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AN INTEGRATED ETHNOGRAPHIC AND EMPIRICAL METHODOLOGY IN A STUDY OF KNOWLEDGE SEARCHES IN AEROSPACE DESIGN

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Abstract

This work continues development and evaluation of a practical approach to a Design Research Methodology developed previously [1] and extended to practical application in [2] and concentrates on empirical techniques for research evaluation. We test a method of integrating an ethnographic approach with analytic observational techniques. The ethnographic study proved a rich source of novel insights into designers' knowledge searches during normal design activities over a 9-week period. These insights were used in conjunction with a diary study and interview data to interpret the self-report and observational data. This lead to the formation of models of the search process and the development of a number of categorisation schemes for search. A methodological analysis of a number of these schemes (1) a search tree based representation, (2) a feature commonality model, was made leading to the adoption of a scheme strongly based on the ethnographical insights rather than an abstract model. Some preliminary results from the use of this model are described and methods for verification and validation of the approach discussed.

Keywords: empirical study; design philosophy; user evaluation, sampling

1. Background and Objectives

A common theme in engineering design research has been the development of models of aspects of the design process using a wide range of research methods, combined with implementation in computer software for the purposes of demonstration and evaluation. However, the methodology employed has frequently been *ad hoc*, reflecting the state of engineering design research as a field. We propose to develop a practical approach to design research methodology, with specific attention to linking (1) integration of research software development and (2) empirical techniques for research evaluation.

Techniques from the social sciences such as ethnography do not sit easily with standard design research empirical methods. This is partly because of their contrasting philosophical basis in personal subjective experience and objective hypothetico-deductive methods respectively. We tested a technique of integrating an ethnographic approach with analytic observational techniques.

1.1 Practical Design Research Methodology

A majority of design research, to date, has focused on developing, and in some cases testing, new design methods. Little of this research has adopted a rigorous research methodology, which is not surprising, bearing in mind the complexity of the engineering design process and

hence design research. The practical approach taken here is based on design research methodology developed by Blessing, Chakrabarti and Wallace [1] with particular emphasis on practical empirical evaluation. In the first stage, *Criteria formulation*, measurable criteria are identified, such as "reduced time to search" together with a network of causal influences linking back to success criteria such as "increased profit". The second stage, *Descriptive Study I*, analyses the existing design process or product aiming to discover relations between the measurable criteria and the design process or product to identify where application of a design method could lead to improvements. In the third stage, *Prescriptive Study*, insights gained in *Descriptive Study I* are used to create an intervention for an improved design process that could result from using the new design support. This intervention creates a starting point for specifying and implementing design support. Finally in *Descriptive Study II* the design support is tested experimentally to determine whether it works as intended and whether it actually impacts the measurable and thereby the success criteria. The approach aims to give information on the applicability and use of methods involved in experimental design, analysis, data collection or presentation. Empirical methods can be applied at the descriptive level of the methodology or at the evaluative stage. The aim of the next stage is to further develop, evaluate and disseminate the framework for an integrated methodology for Engineering Design Research within the context of industrial engineering design. We aim to analyse the methodology of specific case-study projects in real design situations, focusing specifically on integrating the use of experimental and empirical techniques. This will also enable a methodical assessment of the practical use of design research methods, in general, and the development of guidelines for a practical integrated methodology that can be applied to industrially linked problems.

1.2 The Aerospace Knowledge re-use case-study

We describe a case-study: the investigation of aerospace knowledge searches in a real design environment, in order to gain a better understanding of what knowledge and rationale should be captured and how it should be structured. The specific project concerns the causes, sources of information and outcomes of searches for design knowledge that occurred during a period of observation of working design projects by a team of aerospace designers.

1.3 Background

The methodological case-study was carried out as part of continuing research into knowledge capture and reuse in the context of engineering design projects in a real industrial aerospace context [3]. Previously, it was found [4] that on average 24% of a designer's working day was engaged in the acquisition or provision of information. On average, this time consisted of 53 minutes obtaining or being given information, 34 minutes providing information and 17 minutes of overhead. On 90% of the occasions designer's obtained knowledge by reference to their colleagues. It was found that 78% of the time this knowledge required no further information search. However this work required development by focusing on understanding in-depth aspects of knowledge seeking activities, such as why designers require knowledge, and what knowledge and rationale related to past design projects they intended to reuse.

