PHD

Improving the management of Informal Engineering Information through Electronic Logbooks

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Award date:
2010

Awarding institution:
University of Bath

IMPROVING THE MANAGEMENT OF INFORMAL ENGINEERING INFORMATION THROUGH ELECTRONIC LOGBOOKS

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A thesis submitted for the degree of Doctor of Philosophy

University of Bath

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January 2010

Abstract

In modern organisations, the effective use of information and knowledge is a prerequisite for sustaining competitive advantage. To support this, considerable work has been undertaken by both academia and industry to improve the representation, organisation and access of information across and between organisations. This improved information and communication management has had a positive impact on business processes, improved decision making and – importantly – increased levels of innovation.

However, one area that has received less attention is personal information such as logbooks, maintained by a majority of engineers. Many of these logbooks could contain significant amount of design information and knowledge which is not recorded elsewhere, such as design rationale and records of alternatives considered. Indeed, much of what we know about the work of historically important engineers and scientists such as Leonardo da Vinci (1452-1519) has come from their personal collections of notes. Despite this, logbooks are rarely formally managed, with the content usually only available to the authoring engineer. It is arguable that such potentially valuable information should be more easily accessible to the individual and wider organisation, where it could be of benefit as a personal productivity aid, a design record and also for intellectual property and audit/traceability purposes. It follows that there is a need to create improved methods for managing logbook content, which is the challenge that this research addresses.

This research first seeks to establish the reasons for the stubborn persistence of paper logbooks as such a common feature of engineering work, despite almost every other aspect being undertaken in the digital domain. Various studies are undertaken, revealing that logbooks are used for a wide range of purposes, such as the critical role of 'mediating' between various information sources. The requirements arising from these studies are used together with a review of existing e-logbook technologies to produce a comprehensive requirement specification for an engineering electronic-logbook. At its core is a novel information management strategy based combination of templates to pre-structure entries and a lightweight information classification schema to structure the information. They key features of the specification are the ability for logbook information to be searched, shared and integrated with other information systems, whilst retaining important characteristics of paper logbooks (such as sketching support).

The contributions of this thesis are the fundamental understanding of logbook use and content, together with a comprehensive specification for an engineering e-logbook to improve logbook information management for both the individual and wider organisation.

Acknowledgements

The work reported in this thesis has been undertaken as part of the EPSRC Innovative Manufacturing Research Centre at the University of Bath (grant reference GR/R67507/0) and has been supported by Airbus UK via an industrial CASE award. I gratefully acknowledge this support. In particular, I would like to thank:

- My academic supervisors, Professor Steve Culley and Dr Ben Hicks
- My industrial supervisor, Dr Florence Sellini (Airbus UK)
- Joe Cloonan (Airbus CIMPA) for considerable input in the form of discussions, ideas and feedback
- Professor Chris McMahon, my internal examiner, for constructive input throughout
- Dr Baljinder Singh for assistance with development of the EEL demonstrator
- James Wasiak for valuable discussions about the coding scheme used in Chapter 7
- All the engineers and others who provided their time for interviews and feedback, and logbooks for analysis.

Declaration

The coding scheme used for the basis of the comparison of formal and informal information was conceived and developed by James Wasiak in the Innovative Design and Manufacturing Research Centre at the University of Bath, although I provided substantial input in testing and refining the scheme, and made modifications for the purposes of this work, as described in Chapter 7.

The Survey in Chapter 4 was undertaken during the Final Year Project from an MEng degree awarded by the University of Bath in 2004. This thesis significantly updates and expands the analysis and discussion of the results. Similarly, the list of Logbook Information types (Table 6-2), method and some analysis of 16 of the logbooks presented in Chapter 6 has also previously submitted as part of the Final Year Project from an MEng degree awarded by the University of Bath in 2004, although again is presented here in a considerably expanded and updated form, both in terms of the amount and accuracy of the analysis and in the discussion of the results.

Dr Baljinder Singh provided technical assistance in the form of coding help for the development of the technology demonstrator described in Chapter 10. The conception, specification and interface were all of my own design.

Contents

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List of Abbreviations and Acronyms

API	Application Programming Interface
ATA	Air Transport Association
CAD	Computer Aided Design
CAM	Computer Aided Manufacture
DfM	Design for Manufacture
DMS	Document Management System
DMU	Digital Mock Up
DRC	Design Rationale Capture
DReD	Design Rationale Editor
DVD	Digital Versatile Disc
eBOM	Electronic Bill of Materials
EDM	Electronic Document Management
EEL	Engineering Electronic Logbook
EEN	Engineering Electronic Notebook (Gwizdka, 1998)
ELN	Electronic Laboratory Notebook (Schraefel et al., 2004)
e-logbook	Electronic Logbook
FDA	Food and Drug Administration
GPS	Global Positioning System
HCI	Human Computer Interaction
HR	Human Resources
IS	Information System
IT	Information Technology
JPEG	Joint Photographic Expert Group (image file format)
KM	Knowledge Management
LCD	Liquid Crystal Display
MCDA	Multi Criteria Decision Analysis
NASA	National Aeronautics and Space Administration
NCUACS	National Cataloguing Unit for the Archives of Contemporary Scientists
O-A	Object-Activity
OCR	Optical Character Recognition
PC	Personal Computer
PDA	Personal Digital Assistant
PDF	Portable Document Format (proprietary format of Adobe Acrobat files)
PDF-A	Portable Document Format (Archival version)
PDM	Product Data Management
PENS	Personal Electronic Notebook with Sharing (Hong et al., 1996)
PIC	Personal Information Collection
PIM	Personal Information Management
PLM	Product Lifecycle Management
PSI	Personal Information Space
SME	Small to Medium Sized Enterprise
TIFF	Tagged Image File Format (image file format)
URL	Uniform Resource Locator
XML	eXtensible Markup Language

1 Introduction

Engineering Design has been defined as "*the use of scientific principles, technical information, and imagination in the definition of a product, machine or system to perform prescribed functions with the maximum economy and efficiency*" (Fielden, 1963). Information and knowledge are clearly central to this activity; Indeed, the engineering design process can be viewed as an information transformation process (Hubka, 1988; Ognjanovic, 1999). The role of information and knowledge in engineering is therefore the starting point of this research, and working definitions are given. A distinction is then made between formal and informal information in 1.2 and the relative lack of research into informal information is highlighted. What is termed 'personal' information is then discussed in 1.3, with engineering logbooks highlighted as one of the most important personal sources of engineering design information in 1.4. Electronic logbooks (hereafter abbreviated to e-logbooks) are then discussed in 1.5 and it is noted that despite good uptake of e-logbooks in other domains, paper logbooks still dominate in engineering.

1.1 Data, Information and Knowledge in Engineering Design

The effective use of data, information and knowledge is often cited as a prerequisite for design, and translating the perceived need into an artefact in an economical and efficient manner is key to sustaining competitive advantage (Moran, 1999; Dietel, 2000; Chaffey & Wood, 2004). Although discussed in more detail in the literature review, for the purposes of this work, it may be stated here that data, information and knowledge are defined as follows:

- *Data* are facts or figures without context or discernable meaning to the observer.
- *Information* is a combination of data, descriptions and other contextual information, organised to show relationships with the purpose of communicating meaning to an observer.
- *Knowledge* is the internal belief state of a person. Knowledge may be created by integrating information with one's existing knowledge. It is communicated in the form of information.

It would then appear that logbooks fall into the category of information. The critical role of information in supporting the various activities of engineers and designers, and the ability of the designer to efficiently retrieve information has been widely reported. Large amounts of information are necessary not only to support core business processes, but also for design, manufacture and product life-cycle activities (Pugh, 1990; Ullman, 1997; Christian and Seering, 1995; Lowe et al., 2004). The importance of information for engineering organisations was also highlighted in a survey by Court et al. (1998), involving over 300 organisations. This survey revealed that engineers typically spend 20-30% of their time involved in information-based activities, and in particular searching and retrieving information.

It has also been observed that engineers maintain and access a wide variety of information sources (Lowe, 2002; MacLeod & Corlett, 2005:p.15). As a consequence, significant research dealing with information management in the context of engineering design has been undertaken. This work has dealt with topics such as the management of product data for design and manufacture (Peltonen et al., 1996; Crnkovic et al., 2003), the management of design data and documents (Pye, 1996; Heidorn, 2002), and the effective utilisation of trade journals and suppliers' literature (Culley et al., 1999; Lee et al., 2000). Ultimately, improved information and knowledge management can lead to improved product quality, improved performance and significantly reduced time to market (Tichkiewitch & Brissaud, 2004), and increased levels of innovation (Baird et al., 2000). Conversely, a lack of information and knowledge can have serious implications. For example, in the case of poor management of patent knowledge, the result was "*massive litigation costs and wastage of R&D resources*" (Derwent Information, 1998, *cited in* MacLeod and Corlett, 2005:p.9) and in the case of the NASA Mars Orbiter loss in 1999, "*the root cause for the loss...was the failure to use metric units in the coding of a ground software file*" (NASA, 1999).

1.2 Formal and Informal Information

Of particular importance in this work is the distinction between formal and informal information. Formal information provides " *a specific context and measure. It provides a structure or a focus so that individuals exposed to it may infer the same knowledge from it...*" (Hicks et al, 2002). An example would be structured text, such as that found in books and formal reports. Informal information is defined by Hicks et al (2002) as "*personal information or information that is developed between two or more individuals…subjects and predicates may not be clearly defined; the information may change dynamically as content is altered or added*" which means that such information "*provides for the generation of various knowledge perspectives for the individuals taking part*." Examples of informal information include unstructured text such as that found in pictures without titles or order, or unstructured verbal information such as conversations, and handwritten logbooks, which form the focus of this research. Culley & Allen (1999) further state informal information may be held in memory, verbal, or written in either a structured or unstructured (as notes). This concept of informality is explored in more detail in Section 2.3.2, although it may be stated here that engineering logbook information is considered to fall into the category of informal information.

