nature were apparent in the diaries where particular problems occurred when trying to source information from outwith the company. Internal problems were not as frequent;*
- There is a lack of common understanding between departments and problems with other project partners – *misunderstandings, ambiguities and misinterpretation occurred from time to time in the diaries. This happened on a distributed level only. Collocated problems were rare;*
- An additional issue regards awareness. In order to effectively re-use knowledge from past experiences people have to know that it exists – *interviews and questionnaires*

communicated the need for increased visibility at different sites. Examples were given of duplication of effort at sites worldwide.

The following point from the pilot studies was not confirmed but will continue to be investigated:

- Knowledge bases or Domains (KB) are “confused” and “fragmented” – *the questionnaires showed that on average only 2.64 sources were used to satisfy a query. The engineers used a maximum of 4;*

Secondly, the case study findings have begun to address the overall aims of the project. The research questions (reflective of the aims and objectives of the project) have been addressed in the following areas:

- What are the needs of various distributed design teams and their required modes of communication? – *Perceptions of distributed design have been communicated through the interviews and questionnaires while the diaries have shown a live project. For example, the diaries have shown that asynchronous communication is more prevalent and the information profile charts have addressed the needs of engineers at different stages of collaboration;*
- What are types, levels and location of (inconsistencies) within the design process? – *A series of problems relating to distribution and knowledge have been communicated in all the methods. Problems of ambiguity and misinterpretation communicated through the diaries may, in turn lead to inconsistencies if they are not continually checked and confirmed;*
- What is appropriate knowledge that can be used to enhance the design process? – *Knowing where engineers get their information and knowledge from, as shown by the questionnaires, will in turn enhance understanding of appropriate knowledge through examining the content of these sources;*
- What are the most efficient and useful methods of integrating and transferring knowledge? – *the understanding afforded through the case will indicate various options suitability or otherwise in the future.*

In all, an understanding of the overall domain has increased which will aid future investigation.

Further Work

The findings to date address the overall aims and objectives of the project. However, further material from the case will augment the present results. This will come specifically from the following sources:

- An additional in-depth scenario from the daily diaries completed from a different perspective, and;
- Information flow studies for distributed activity.

Much of the above work will enable continued analysis and comparison with the findings presented in this paper.

Furthermore, the medium term will witness the completion of a further case that will enable a different perspective on industry and enable the required cross case analysis. One element of focus will include the identification of types of inconsistencies within the distributed design process. Finally, the medium to long term will include some form of prescriptive solution in response to this descriptive phase, as detailed in the background section.

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