1.4 Research Questions

A number of primary research questions were addressed. What triggers designers' need for knowledge? How do designers search for knowledge once they have identified their need? What types of knowledge do designers require? What types of knowledge do designers obtain as a consequence of their search? How do designers use the knowledge they have obtained?

Three main media were taken into account: face-to-face communication, telephone calls and e-mails. The aim was to investigating the strategies designers follow and the actions they undertake during their knowledge searches. This was accomplished using interview techniques, and observational methods.

2 2. Methods

In order to address the issues of capturing realistic detail of activity two combined methods were developed (1) ethnographic participation and (2) diary study with retrospective protocols interviews and shadowing with recording.

2.1 Ethnography

The approach we take is strongly influenced by advocates of cognitive ethnography [5] but rather than integrate ethnographic techniques with analysis we have utilised a participant observation stage as part of a preliminary phase to the research in order to generate new insights into the detailed design activities and estimate parameters for carrying out detailed observation in the second phase. The researcher was placed on site as a member of the design team with a genuine design task and team role. This enabled a truly ethnographic perspective, allowing the formation of opinions and insights into the design knowledge activities from the day-to-day inter-personal and social involvement with co-workers and the formal management and information structure of the working environment. This method was used as a preliminary stage without bias or hypothesis prior to the use of further hypothetico-deductive methods during the rest of the study.

2.2 Methodological objective

The methodological objective was to seek a research approach that allowed insight into the nature of knowledge searches during the day-to-day project without recourse to methods that generated unrealistically large quantities of difficult to analyse data or generated artefacts of the research techniques.

2.3 Ecological validity

In addition, consideration of the social psychology of the experimental situation led to the adoption of methods that were ecologically valid in that they minimised interference with the normal design. For this purpose an ethnological approach required the researcher to participate in the design teams and their day-to-day activities on the site to be studied. A temporary placement was used for this purpose giving the researcher an actual design task. This was intended to make the researcher part of the organisation in order to: (i) further identify research issues; (ii) gather a personal experience of seeking design knowledge; (iii) gather social and technical context embedded in the environment under investigation. A number of ethno-methodological tools were utilised by the researcher during this pilot stage including the use of diaries, interviews, surveys of search behaviour and the collection of relevant management and organisational documentation

2.4 Sampling

To be able to generalize the results of a research study in the industrial design group, sampling should take into account: the stage of the design process; the number of people involved in a design task; the duration of the design tasks in progress; and the differences of

responsibility, experience and technical competence. All these parameters can contribute to give a fairly precise estimate of the number of interviews and observations necessary to collect a representative set of data. Previous research in this area [4] was used to set the initial estimates of these parameters operationally.

Table 1 Parameters of search events from [4]

working process data	(3 instances per day);
specific product data	(1.7 instances per day);
expertise-factual knowledge	(0.5 instance per day);
expertise-basic familiarity	(0.5 instance per day);
expertise-evaluation interpretation	(1 instance per day);
expertise-established awareness	(1.4 instances per day);
housekeeping	(unknown);
not applicable	(unknown);

From these estimates and the size of the data set that was required, an estimate of the required number of observational days was calculated. Although the original work did not state the instances of categories such as 'housekeeping' and 'not applicable', it was inferred that, of the 16 elements of knowledge daily obtained from a designer, there were 8 falling into either 'housekeeping' or 'not applicable'. This implied that there was a ratio of 1:2 between the knowledge elements falling into the first six categories and the total number of acquired elements. If the same ratio is expected for knowledge provision, then approximately 13 relevant elements of knowledge should be collected per day. Assuming that in this study at least 8 instances of knowledge will be collected in each category, 16 observational days would be necessary. If 1h 43min of data were collected per observational day, 27h of data would be collected during the 16 observational days. Because each hour of observation would require as much as 18h to prepare and analyse the data [3], 61 days would then be expected to complete the analysis, in line with the resources available. Observational days were then divided among three design groups on the basis of the findings in the ethnographic pilot in order to representative each group effectively. The study was divided into two phases, separated by months for analysis, to ensure that insights gained from the first phase could be used to set the frequency and nature of observations in the second.