This is an important distinction as it is argued that whilst there is a large body of work on information sources in engineering design, most focus on formal, structured information and its associated information systems, such as Electronic Document Management (EDM) and Product Data Management (PDM) systems. In contrast, less work has been undertaken that deals with informal information. Design rationale capture (DRC) systems attempt to structure and record information about the rationale behind a design (Bracewell and Wallace, 2003) and their success hints at the potential for relatively informal information to become a valuable personal and organisational resource, at least in some circumstances. A related concept to informal information is that of *personal* information collections and their management for both knowledge work in general and in the engineering domain. This is now discussed.

1.3 Personal Information and its Management

Much of what can be termed informal information is also personal in nature. Jones & Teevan (2007) state that the term personal information can be used to describe "*the information a person keeps, directly or indirectly, (e.g. via software applications) for personal use*". Such personal information is generated in large quantities throughout the engineering design process by all members of the organisation and is held in multiple stores, such as diaries, computer systems, personal digital assistants (PDA's) and many others (Lowe, 2002). These various sources constitute the individuals' personal space of information (PSI), which generally has ill-defined boundaries, and *"at its periphery the PSI includes information that the person might like to know about and control but that is under the control of others"* (Jones & Teevan, 2007). Within these personal information spaces, there have observed to be sub-sets, or personal information collections (PIC's) which are "*a self-contained set of items...Typically the members [of which] share a particular technological format and are accessed through a particular application."* (Boardman, 2004, p.15 *cited in* Jones & Teevan, 2007).

A growing amount of research in the area of managing such personal information collections (generally termed personal information management or PIM) has been carried out by both information researchers and computer scientists. PIM is "*the practice of managing the information that helps us in our daily lives*" (Bellotti & Smith, 2000). This is applicable for both physical and electronic information collections and PIM activities may best be thought of as how individuals "*establish, use, and maintain a mapping between information and need*" (Jones & Teevan, 2007).

For example, it may be imagined that the *need* to re-visit some design alternatives by finding the original sketches (the information) may be met by looking in logbooks (the mapping mechanism). Whilst some of these things that maintain the mapping between needs and information have been successfully replaced by electronic versions (particularly diaries and contact managers), other types of personal information such that found in logbooks and other informal, personal notes have largely resisted the introduction of new tools. It has also been suggested that the sheer number of tools available to try and manage the very diverse range of personal information types has - instead of actually solving the problem – led to increased "*information fragmentation*" (Jones & Thomas, 1997). There are also many additional dimensions to why individuals create and maintain personal information collections, beyond simply storing information they think might be useful at a later date. These include a range of cognitive and emotional needs, such as controlling the circumstances in which information is disclosed (Grudin, 2001), which make designing new alternatives to familiar paper-based tools challenging (Sellen & Harper, 2002). These are discussed in more detail in the literature review in Chapter 2.

1.4 Engineering Logbooks

This research is aimed specifically at 'engineering logbooks' which are arguably both informal and personal in nature, representing a personal information collection in the 'sea' of the individuals' personal information space, in a relatively unstructured form. It is also increasingly recognised that such personal information could be of significant value to the wider organisation as well as the individual, yet it remains a relatively "*untapped source*" (Topi et al., 2006).

Whilst this research refers to 'engineering logbooks', there exists a number of similar artefacts, employed in the fields of engineering and design (both engineering design and industrial and product design) which fulfil similar roles – these informal (often relatively unstructured) records are variously referred to as 'idealogs' (Currano & Leifer, 2009), 'Design journals' (Hyman, 2003; Oehlberg et al., 2009), 'engineering notebooks' (Bystrom & Eisenstein, 2005) and 'design notebooks' (Ullman, 1997). There are also more specialist records kept in what are also termed logbooks, such as records of flight tests, maintenance etc. which are not the focus of this research.

In other fields, the term 'inventors notebook' is also used to denote a logbook used to record the discovery or creation of a new idea, product etc, with the principle objective being intellectual property protection (Grissom & Pressman, 2000). 'Laboratory notebooks' or 'lab books' are the "*de facto standard*" (Schraefel et al., 2004) in chemistry and other sciences to record the details of experiments. Again, these typically consist of handwritten information of varying degrees of structure, kept as a legal records, as well as for personal re-use.

Whereas other sources of personal information (such as diaries) may hold more general information, it is argued that the logbook in-particular has special significance for engineering work. Keeping a record of work forms part of an engineers' training and is compulsory for many educational courses, including those at the University of Bath. It is often also a company requirement, with the logbook serving as a record for intellectual property claims (Hyman, 2003). The significance of logbooks as records of engineering design is also demonstrated through their importance as historical artefacts, as demonstrated by the insights gained from the logbooks of Leonardo da Vinci (1452 - 1519). More recently, the personal records of scientists and engineers are being indexed and stored for future research (NCUACS, 2006) and despite significant advances in computer-based tools to aid the designer at all stages of the design process, many very complex and high-technology inventions and concepts still apparently start their life in a paper-based logbook or notebook (Figures 1-1 and 1-2):

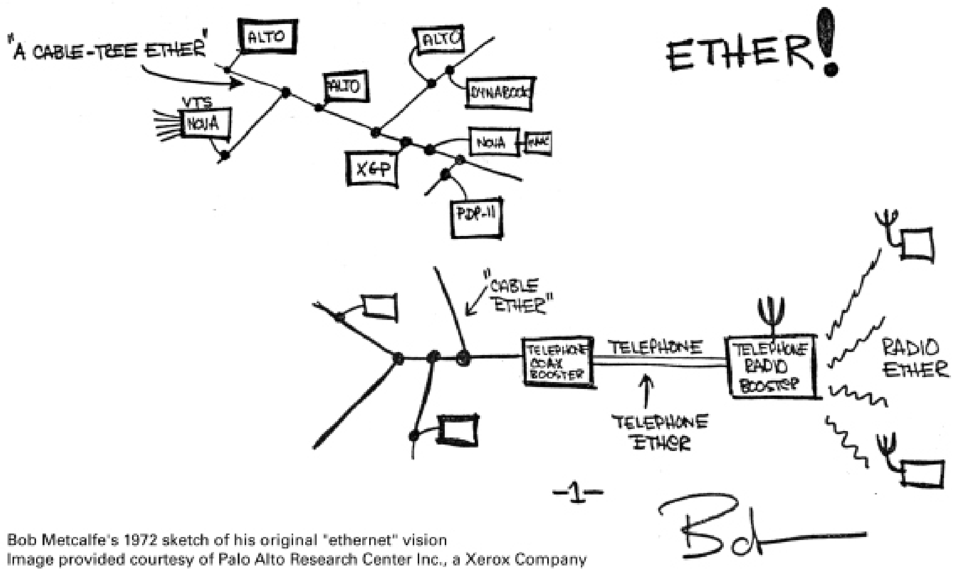


Figure 1-1 – 1972 Sketch of Bob Metcalfe's vision for Ethernet

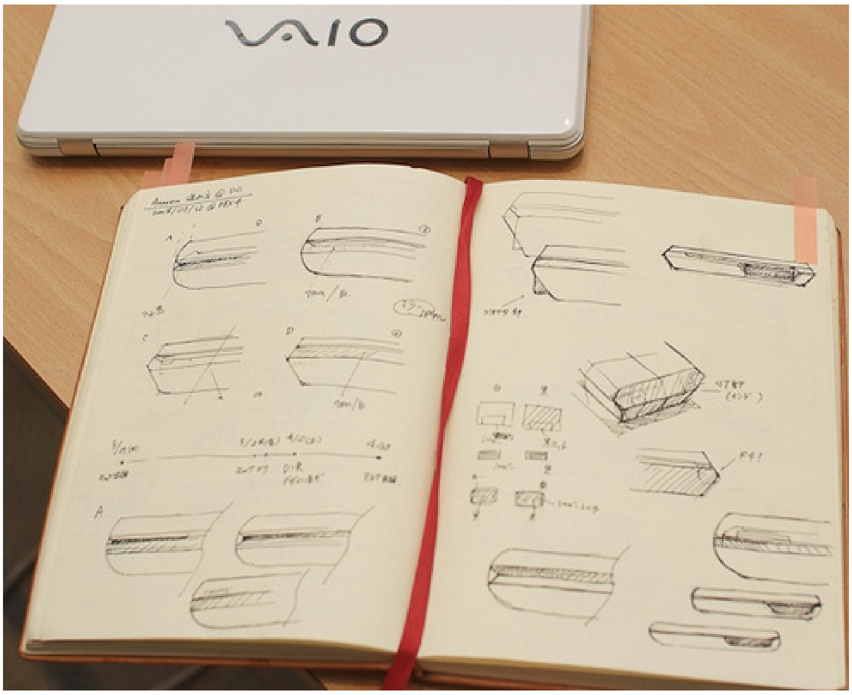


Figure 1-2 – Sketches detailing the design of a Sony Vaio P laptop computer

It is therefore argued that such traditional paper logbooks may be the only source of important design information and knowledge including: fundamental design knowledge, rationale that supports decision making, information for design audit purposes, legal records for accountability, and the outcome of discussions with experts and colleagues. However, because this information is often kept in relatively informal, unstructured ways by the individual engineers and designers, searching, sharing and re-use are difficult or impossible. It may also be discarded at the end of a project, making its re-use impossible. According to Butler (2005), the "*pitfalls of paper are estimated to cost the drug industry alone over US$1 billion annually in lost opportunities and duplicated research*". It is therefore argued that systems which afford more effective management of such material could provide individuals and the wider organisation with:

1. A more complete understanding of previous issues and how they were resolved, representing information and knowledge for others to continue or validate previous activities such as analysis and modelling.