2.5 Preliminary Observations

A deliberate feature of the methodological approach was the use of convergent methodology. In this approach, a number of techniques that were, in principle, capable of independently separable estimates of target data, were used simultaneously. The advantage of this approach was that it allowed findings to be cross-checked against each other and evidence to be accumulated by more than one method without favouring any one interpretation. For this reason, it was expected that ethnographic insights, interpreted interview data, survey data and recorded retrospective interviews could be used together to unify interpretation of the observations as a whole. Each method was assumed to possess advantages and disadvantages with respect to objectivity, accuracy and the degree to which they were capable of revealing, non-formal, unconscious or un-stated aspects of the search. Different methods allow differing degrees of subjectivity to affect their result forming a spectrum of objectivity across methods. The Ethnographic participant observation was assumed to give access to insights into the motivation, social and organisational context of the designers environment, while a diary study was seen as well suited to retrieving a large amount of day-to-day information about the particulars of searches. In order to supplement the diary information, retrospective interviews were used to gain information from the designers about specific aspects of their searches not recorded. A conventional survey was carried out as a convergent “triangulation

point" to check for consistency of findings across methods. Some preliminary findings from the ethnographic study include the following observations.

- Designers talk to their colleagues for all sort of reasons such as accessibility or social reasons
- New knowledge searches can be triggered by completely unrelated knowledge searches.
- Searches of specific information require a good understanding of related design issues to be able to interpret and choose.
- Knowledge searches become more focused as they proceed.
- Finding colleagues that would provide technical information is not generally a problem for designers. They struggle more to find non-technical process information.
- As knowledge searches proceed, the way in which questions are formulated become more specific as it builds up on the understanding developed in the previous steps.

Importantly, these findings were subsequently utilised in interpretation of the data acquired by other methods and in the development of a model and categorisation scheme for the conventionally acquired observational data.

3 ANALYSIS

The knowledge search triggers, sources, media and outcomes collected from the initial pilot study by all methods were used to define the categorisation schemes used. A number of definitions were made for the purposes of analysis, the principal one being a definition of search as constituted of one or more sub-events where the required information remained the same although the source, media and trigger could vary. A number of sub-events or searches could share the same goal. The principal data-recording format was also the format used in the record forms of the diary study. This format was arrived at through observation of common design searches. The participant noticed that searches possessed a number of definite parameters and these were utilised as diary headings. Figure 2.

GOAL	TRIGGER	REQUIRED INFO	SOURCE	MEDIA	START TIME	OUTCOME	END TIME & DATE
Engine A - understand differences between Engine B & Engine A HP turbine disc	Compare	What material was used on the Engine B?	Scheme sheet	Paper scheme RTS 80733.	09:20	HP turbine disc material is MSRR 7252 REC	09:50
Engine A - understand differences between Engine B & Engine A HP turbine disc	Compare	What material was used on the Engine B?	Detailed drawing of part	Paper copy FW 13054	09:20	HP turbine disc material is MSRR 7252 REC	09:50

Figure 2. Example of the format for the Diary study

The principal questions to be addressed included: (1) the classification of goals, triggers, required information and sources of information; (2) statistics of searches across and between designers; (3) the distribution of search types by source and media and their utilisation across and between searches; (4) the relationship of outcomes to search types; (5) sequential information about the duration, order and contingent probability of search events. Preliminary statistics could easily be calculated from the diary data with respect to source, media and

outcome. For example the numbers of searches carried out for each source type and by the nature of the outcome is shown in Figure 3 for two designers.

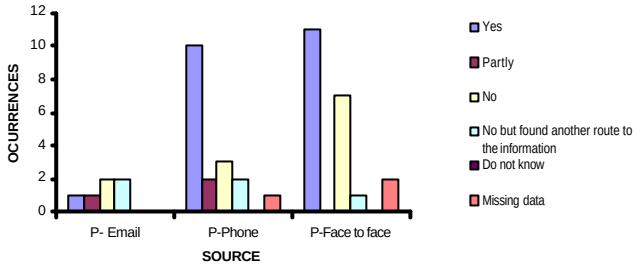

Figure 3. Pilot statistics of number of searches broken down by outcome and source.

Insights from the preliminary ethnographic observations were used in conjunction with the diary study and interview data to interpret the self-report and observational data. This interpretation lead to the formation of several models of the search process and the development of a number of categorisation schemes for search

A methodological analysis of three of these schemes contrasts the information made explicit by three differing representations of knowledge searches: (1) a search tree based representation, (2) a feature commonality model.

Following AI approaches to the analysis of plasnning and problem solving a search tree approach was adopted where it was assumed that a hierarchy of decision could be represented by state represented as goals and sub-goals and the processes required to achieve changes of state [6]. A related approach would be to represent searches in terms of the time-line of their occurrence of search events with parallel representations of simultaneous multiple search events where they occurred.

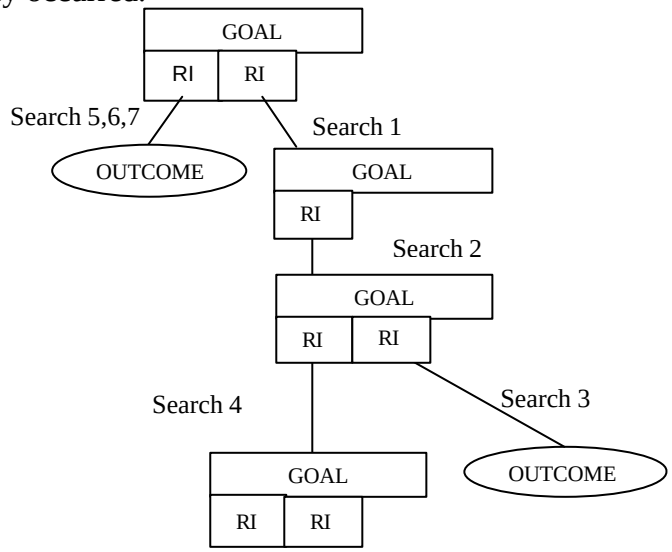

Figure 4. A search- tree representation of knowledge searches. RI = Required Information

Common and Distinctive features in Search Objects

It is also possible to consider each search to be cast as starting with the possession of an information object that contains a number of characteristics or features and the seeking of an object also possessing a number of features. The relationship between the possessed and sought information is then a similarity relation where quantitative differences are ignored and objects possessing the same and only the same features are considered to be identical. This

approach leads to a common/distinctive feature analysis of searches based on set theory where the similarity between two search objects can be expressed in terms of their common and distinctive features:-

$$S(i, j) = g(\mathbf{i} \cap \mathbf{j}) - \alpha f(\mathbf{i} - \mathbf{j}) - \beta f(\mathbf{j} - \mathbf{i}), \alpha, \beta > 0$$

Where each object I is represented as a set of features denoted **i and** the similarity **S** between i and j is a function of the number of features they have in common, the number in i that are not in j, and the number in j that are not in i. This gives rise to a measure that is a linear combination, measuring the common and distinctive features of the two search objects. The α and β here represent potential asymmetric weightings of the common and distinctive features, normally assuming that $\alpha = \beta = 1$. This can be used to classify searches according to the trigger and required information, based on a set theory model. For example:-

Table 2 Set theory classification of searches.