2. A single location for ideas, sketches and notes about a given project or design, improving the 'collective memory' of an organisation – that is, their knowledge of (and ability to find) material for design re-use, as well as for intellectual property and audit/traceability issues.

3. Better support for concurrent and distributed design activities through easier sharing of informal, personal information.

1.5 Electronic Logbooks

Despite these apparent advantages - and Blemel's (1989) assertion that "*the automation of engineering notebooks should be simple and easy*", the uptake of electronic logbooks – or even improved paper versions – in the engineering domain has been very low. Whilst some of the functions of traditional logbooks have been eroded through new technologies such as personal digital assistants (PDA's), groupware such as shared calendars and email, traditional paper logbooks still appear to dominate the engineering domain. The relatively small amount of existing research into logbooks is reviewed in Chapter 2, and a full review of existing e-logbook attempts is presented in Chapter 8. In summary, however, it appears the low uptake is due to two main factors: a lack of understanding of how paper logbooks are currently used and lack of guidance or strategy for how logbooks may best be translated into the digital domain.

However, one domain in which e-logbooks have met with considerable success is in the pharmaceutical industry and natural sciences. This has been attributed to *"...the introduction of the* "*specific ELN [electronic lab notebook]*" which "integrates tools that aid the researcher, such as searchable reaction databases, chemical synthesis planning, and integrated chemical inventory” (Elliott, 2006). The role of e-logbooks in supporting compliance with legal and regulatory requirements has also been a significant driver, with the US regulatory body, the Food & Drug Administration issuing guidelines for compliance with regulatory requirements (US FDA, 2009) including requirements for electronic records and systems. Anticipated market growth is around 40% per year and “*some 83 per cent of organisations now have at least some interest in ELN; 43 per cent of those are seriously considering a purchase, defining requirements, or evaluating systems*” (Elliott, 2006). Further, a number of parallels may be drawn between the pharmaceutical and engineering design domains: Both generate vast quantities of data in the process of drug or product development, companies in both domains often rely on the protection of intellectual property to achieve competitive advantage and both operate in heavily regulated legal environments and within strict quality regimens.

1.6 Research Aim

Investigating the issues surrounding the creation of an electronic logbook to better support the management of informal logbook information in the engineering domain is therefore considered a timely and important research issue. The current gaps in understanding implicit in the above discussion are along two dimensions: A lack of understanding of the current use of paper logbooks (and therefore the requirements for an electronic replacement), and the lack of strategy and guidance on how current and emerging technologies could be used to best support any such requirements. It is these two topics that form the focus of this research and will be used to inform the literature review and creation of the research questions in Chapter 3.

This research therefore aims to firstly investigate existing paper-based engineering logbooks in terms of how they are used and what they contain. This knowledge will then be used together with reviews of new and emerging technology to inform the requirement specification for a next-generation engineering electronic logbook (e-logbook). The objective is to improve the management of this potentially important information, in terms of both increasing its potential for re-use for the individual (to increase personal productivity by more effective translation of logbook information into more formal records) and for the organisation (as a more complete record for re-use in various ways, such as for intellectual property and audit purposes).

1.7 Concluding Remarks

This chapter has argued that:

- The effective use of information and knowledge are prerequisites for successful organisations and essential for engineering design activities.
- Formal information sources have been relatively well researched and the resulting tools and methods have been widely adopted, with considerable benefits. Conversely, informal, personal sources have received less attention and tools and methods for their management have been less widely adopted. However, there is now a growing recognition of their importance and potential to support re-use of design information.
- Of these informal sources, engineering logbooks are potentially the most valuable. They often form a legal record of engineering activities and maintaining a logbook is part of an engineers' training. Their potential importance is also evidenced through what has been learned from the logbooks of historical scientists and engineers. However, the informal, unstructured nature of logbook information limits – or completely prevents – its effective re-use. This could result in legal issues, missed opportunities and financial disadvantage.
- There has been a very low uptake of electronic replacements that provide enhanced management of such information in the engineering domain. This is despite considerable successes for other personal information management tools such as shared calendars and other groupware and for electronic logbooks in other domains, notably the pharmaceutical industry where there are reported to be significant financial benefits. This is because of a lack of understanding of how existing paper-based log books are used and a consequent lack of understanding of how best to exploit existing and emerging technologies.
- The aim of this research is therefore to investigate how and why current paper logbooks are used, and how this knowledge can be used together with existing and emerging technologies to create an engineering e-logbook to better manage the information they contain.
- Providing more effective management of this information could provide benefits to both the individual (in terms of personal productivity) and also to the wider organisation (for intellectual property and audit/traceability purposes).

1.7.1 Thesis Structure

The rest of this thesis is structured as follows:

- Following a review of relevant literature in Chapter 2, research questions are formulated and a methodology to address them is presented in Chapter 3.
- Research into aspects of logbook use is presented in the form of a survey in Chapter 4 and an investigation of logbook use in the wider context of engineering work in Chapter 5.
- Logbook content, structure and organisation are then explored in Chapter 6, followed by a study comparing logbook records to their more formal counterparts in Chapter 7.
- A detailed review of existing e-logbook technologies with respect to findings in the previous chapters is then presented in Chapter 8.
- The results from these studies are then used to formulate requirements for the next-generation of engineering e-logbooks, with a detailed requirement specification presented in Chapter 9.
- This is followed by the creation of a technology demonstrator aiming to show how an e-logbook could be deployed on the Tablet PC platform, together with a pragmatic strategy for its evaluation and deployment in Chapter 10.
- Finally, the main contributions to knowledge are discussed and further work are outlined in the overall conclusions in Chapter 11.

2 Literature Review

The focus of this research is the engineers' logbook and the opportunities to improve the management of engineering logbook information through the creation of an electronic alternative. To this end, this literature review starts by exploring the nature of data, information and knowledge in Section 2.1. Working definitions are given, which are essential to understand what is meant by information management in the context of this research. Section 2.2 briefly reviews the topic of Knowledge Management (KM) and - in light of the definitions adopted - contends that much of what is termed KM is actually information management. Information management in the engineering domain is then discussed in Section 2.3, where the split between formal and informal types of information is further explored. Arguing that much informal information is also personal in nature, Section 2.4 reviews the literature on personal information and its management and a range of perspectives on its purpose are discussed. Finally, existing work on personal and informal information and its management in the engineering domain is discussed (2.5), with particular reference to existing research concerning logbooks in Section 2.6.

2.1 Nature of Data, Information and Knowledge

It has been noted in the introduction that the effective use of information and knowledge is critical to sustaining competitive advantage through improved product quality, better performance, significantly reduced time to market (Tichkiewitch and Brissaud, 2004), and increased levels of innovation (Baird et al., 2000). However, the terms 'data', 'information' and 'knowledge' are often used rather loosely and have many different meanings (Lowe, 2002; Hicks et al, 2002). As the focus of this research is improving reuse of such resources, it is necessary to define and differentiate these terms. Lowe (2002) notes that of the three terms, "*knowledge is the term that is often least widely understood and most inappropriately appli*ed" and as such will be the starting point of this discussion.

2.1.1 Knowledge

Knowledge especially is a "*multifaceted concept with multilayered meanings*" (Nonaka, 1994) and as such there are a number of what may be termed theories of knowledge from epistemology and other fields. A common and long-standing definition is knowledge as a "*justified true belief*" (Pollock & Cruz, 1999:p.13), although this has subsequently been challenged (Gettier, 1963). Distinctions between various *types* of knowledge – such as perceptual knowledge, *a priori* knowledge and knowledge from memory, have also been made[1]. A practical and useful

[1] Note that this list is not intended to be definitive and there is considerable debate as to whether some types of knowledge - such as a priori knowledge and knowledge from memory - exist at all. For a more detailed discussion, see Russell (1912) and Pollock & Cruz (1999).

distinction is made by Gilbert Ryle (1900-1976), between 'know-how' and 'know-that'. Ryle (1949) argued that know-how refers to a skill someone may possess, but that is difficult to articulate, such as how to play a sport, or manage a project team. In contrast, know-that refers to knowledge of a specific fact that is usually easy to convey to others, such as the tensile strength of a material. In a similar fashion, Michael Polanyi (1891-1976) distinguishes between *tacit* and *explicit* knowledge. Polanyi (1967) argues that "*we can know more than we can tell*", citing the example of being able to recognise a face in a crowd, but not being able to articulate exactly how we can do this. Polanyi also goes further, asserting that "*personal, tacit assessments and evaluations…are required at every step in the acquisition of knowledge – even 'scientific' knowledge*" (Polanyi & Prosch, 1977). Polanyi thus stresses knowledge as a belief and also the personal nature of knowledge. Nonaka (1994) also explores the distinction between tacit and explicit knowledge, but in the context of organisational knowledge creation. It is expanded "i*n a more practical direction"* by assuming that knowledge is created through conversion between tacit and explicit knowledge.

Further distinctions between different types of knowledge have been made in the engineering domain. Ullman (1997) distinguishes between three types of knowledge engineering designers use during their work: *General knowledge*, gained through general education and experience not specifically related to the engineering domain, *Domain-specific knowledge*, gained through study or experience in that particular domain and *Procedural knowledge* gained from experience of how to undertake tasks. The latter is often based upon a combination of the first two types of knowledge.

Potter (2000) explores knowledge from the perspective of Artificial Intelligence (AI) in conceptual design synthesis. Knowledge is defined as "*that which allows an entity to act intelligently*" and "*as such knowledge is wholly subjective – it is not and cannot be independent of the entity*". Potter first makes a high-level distinction between *declarative* and *procedural* knowledge which – like the types of knowledge listed by Ullman (1997) – are in many ways analogous to Ryle's (1949) split between know-that and know-how. He then lists four categories of knowledge and asserts that all four "*must be present in some form in any complete design system*":[2]

[2] Potter (2000) notes that an "apparent omission from this model…is *common-sense knowledge*, that is, the knowledge thought to provide the foundations for all intelligent human behaviour", which could be seen as similar to Polanyi's 'personal knowledge'.

- *Domain Knowledge* – knowledge of the entities that constitute the domain under consideration, such as knowledge of physical elements and their behaviours. Primarily declarative in nature.

- *Inference Knowledge* – knowledge of what conclusions may be made and how to make them. Largely procedural.

- *Strategic Knowledge* – knowledge of how elements of inference knowledge can be arranged and controlled to form a strategy. Again, this type of knowledge is largely procedural.

- *Working Knowledge* – knowledge of the current design specification, choices made etc. It is unique for each design and largely declarative.

Finally, McMahon & Draper (2002) present a typology adapted from Blackler (1995) with specific reference to engineering design, shown in Table 2-1:

Knowledge type	Knowledge dimension	Definition	Engineering design example
Embedded	Explicit	Systematic routines, procedures and practices	Company documents on design procedures and sign-off
Encoded	Explicit	Knowledge represented by signs and symbols in books, manuals and recorded works	Engineering textbook on the principles of aerodynamics
Encultured	A combination of the two	Knowledge from the process of achieving shared understanding	Personal logbook of experience on design project
Embrained	Tacit	"Knowledge about" – the ability to work with complex ideas and concepts	Personal experience of a variety of design projects
Embodied	Tacit	"Knowledge-how" – practical thinking; problem solving	Personal ability to plan and execute a design project

Table 2-1 – Engineering Design Knowledge Topology (*adapted from McMahon & Draper, 2002*)

This typology is particularly relevant to this research as it identifies engineering logbooks as containing 'encultured knowledge' , consisting of both tacit and explicit knowledge from the process of achieving shared understanding. This suggests logbooks and other personal or informal information may play an important role in 'bridging the gap' between these types of knowledge.

These perspectives are useful because whilst they have some important differences, all shed light on the nature of knowledge and the diverse forms it may take. Importantly, most assume – whether stated explicitly or not – that knowledge is something held by a person, in their mind (or in the case of AI, held in the 'memory' of a machine). This is a widely held view (see, for example, Court, 1995; Stenmark, 2002 and Hicks et al., 2002) and one that will be adopted for this research.

2.1.2 Data and Information

The terms data and information are also used either interchangeably, or in different ways for different purposes. For example, data has a clearly defined meaning in the context of computer science, as bytes of data, meaning quantities or characters operated on by a computer (OED, 2006). Similarly, Shannon's (1948) Information Theory takes information to mean simply a sequence of letters, or a signal transmitted by radio waves, pointing out that "*the semantic aspects of communication are irrelevant to the engineering problem*". The nature of data and information will now be discussed and as the concerns of those practicing 'information management' are quite different (dealing with issues such as accuracy, completeness and provenance), these issues will also be summarised below.

Foskett (1996) defines data simply as "*unprocessed facts*" More generally, however, data and information have usually been defined with reference to each other, or knowledge. For example, Davenport & Marchand (1999) regard knowledge as "*information in people's minds*". Similarly, Tsichritzis & Lochovsky (1982:p.3 *cited in* Benyon, 1990) contend that information is 'an increment of knowledge which can be inferred from data'.

The concept that information is generated from data is a widespread one. For example, Wilson (1987, *cited in* Court, 1995) defines information as "*the data plus the meaning connected with it*" and Checkland (1981) observes that "information is best used to denote a combination of fact plus meaning an observer attributes to it". Similarly, Abram (1997 *cited in* Lowe, 2002) defines data as "*raw facts that have no context or meaning on their own*". Benyon (1990) and Court (1995) hold similar views and also give practical examples to highlight the distinction between data and information. Court lists examples of data as being '6/1' or '070M20', illustrating that knowledge cannot be inferred from raw data presented without addition context and relationships. In the above examples, this data can be made into information by giving a description and the relationship to the data. For example: '6/1 represents the inlet pressure ratio of a gas turbine engine' and '070M20 is a classification number for a Carbon-Manganese steel containing 0.2% Carbon and 0.7% Manganese'.

Exploring further the structure of information, Benyon (1990) shows a bus timetable, splitting it into context, data descriptions and the data symbols, arguing that "*information is only made* *available when these pieces of data and their associated descriptions are related together in a manner relevant to the receiver of the information*." (Figure 2-1):

TIMETABLE N8 effective June 30 1988
Leicester Hi-frequency to and from Market Harborough
Weekdays from Leicester

Route Number	Leicester Depart	Kibworth Depart	Market Harborough Arrive
348	6.45	6.55	7.07
351	7.00	7.10	7.22
348	7.15	7.25	7.37
351	7.30	7.40	7.52

} Context
} Data Description
} Symbols

Figure 2-1 – Bus Timetable Showing Elements of Information (*adapted from* Benyon, 1990)

The implication here is that the receiver of the information may interpret it differently depending on their existing state of knowledge, which supports the concept of knowledge as an internal state, and Polanyi's definition of personal knowledge. Another example of the relationship between data and information can be illustrated with 'metadata' – data about data (or more accurately in this case, data about information). For example, this document was written in Microsoft® Word™ and is an electronic file containing what could be termed information. The properties of the file include some further data, such as the author's name, the number of words and the date the file was last accessed etc. This data alone is meaningless until it is presented in the form of data, a description and a relationship.

2.1.3 Definitions of Data, Information and Knowledge

Considering these various viewpoints in the context of this research, data, information and knowledge are defined below:

- *Data* are facts or figures without context or discernable meaning to the observer.
- *Information* is a combination of data, descriptions and other contextual information, organised to show relationships with the purpose of communicating meaning to an observer.
- *Knowledge* is the internal belief state of a person. Knowledge may be created by integrating information with one's existing knowledge. It is communicated in the form of information.

2.2 Knowledge vs. Information Management

Like knowledge itself, the term Knowledge Management (KM) also suffers from a multiplicity of definitions and viewpoints. However, most research may be classified according to two general approaches: The 'first-generation' technology-centric approaches and those that encompass a range of organisational, management and technological approaches[3] (McElroy, 2002). This is similar to the distinction made by Hansen et al. (1999) between *codification* and *personalisation* approaches. The codification approach places emphasis on the codification, storage and reuse of knowledge in databases whilst the personalisation approach views knowledge as something that is shared between people, with technology's main role being one of facilitation.

The origins of the first approach are explained by Hildreth & Kimble (2002), who note that initially knowledge management was "*seen as an extension to Artificial Intelligence (AI) where knowledge was viewed as information: a commodity that can be codified, stored and transmitted*" and was dominated largely by technological solutions. Abram (1997) criticises this approach, noting that "*the plain fact is that knowledge per se cannot be managed. In fact, capturing knowledge in any form other than the human being's brain reduces it to information, or worse, data*." However, Abram does go on to say that whilst knowledge cannot be managed, the *knowledge environment* can. This is the aim of the personalisation approach and a wide range of KM tools and techniques now exist.

It would appear, therefore, that much of what is termed knowledge management is actually information management. This is captured by Offsey (1997:p.113), who notes that *"what many software vendors tout as Knowledge Management systems are only existing information retrieval engines, groupware systems or document management systems with a new marketing tagline*". As this research aims to improve support for the creation and re-use of personal information in the engineering domain, the primary concern is therefore with what could be termed information management rather than knowledge management.

However, that is not to say that such information systems do not influence knowledge creation and sharing in an organisation. The prevailing view of knowledge and information as being closely interrelated means that by improving the ability to create, access and reuse information, knowledge creation and sharing may also be improved. For example, McMahon & Draper (2002) suggests logbooks are involved in the creation of 'encultured knowledge' (knowledge derived from gaining a shared understanding of a project) and are constructed with tacit and explicit knowledge. Similarly, Section 2.3 (below) explores the purpose of personal information and

[3] This split is somewhat analogous with Stenmark's (2002) distinction between the *Commodity* and *Community* view of knowledge discussed in section 2.1.

suggests that personal information resources such as logbooks do serve purposes closely aligned with personalisation approaches, such as fostering social interaction (Toda, 1991). Therefore, whilst this research will focus largely on improving logbook *information management*, the strategies and tools developed will almost certainly impact common KM practices, such as expertise location and fostering social interaction.

2.3 Information Management in the Engineering Domain

This section explores information management in the context of engineering. First, the importance of information management is explored, followed by a discussion of the difference between formal and informal information (Section 2.3.2) in which it is argued that much informal information is also personal in nature. Therefore approaches to personal information and its management is then explored (Section 2.3.3), before research on the source of personal information of most relevance to this research (logbooks) is reviewed.