I have an OBJECT that I know a lot about. I know exactly where to look for detailed information about:-		
OBJECTs with similar features	OBJECTs with different features	OBJECTs with identical features
I have an OBJECT that I know very little about. I d not know exactly where to look for general information about:-		
OBJECTs with similar features	OBJECTs with different features	OBJECTs with identical features
I have a few Features. I do not know exactly where to look for general information about:-		
OBJECTs with similar features	OBJECTs with different features	OBJECTs with identical features
Features which are the same	Features that are different	
I have a lot of Fs. I know exactly where to look for detailed information about:-		
OBJECTs with similar features	OBJECTs with different features	OBJECTs with identical features
Features that are the same	Features that are different	

This analysis assumes that object features can be considered equivalent to knowledge of address of the required information (not an unreasonable assumption in the highly structured and organised domain of aerospace design), and that the boundaries of an object can be defined within the engineering context by the scale or granularity of the search. It is also assumed that possession of a few features is equivalent to vague or general knowledge and possession of many features is equivalent to detailed or specific knowledge. Quantitative features can be represented in such a system by overlapping sets [7].

3.1 Problems with these Approaches

There are a number of problems with these approaches. A key problem lies in the difficulty of identifying the designers' existing knowledge from the transcripts. In both representations we assume that it is possible to ascertain the level of features that are assumed to make up an object by the designer and the nature of the information sought. The search tree representation makes explicit the order and relatedness of sub-searches and searches as a goal tree but does not represent information about intentions, triggers and their relation to outcomes. Even with the use of retrospective interviews focussing on the dairy entries as cues as to what occurred, much of the information required by these abstract representations cannot be gained from the data. A representation is required that is capable of representing the stated aims of the designers while at the same time making explicit useful information about the engineering motivation and parameters of search. In the methodology employed, information is in principle available from the ethnographic study to define this representation. Hence an ethnographic-based categorisation scheme was developed based on the following definitions and elements:-

Table 3. Definitions of search types

	POSSESSION	SEARCH TYPE		SEARCH CONTEXT
1	Information being searched for is already available as outcome	Exact Information	1S	Static
			1C	Current
			1P	Past
2	Information being searched is not available as outcome	Exact Information	2S	Static
			2C	Current
			2P	Past
3	Information being searched is not available as outcome	Exact search to understand	3S	Static
			3C	Current
			3P	Past
4	Understanding being searched is not available as outcome	Understanding Search	4S	Static
			4C	Current
			4P	Past

A number of key parameters are used to characterising different aspects of the searches:-

- **Possession** of knowledge was identified as an important feature in modelling the searches because has enabled to partially characterise the conditions prior to start of a search. Availability of the information was inferred either because the designer stated it or because the information was previously searched and found.
- Three categories of search were developed: (i) exact search; (ii) exact search in order to understand; and (iii) search for understanding. *Exact searches* are undertaken to confirm, identify, obtain and define various information and data types. *Exact search in ord3er to understand* are undertaken to obtain an exact piece of information that would subsequently permit to gain understanding on a particular issue.
- With **search context**, information and understanding been sought by the designers may be *static*, i.e. not associated to the project, *current*, i.e. associated to the current project, and past, i.e. associated to past projects.
- In this study the terms *information* and *understanding* are extensively used hence their definition is required. The term *information* is used to indicate all the circumstances in which the designer is seeking any of the types below. The term *understanding* is used to indicate searches for both domain and procedural knowledge.

The frequency of occurrence of the different categories can be calculated from the diary data representation. For example the distribution of the classification categories over the whole data set is shown in is reported in Figure 5. The predominance of 2S and 2C categories indicated is an interesting preliminary result and suggests that useful analysis and insights into search will be gained when this information can be broken down with respect to source and media and by stages of the design process.

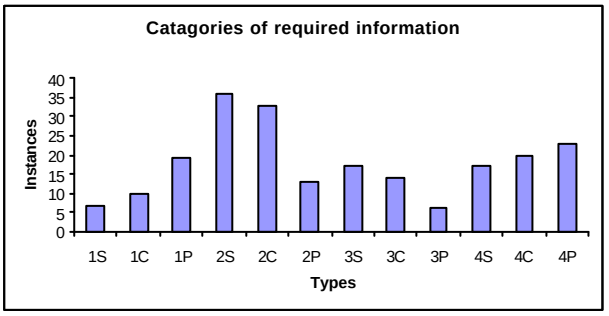

Figure 5. Distribution of Search Categories across all data

4 Discussion and Conclusions

The primary methodological approach in this work has centred on the use of multiple methods aimed at answering the same questions. The degree of convergence of results from differing methods will be used to assess the robustness of the findings. The successful collection of basic statistics regarding the frequency of uses of information sources, and media provides base-line data that can be compared with new distributions of the statistics on the basis of the classifications of search types. The two stage design of the study have ensured that interpretations and models of the data used during analysis in the primary collection stage can be utilised to modify the goals, questions, and focus issues addressed during the second detailed shadowing phase, yet to be carried out.

4.1 Approaches to analysis

The goal of the analysis used in this work was to examine observational data in the light of the researchers detailed ethnological insights. A description of the data was then used to form a model of the search processes used by the designers. This model was devised on the basis of a classification of the data. The theoretical constructs behind the classification were then used to construct operational definitions of theoretical entities such as “triggers” and “understanding” and used to formally reclassify the data. This can then be verified by a number of judges of varying backgrounds. Finally, the results were used to draw general conclusions on the basis of the ability of the classification and model to account for designers’ actions. Areas in which this was inadequate will be taken to represent a mismatch in the classification and the underlying model, allowing it to be modified and refined.

There are a number of methodological strengths and weaknesses that have emerged from the analysis, to date. It is clear that the diary study and retrospective interviews may not capture all the intentions and parameters of designers’ searches. In particular, as they are a form of self-report there is a possibility of self-modification and censoring of the events described. Even if self-report were perfect, they cannot capture the underlying thoughts or unstated context of a search event. Finally, all the entries in the diary have to be interpreted by the person transcribing the data who may also be the individual making the judgement of the classification of specific events. One advantage of the ethnographically originated classification scheme is that it focuses only on information and understanding that is stated by the designers and not that created as a result of inferences based on the interpreter’s knowledge.

The advantages of the methodology adopted lie in the naturalness of the observational techniques used during the ethnographic stage and the detailed and intensive nature of the observation and recording resulting from the diary study and retrospective interviews. In the former case, the data is more likely to reflect actual practices by designers rather than artifacts of observation. In the latter case, the study took advantage of an unprecedented opportunity to examine the processes of search for a large group of working designers during their day-to-day activities, in considerable detail. The detail level of this analysis is one of its strengths and has a greater chance of revealing the microstructure of knowledge searches than previous studies once the data is fully analysed.

It also seems likely that the findings of the study could reflect patterns and processes in human search behaviour that designers had previously been unaware of. On the basis of these findings it should be possible to improve company practices, information sources, intranet structure and usability in order to improve the efficiency of search activities during design tasks. It may be possible to generate guidelines for search for use or training purposes that

may reduce time wasted by novice designers. The preliminary findings from the methodological analysis indicate that the data collected to date may be insufficient to fully identify the triggers or immediate causes of search events and the background to sequences of events sharing the same overall goal. This possibility leads to consideration of ways of modifying the ethnologically driven model and classification, in conjunction with indication of ways of improving the observational techniques and the nature of the questions asked. Preliminary findings suggest that more attention should be paid, in interviews and instructions, to triggers and the reasons and perceived context of search. In particular, the nature of information already possessed by the designer and the nature of information sought, along with why information is sought and how it is expected to be used to find the appropriate knowledge, are critical.

As a result of insights gained during the first stage, knowledge searches were found to be classifiable according to a number of characteristics. This has lead to an understanding of the nature of knowledge searches such as triggers, sources, media, frequency and outcomes, as well as of the detailed engineering context. The significance of the ethnographic approach lies in the deeper understanding of the day-to-day engineering issues that can be used to formulate more analytical models.

Following the methodology adopted in [2] the effectiveness of the approach will be further assessed using a variety of techniques including an evaluative questionnaire and interviews to be carried out by the design teams after presentation of the research findings. In particular, the methodological evaluation will look for evidence of improvements to success criteria, such as greater efficiency of search.

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