2.3.1 Importance of Information Management

It was noted in the introduction that the effective use of information and knowledge is often cited as a prerequisite for sustaining competitive advantage (Moran, 1999; Dietel, 2000; Chaffey and Wood, 2004), and that the financial and engineering implications of failing to have access to the right information can be severe (Derwent, 1998, *cited in* MacLeod and Corlett, 2005, p.9; NASA, 1999). Engineering processes and in particular the engineering design process are heavily dependent on information and can be viewed as information processes, or an information transformation process (Hicks et al, 2002; Hubka, 1988; Ognjanovic, 1999).

The importance of information is underlined by the fact that design activities both consume and create large amounts of information as they proceed (Court et al., 1998). During the early stages of the process the designer will acquire information from many sources, such as handbooks and design guides, catalogues, journals, books, conferences and training courses, to name but a few (MacLeod and Corlett, 2005). As the design proceeds, this information will be used to inform decisions, undertake modelling and analysis and identify what further information is needed. Throughout this process, the information will be evaluated and recorded by members of the design team in a variety of formats, such as CAD models, numerical models, physical mock-ups, reports, sketches, notes and meeting minutes. Furthermore, at each stage of the process, a proportion of this information will be formally recorded in technical reports and other design documentation such as CAD models to support the project as it progresses.

Another aspect to consider is Pahl & Beitz’s (1984) assertion that almost 80% of design is adaptive or variant, rather than original. Therefore, access to information that already exists within a company is particularly important for future projects. This design information may describe past designs, document the decisions taken and describe potential limitations of existing designs, or their suitability for adaptation. It can therefore be argued that the efficacy of the design process is highly dependent on the effective utilisation of this existing design information in the majority of cases.

2.3.2 Formal and Informal Information

In order to support the increased re-use of existing information, considerable work has been undertaken to develop strategies and tools for the improved management of engineering design information. As part of this, several authors have made the distinction between *formal* and *informal* sources of information. This distinction is important because it is suggested by Hicks et al., (2002) that formal and informal information have different requirements for their capture, storage and re-use. Hicks et al., (2002) go on to define the differences in terms of the structure and representation of the information, arguing that formal information provides "*a specific context and measure...a structure or a focus so that individuals exposed to it may infer the same knowledge from it...*". It may be textual, pictorial or verbal, but must be conveyed in a logical, structured manner. Conversely, informal information is considered to be "*personal information or information that is developed between two or more individuals…subjects and predicates may not be clearly defined; the information may change dynamically as content is altered or added*", which means that such information "*provides for the generation of various knowledge perspectives for the individuals taking part*." This is illustrated in Figure 2-2:

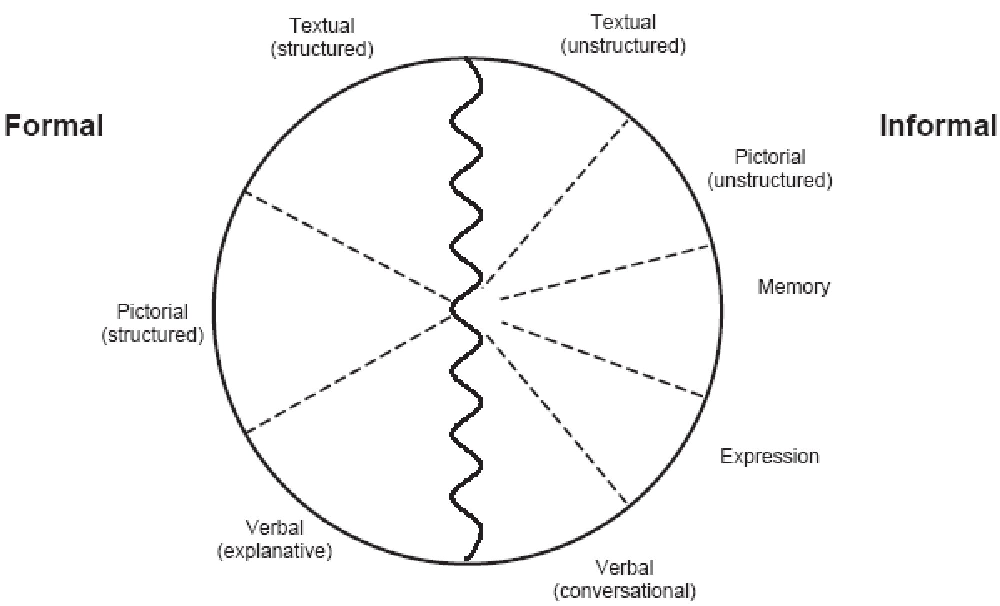


Figure 2-2 – Formal and Informal Information (*reproduced from Hicks et al., 2002*)

Culley & Allen (1999) take a similar view, defining informal information as either that held in memory, verbal (spoken) information communicated between people, "*written (unstructured)*", encompassing information made in "*note form"* such as logbooks and emails and "*written (structured)"* which is *"information in a catalogue environment that be loosely defined as informal*". In this context, the information is in a 'structured' form, supplemental to the formal product information and may be "*in the form of case studies or test results*".

The nature of informal information is also discussed by Yang et al., (2005) who notes that there a scale, ranging from informal (meetings, brainstorms) through "*semiformal*" to formal (final reports and CAD models). Informality is defined with reference to the level of structure, which is "*unstructured text, captured as it is generated*" and "*fragmentary documents, such as those captured in design logbooks*".

Wood et al., (1998) also associates informality with the level of structure. However, neither Yang et al., (2005) nor Wood et al., (1998) explicitly define what is meant by structure, although the implication is that the level of structure relates to how easy it is for someone to gain an understanding of the information. For example, in the context of creating indexes or thesauri for information retrieval, Yang et al., (2005) conclude that whilst thesauri created from informal information give the best informal retrieval performance, they are also the hardest to construct because of the "*implicit and incomplete nature"* of the information.

Liang et al., (1998) also characterise informal information, arguing that is typically has a narrower intended audience, little or no 'built-in' context and a low creation effort, but high re-use effort. Two aspects of formalising such information are discussed – re-working the information "*so that is has clear semantics from a logical or computational point of view"* and the related concept that information may be made more formal by "*adding enough context to the information that its meaning is more explicit to people"*. Again, they define the level of formality on a scale with 'notes' being the most informal (narrow intended audience and little or no context) and the resulting 'reports' being the most formal, with a wide intended audience and high levels of contextual information.

Finally, the level of formality may also be related to the process by which the information was created. For example, information created outside an officially recognised system - or without following procedures sanctioned by the organisation - may be considered 'informal' in the sense that it is 'unofficial'. This frequently has corresponding implications for how the information may be treated by others (e.g. not being able to use it for certain tasks without further verification or validation).

The concept of informality is clearly multi-faceted and no commonly accepted definition appears to exist. For the purposes of this research, informal information is defined along the four main dimensions apparent in the literature, each with corresponding characteristics: *Content* (typically fragmentary, implicit and dynamic) *Structure* (generally lacking in context and semantics, and often presented in a form not considered conventional in terms of language used or layout), *Process* (usually created without reference to an 'official' or commonly accepted convention or procedure) and *Intent* (often being aimed at a narrow audience, or designed to be useful for a limited time only). This is illustrated in Figure 2-3:

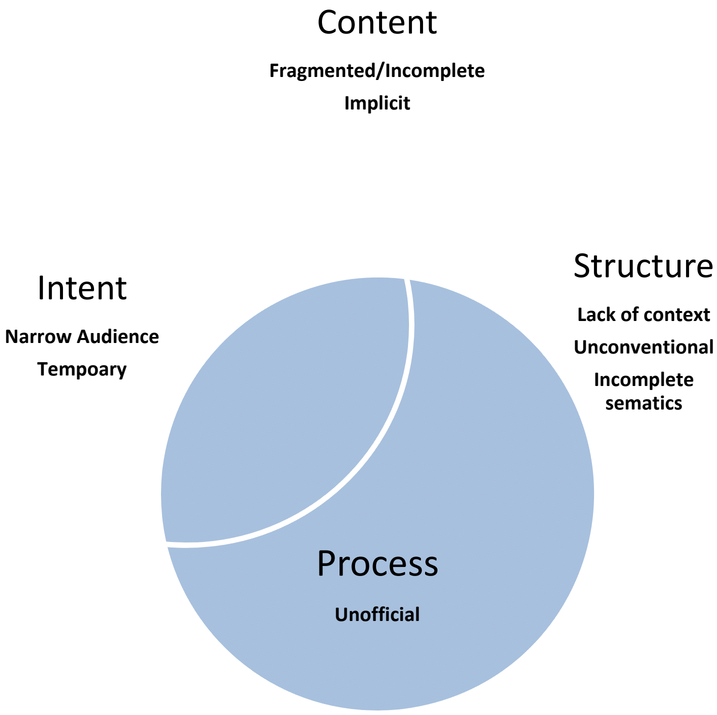


Figure 2-3 – Dimensions and characteristics of informality

Note that not all of these characteristics need to be present for the information to be considered informal. Rather, information conforming to any one or more of these characteristics should be thought of as on a 'scale of informality'. For example, the supplementary catalogue material classified as informal in Culley & Allen (1999) would appear to have a wide audience, and be relatively structured, although the content may lack content be considered incomplete without the corresponding formal catalogue, or may have been produced 'unofficially' for a particular customer. At the highly informal end of the scale, a telephone number quickly scribbled on a post-it note is a fragment, with no context, little semantics, intended only for the person who created it, and useful perhaps only for a matter of minutes.

2.3.3 Managing Formal and Informal Information

There is a large body of research concerning the management of formal engineering information. For example, there have been considerable advances in the management of design documents with Electronic Document Management (EDM) systems (Hendley, 2005), the management of product definition data with Product Data Management (PDM) systems (Gain, 1996) and electronic catalogues to assist in part selection (Allen et al., 2002). Their success can be attributed to a combination of significant technological improvements made over the last few decades, such as more sophisticated ways of organizing and accessing information (Baeza-Yates & Ribeiro-Neto, 1999) and the adoption of standard information representation and exchange formats, such as XML. In contrast to this large body of work dealing with formal information, less has been undertaken in the field of what can be termed informal information management. This can be attributed to technical difficulties in dealing with the often unstructured nature of such information and a perceived lack of value of these sources

More recently, there has been a recognition of the importance of informal information as a means of accessing tacit knowledge, through processes Nonaka (1994) terms socialisation, externalisation and combination. The increasing recognition of the value of such information - together with advances in computing - means that there has been significant work in several areas. Firstly, systems to capture design rationale have met with some success. According to Lee (1997), design rationale includes "*not only the reasons behind a design decision but also the justification for it, the alternatives considered, the trade-offs evaluated and the argumentation that led to the decision*". One of the most successful of these is the Design Rationale Editor (DReD) of Bracewell & Wallace (2003), which has been used effectively in the engineering domain. Such systems have increased the richness of information recorded during design activities that may have otherwise been lost.

Secondly, due to its unique role in engineering and design work, the activity of sketching has also received attention from design researchers. Much of this work focuses on gaining a better understanding of how sketching influences the outcome of design activities, or providing tools to allow more computational support for activity (see, for example Diehl & Lindemann, 2006; Gross & Do, 1996; Yang, 2008).

Finally, the capture and re-use of conversations, meetings and other informal sources (some of which are also personal) is also receiving attention, mainly because of technological advances allowing the automatic indexing and analysis of such material (Softsound, 2007) and because there is a recognition that much of the information transmitted verbally is lost or not formally recorded (Huet et al., 2006).

There has also been an amount of work in the field of personal information management (PIM). This is relevant to this research as it is argued that much informal information is also often personal in nature (that is, the intended audience is often narrow). Definitions of personal information and the tools and techniques used for its management are therefore now discussed.

2.4 Personal Information and its Management

The term 'personal information' has been defined within a number of fields of research. Most commonly, the term is used to denote information about a person. Examples would be a persons' address, credit history or other details held by a company and is thus not directly relevant to this research. The term is also used by information researchers in the context of how people use information, and in the Human Computer Interaction (HCI) field where the main objective is more efficient use of such information through the use of technology. Existing work on personal information in these areas is summarised below and its relevance to personal information in engineering is discussed.

2.4.1 Existing Definitions

The concept of personal information has been explored by Jones & Teevan (2007) who argue that there exists a 'personal information space' (PSI) and that "*personal Information is all the information items, applications, tools and other constructs that are, at least nominally, under that person's control*". This includes a person's "*book and paper documents, email messages (on various accounts), and e-documents, and other files (on various computers), along with the applications (e.g. Microsoft Outlook™), tools (like search tools) and constructs such as piles of paper, or 'associated properties', like metadata*". Items like logbooks, diaries and email systems form 'personal information collections' (PIC's) which according to Jones & Teevan, may be thought of as "*islands of relative structure [in a sea of personal information]*", and are characterised by elements such as how they are organised, their spatial layout and other unique properties.

Whilst this definition may be considered imprecise or fuzzy, this accurately reflects most users PSI's, often characterised by a mixture of mainly informal and unstructured 'information scraps' (Bernstein et al., 2008). In addition, many tools and constructs – such as wikis and blogs - blur the boundaries between personal and group or enterprise information. This conceptual space is illustrated in Figure 2-4:

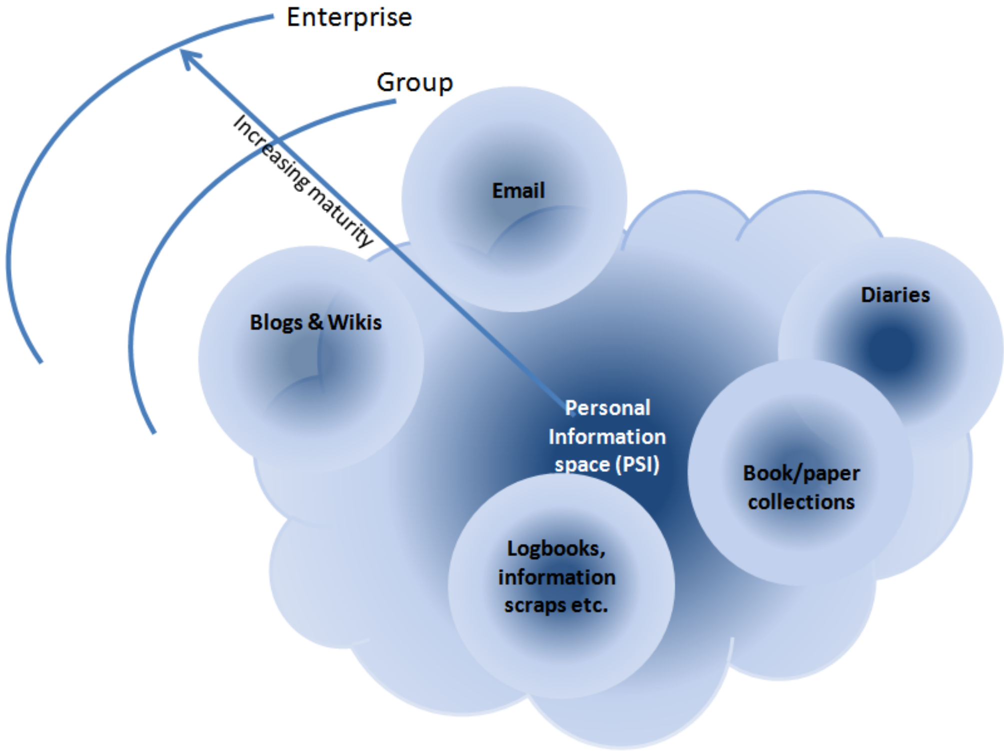


Figure 2-4 – Conceptual space

Other researchers have also explored individuals' information needs, how they find the information and how they then use it (see, for example, Choo et al, 2000). In the context of 'information overload', it has been suggested by Bruce (2005) that "*in response to this challenge, individuals create a personalised subset of the information world that they can use when they are faced with information needs*". These 'personal information collections' are further defined as consisting of various Forms of content (documents, notebooks, web pages etc), Structures for representing and organising the information (folders, hierarchies etc) and Pointers to the information, such as bookmarks, links and people. This is a very similar concept to the PIC's of Jones & Teevan (2007) and have been described by Bruce (2005) as "*the space we turn to first when we need information to do a task or pursue an interest. It is a collection of information sources and channels that we as individuals have acquired, cultivated and organised over time and in response to a range of stimuli. The personal information collection is an organic and dynamic personal construct that we take with us into, and out of, the various events that frame our daily working and personal lives."* (although it may be argued that the advent of always-available network connections and enhanced search technology means the primacy of personal collections has been eroded since 2005). Others have used the terms information space (McKnight, 2000), personal information environment (Malone, 1983), and personal file store (Lowe et al, 2004). It has also been noted by a number of authors that such collections are not simply created for a specific purpose, but are created "*in anticipation of some future need for that information – personal anticipated information need…"* (Bruce, 2005).

In contrast to this, personal information management (PIM) refers to the methods by which individuals handle, categorise and retrieve information (Jones & Thomas, 1997). It is "*the practice of managing the information that helps us in our daily lives*" (Bellotti & Smith, 2000). From an HCI perspective, personal information has been defined as information owned by an individual and under their direct control (Boardman, 2004) which is consistent with the definitions discussed above. In a similar way that Bruce (2005) separates content from structure, Boardman (2004) also recognises that personal information may consist of items and collections.

It is thus possible to see that PIM activities may be "*viewed as an effort to establish, use and maintain a mapping between needs and information*" (Jones & Teevan, 2007). This concept is illustrated in Figure 2-5, below:

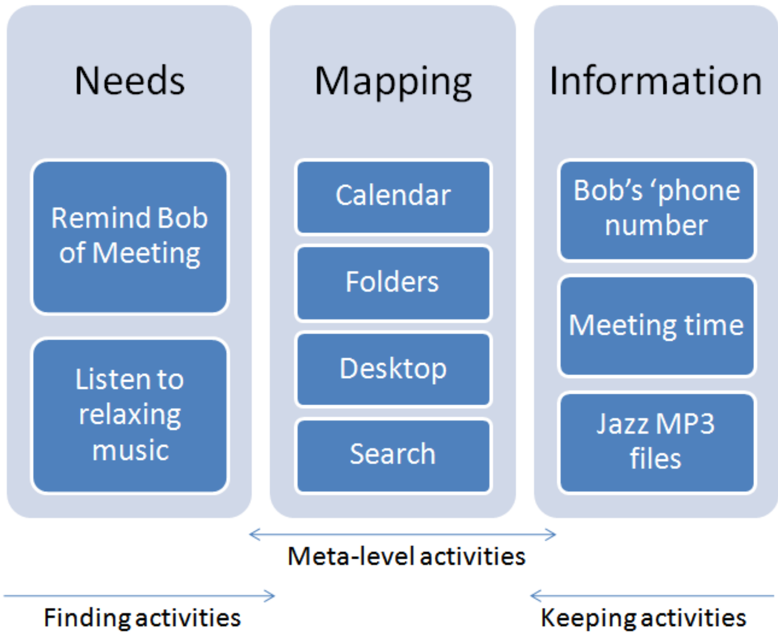


Figure 2-5 – Personal Information Management (PIM) as mapping between information and need (*adapted from Jones & Teevan, 2007*)

As a consequence of a greater recognition of the 'knowledge worker' as an organisation's most valuable asset (Moran, 1999), there now exists a huge range of PIM tools and software. These include diaries and organisers, email systems, electronic notebooks and databases to catalogue information collections, from journal papers to DVD's (See Boardman, 2004 for an overview). However, it has been suggested that the sheer number of tools available to try and manage the very diverse range of personal information types has - instead of actually solving the problem – led to increased 'information fragmentation'. Instead of actually providing integration "*tools such as Microsoft's OneNote™…introduce wholly new forms of information*" (Jones, 2004), as OneNote™ uses a proprietary file format. It has also been found that uptake of electronic PIM tools was low, and they were often used in combination with traditional 'pen and paper' tools (Jones & Thomas, 1997).

More recently, there have been moves towards greater integration of PIM tools (see, for example, Boardman, 2004; Microsoft corp., 2007), although this is also not without its problems as it has been suggested by Jones & Thomas (1997) that "*incorporating multiple functions into a single, computer-based device may well level out the unique properties of traditional technologies*", and that the use of multiple tools (both traditional and electronic) provides enhanced redundancy and flexibility.

2.4.2 Other Dimensions of Personal Information

The literature also reveals that personal information may have a number of more subtle purposes and are not simply used to retrieve useful information when required. Seven of these purposes have been distilled from the literature and are discussed in turn below:

1. As a form of **invisible innovation** to "*subvert*" unsuitable information systems (Spinuzzi, 2003). Examples of what Spinuzzi calls 'subversion' include having 'crib sheets' due to insufficient onscreen help or unintuitive menu systems, or recording on paper intermediate results from modelling programs where no facility exists to store or print them. This concept is similar to the observation that personal information is also used to deal with very complex systems (Topi et al., 2006).

2. As a means of **maintaining privacy** by controlling the circumstances of disclosure (Grudin, 2001). In this case, a personal information collection may be used to keep track on who has what information, or withhold information altogether, with good intentions or otherwise.

3. As a way of maintaining **social relationships** (Toda, 1991 *cited in* Grudin, 2001). It has been suggested that keeping personal collections increases social interaction and the chance of opportunistic sharing of information that may lead to benefits such as more creative solutions or future collaboration.

4. Linked to the purpose of maintaining social relationships, using other people's personal information is a way of **obtaining trustworthy information** easily. Many studies of information use cite colleagues as a major source of information (see, for example, Ward, 2001) and because colleagues often share much of the same of what has been described as an 'unarticulated background' of company culture and domain knowledge, information from such sources is generally more trusted and less open to misinterpretation (Tsoukas, 1996). If information is not understood or incomplete, the recipient can question the owner directly, thus minimising effort, which is another important factor in information use (Choo et al., 2000).

5. Referring to artefacts such as filing cabinets, personal information sources can also be used as **"*Cognitive scaffolding*"** (Norman, 1993). For example, it would be difficult to remember where each of a thousand customer files were located if they were merely in a single large, random pile. Artefacts such as filling cabinets and their electronic equivalents mean we need only remember the structure (e.g. they are all filed alphabetically) to locate the information.

6. To support **"*self-explanation and problem solving*"** (Trafton & Trickett, 2001). For some people, the act of writing information down or collecting and organising sets of documents supports retention, problem solving or understanding. In this case it was shown that the act of creating personal information (in this case in notebooks) increased the accuracy of scientific reasoning about problems and the amount learned by the participants

7. In the case of paper archives of personal information, the paper also **reminds through its physical presence** and is often faster to access than electronic sources. Copies of publically available information may also be kept because the reliability and permanence of external stores is not trusted (Whittaker & Hirschberg, 2001). This is important because it has been shown that accessibility is the single most important determinant of source use (Fidel & Green, 2004).

The issues surrounding personal information and its management would therefore appear to be a complex mixture of cognitive and social factors, all of which must be considered when both investigating the topic and when designing systems for improving its management. For example, section 2.4.1 highlights several authors concerns about new electronic PIM tools (such as online calendars) being used alongside traditional pen and paper, which could suggest the new tool in question has failed to take into account one or more of the reasons discussed above.

2.5 Personal and Informal Information in Engineering

There has also been research on what constitutes personal or informal information in the engineering domain. A number of types of information kept in 'personal stores' have been identified, including: memos, faxes, email, meeting minutes, company reports, journal articles, calculations, collections of drawings, guideline extracts, catalogues, presentations and collections text & drawings (Lowe, 2002). A further questionnaire by Lowe revealed that such personal stores of information satisfy 37% of the owners information requirements, rising to 45% for technical specialists, reinforcing their importance. In detailed studies of design practice, it has been shown that designs are often annotated or adjusted informally on paper before the changes are incorporated into the final, published design. This paper is then stored by the individual or discarded (Henderson, 1999), again highlighting the potential importance of such sources to the organisation as well as to the individual's work practices. Similarly, Whittaker & Hirschberg (2001) analysed in detail archives of paper-based personal information in an industrial research environment and found that personal information and are kept for a variety of reasons, such as not being available elsewhere, to ensure quick access to frequently used information, inflexibility in – and distrust of – 'formal' archives. They also draw implications for designing electronic systems for supporting personal information, suggesting that novel visual interfaces may help individuals better organise and retrieve information and that being able to retrieve information based on its contextual information is important.

However, it is argued that there is a relative lack of research aimed at gaining a fundamental understanding of both *what* and *how* this type of information is used, especially in comparison to the amount of research into more formal information use, with Topi et al., (2006) referring to personal, informal information as a "*largely untapped resource"* for organisational knowledge.

2.5.1 Importance of Logbooks

Of all the types of personal information identified as being kept by engineers, logbooks are potentially one of the most important for three reasons. Firstly, they are one of the only types of personal information management tool in which engineers receive any training, with Oehlberg et al., (2009) noting that logbooks (or 'design journals') are referred to in teaching material such as engineering textbooks. It is also a requirement that students keep a logbook for certain parts of their course, to both encourage "good practice" and to allow the instructor to better assess the students' progress.

Secondly, many organisations mandate the use of logbooks or "*design journals"* to ensure a record of the development of idea for intellectual property claims (Hyman, 2003), with Oehlberg et al., (2009) arguing that this role as a legal record "*is often what prompts a company-wide policy mandating that the entire organization adopt formal design journal practices".*

Finally, the historical importance of logbook material is clear: Much of what is known about engineers and inventors of the past has been extracted from their historic working papers and notes, with perhaps the most famous example of this being the notebooks of Leonardo da Vinci (1452 - 1519). From his notebooks, it has been possible to understand some of his designs and even reproduce them. Similarly, the National Cataloguing Unit for the Archives of Contemporary Scientists (NCUACS, 2006) continues to archive logbooks and other personal material from more contemporary engineers and scientists such as Sir Frank Whittle for historical research.

It was noted in the introduction that the artefact termed in this research the 'engineering logbook' is very similar (in terms of both structure and intended use) to other informal records, called variously design journals, notebooks, inventors notebooks, etc. As the aim of this research (as stated in Chapter 1) is to investigate how and why current paper-based engineering logbooks are used, at this stage a broad definition of engineering logbooks that encompasses all aspects of engineering and engineering design work will be adopted. The term 'engineering logbook' is therefore defined as an informal (unstructured) and often personal record, created in support of many types of engineering design work, including (but not limited to) design and analysis, management and support functions. The term is not intended to also encompass the fields of industrial design and product design, defined as largely separate by Horváth (2004), who notes that both are characterised by an increasing focus on art, and less on applied science. Although the output of this research may have some applicability in these fields, this is not the primary aim.

2.6 Existing Logbook Research

Existing research into logbook use may be grouped into two types: fundamental, descriptive research into current logbook practice and the creation and testing of electronic logbooks (e-logbooks). The latter type is reviewed in detail in the technology review in Chapter 8, along with more general supporting technologies. It was decided to present the technology review later in the thesis because much of the discussion concerns their ability to support requirements arising from research into existing logbooks.

The focus of this section is therefore on reviewing the former type: existing research into current logbook practice[4]. A literature search has revealed nine main studies that investigate aspects of existing logbook use, each of which are now discussed. Firstly, Wilcox et al., (1997) conducted an 'artefact walkthrough' with 11 knowledge workers including executives, managers and researchers (although not engineers), to investigate logbook type, organisation, structure and marking (how important entries were identified). Logbooks were either paper books or folders of paper. In terms of organisation, logbooks were organised either chronologically, or by subject in a folder. Logbooks were structured as 'entries' – with "*one logical page per entry*", with lines to denote the end of a topic, and new ones started on a new page. Many people marked important information by underlining or circling it. In terms of how logbook information was retrieved and re-used, most used their logbooks for reviewing past meeting notes or tasks, and also for more specific information such as contact details, which was searched for by estimating a date and searching through logbooks pages. Participants then used this information for a variety of tasks, such as writing emails, presentations and papers. Frustrations reported with current logbook

[4] Note that some literature includes aspects of both studies of existing logbook use and e-logbook solutions in the publication. In these cases, the descriptive research and any recommendations given are reviewed here, whilst the resulting e-logbook functionality with respect to requirements for engineering e-logbooks is reviewed in Chapter 8.

practice included the rate of input, and difficulty organising and retrieving information scattered throughout the logbook. Some participants also expressed frustration at having to re-type logbook information to reuse it, although they wanted to retain pen input, and appreciated the light weight and compact size of their notebooks and the low cognitive overhead associated with marking-up content.

Schraefel et al., (2004) undertook various types of user-centred study into the logbook keeping practice of chemists (termed lab books in this domain), including ethnographic techniques and interviews with chemists to understand the use of lab books as part of a wider process of conducting experiments. This revealed that a single paper-based logbook is typically used, with information about the experiment such as sketches of equipment an quantities of chemicals used being entered as the experiment proceeds. Once the experiment is complete, the logbook is referred to by browsing pages to formalise the results of the experiment by writing a report. They also investigated note-taking practice in detail through asking the chemists to compete a simple experiment to understand where logbook information comes from and how it is then re-used. The results show that information came from a variety of sources, such as pro-formas detailing the experimental protocol, and observations of equipment such as weights and measures and equipment layouts. They found that despite their stated importance as a legal record, entries were often lacking in detail and contextual information, and that information was frequently transferred between various paper forms and entries in the logbook. The results of this research were used to produce an e-logbook that embodied the principles of free-form pen input, whilst affording more structured recording of elements of the experiment, more structured search features and more integration within a wider workflow.

Mackay et al., (2002) used a participatory design method, involving the end-user of the research in a comprehensive way to inform the design of enhanced logbooks for biologists. The methods included brainstorming sessions and workshops where participants prototyped designs to overcome difficulties they had with the current logbook practice. The participants current logbook use mostly involved gathering and collating relevant documents such as sketches and test results. These were then often annotated and recorded in the logbook along with other handwritten notes, with the result being "*a concise, chronologically organised, permanent record of the biologist's hypotheses, experimental procedures, and research results.*" Whilst the simplicity and flexibility of paper for such multi-media recording was appreciated, it was noted that shortcomings of this current practice were the subsequent difficulty in indexing to improve searching, and a lack of ability to easily share logbook content. Logbook practice from the perspective of archivists was also explored. This revealed that although the value of the logbook as a legal document was recognised, the shortcomings identified issues including the cost of storage, deciding what to keep (by trying to assess future value) and how to maintain links between logbook accounts and physical artefacts.

Turning to engineering, it was noted in Section 2.3.3 that there is a growing amount of research into the role of sketching in engineering and design (see, for example, Yang, 2008), although these studies have focussed largely on the sketch itself and not in the artefact in which it was created (often a logbook). There have also been studies of various aspects of logbook use undertaken in the engineering design domain:

Firstly, improving access to informal information has been explored by Wood et al., (1998) and more recently by Yang et al., (2005), both of whom use a thesauri-based approach to classify and structure the information to aid its retrieval for the purposes of "*leveraging lessons from the past for design decision making*". Yang et al., (2005) draws on informal electronic notes from various graduate courses in electromechanical design. The notes were created by the participants using a simple web-based electronic notebook called PENS (the Personal Electronic Notebook with Sharing of Hong et al., 1996) and subsequently classified both manually and automatically using the Dedal framework (Baudin et al., 1991) of *subjects* and *descriptors*. The resulting thesauri were then used to increase the performance of an information retrieval system. It was found that although manually produced thesauri from informal notes were most useful in increasing information retrieval performance, the classification of the informal notes was difficult due to their "*implicit and incomplete nature"*. However, it was also found that the informal "*in process"* information did differ with respect to the terminology used, implying that the *"final design documents do not provide a shortcut useful for representing the evolution of ideas..."*

Liang et al., (1998) also make some observations on the nature of re-use of both formal and informal information (notes created on PENS, presentations and formal reports). Data from the design projects carried out in small teams was collected and made available to the current year's students. It was found that 92% of the notes accessed related to the current year's project, with very little re-use of the past year's information. With the current year's information, whilst the informal PENS notes were the most commonly accessed type of information for the team that created them, other teams would tend to access more formal types of information from other teams, arguably because it had more context and was thus easier to understand.

How the information in 'design journals' is represented has also been explored. Sobek (2002) analysed the design journals of 21 undergraduate students on a mechanical engineering course. The journals were coded for both at what level of design the students were operating (concept, system or detail) and how the information was represented (written, sketch etc.) by counting the number of days on which those items were present. The results revealed that journals consisted largely of written notes and sketches, and also that students tended to move quickly from concepts to detailed design, due to a possible lack of tool support for the system level.

More recently, Oehlberg et al., (2009) has undertaken a longitudinal study of logbook use (termed design journals in this research) over a period of four years, with the aim of describing how their use was changing. Logbooks were collected from a graduate-level product design course and were analysed in two ways: Firstly, the sketching detail level was analysed on a scale relating to how much information could be determined from sketches. Secondly, the content was characterised as being either tangible (paper-based), digital, or hybrid (a combination of both). The findings showed that there is a trend towards keeping hybrid journals. There was also a correlation between the keeping of hybrid journals and an increased level of detail in sketching, and capture more contextual information. Several guidelines for design of future journals/logbooks were also included, recommending that hybrid journaling is supported and that interaction with the journal is tailored to the design stage, supporting both high levels of quick sketches, as well as more detailed ones later in the process. There is also a guideline to enable sharing of journal content, and to support varying levels of curation (i.e. levels of structure and organisation imposed) to account for different note-taking styles.

Currano & Leifer (2009) also explored the role of logbooks (termed 'idealogs') in an undergraduate engineering course. Logbook-keeping practice over the course of two projects was investigated via a survey of 30 students, investigating their experiences of using idealogs, the methods they used, what they recorded and why. The responses to the surveys were analysed by grouping keywords suggesting different modes of use, including ideation (idea generation, brainstorming etc.), communication (sharing, communicating and showing ideas) and documentation (recording, logging, keeping track of and reviewing ideas etc). It was concluded that idealogs as should be thought of *"...not primarily as an information repository, but as a medium for design thinking*", although all three roles were in evidence.

2.6.1 Discussion

Whilst studies such as that in Wilcox et al., (1997), Schraefel et al., (2004) and Mackay et al., (2002) are interesting and the findings may be relevant to this research, all relied on participants from one organisation. More fundamentally, they were not conducted in the engineering domain. Therefore, although similarities between, for example, general knowledge work and engineering may exist, it cannot be assumed, meaning the results may not be applicable to the focus of this thesis.

Research into various aspects of both use and content of logbooks has also been undertaken in the engineering domain. Both Yang et al., (2005) and Wood at al., (2008) investigate strategies for dealing with informal information generated from an e-logbook called PENS (Hong et al., 1996). Liang et al., (1998) also used PENS, in this case to investigate patterns of re-use of notes, although this study did not reveal how or why the notes were re-used (or not).

Whilst all three studies provide interesting insights into the nature of informal information, a shortcoming (in terms of understanding how and why existing paper-based logbooks are used) is that all three make use of PENS (a relatively simple web-based tool, affording the recording of text and simple graphics) which has a largely unknown effect on the note-taking practices of engineers compared to paper-based logbook use.

Oehlberg et al., (2009) picks up on this theme of changing logbook practices, taking a rigorous approach to describe how logbook use is changing to involve more electronic sources alongside traditional paper logbooks, noting how such 'hybrid' journals appear to better support the recording of contextual information to aid re-use. Some general recommendations for future logbook design are also made. However, the analysis of logbook content centred on the detail level of sketches (reflecting the main activity of product design in which the participants were involved). Although the logbooks appeared to be used for a wide range of other information types, these were not identified. In addition, because the logbook were produced for one particular aspects of engineering (new product development), the results may not be representative of the wide range of engineering work.

Currano & Leifer (2009) identified that logbooks fulfil a number of different roles and argues that logbooks have a prominent role of helping engineers develop ideas, not just as a means of documenting information. Whilst this is an interesting point on which to reflect, *how* these modes of use are supported (in terms of what the logbooks contained and how it was used) has not yet been addressed.

Finally, Sobek (2002) attempts to quantify the content of existing paper-based logbooks, classifying a number of 'design journals' by level of design work and information representation. However, the journal-keeping was mandated, counted towards 15% of the students' grade for that course, and came with certain instructions, such as starting entries on new pages and not stapling computer print-outs into the journal. In addition, the reasons given for the patterns observed were speculative, with a suggestion that further work was needed in this area.

It is therefore argued that despite the studies reviewed above, there is still a lack of fundamental research into what engineering logbooks contain and how they are used, and also a lack of concrete guidelines for the design of e-logbooks, particularly in the engineering domain. This is also evidenced by the larger number of e-logbook research studies found during the literature review in which the basis for the design of the e-logbook was either anecdotal or assumed, or was to test a particular type of technology or idea. Whilst some of these studies did yield useful and interesting results (see Chapter 8), it is arguable that many such results could have been understood more thoroughly by relating them to current logbook practice. Further, five of the six studies in the engineering domain described above used participants drawn exclusively from educational courses, not practicing engineers. Whilst this did support the objectives of their studies, it leaves open the question of whether the results reflect 'real world' engineering practice, especially when the logbooks studied counted towards course credit, or the participants knew they were being assessed.

However, one area in that all the research has provided useful insight is in the range of methodologies and methods adopted to tackle the problem. It appears that two main types of research are used: analysis of documents and various types of user studies, including interviews, ethnography and participatory design techniques, which combined seem to produce a richer picture of logbook use than either in isolation.

2.7 Concluding Remarks

This review has highlighted the importance of information and knowledge in engineering design and argues that there is a lack of work on informal information compared to more formal sources. It was argued that much of what can be characterised as informal information is also often personal in nature. A range of perspectives on personal information have therefore been explored, revealing a range of technical and social reasons for its use. Of the various types of personal information used by engineers, it was argued that logbooks are potentially the most important, and existing research into current logbook practice was reviewed. This revealed a general lack of fundamental knowledge of what engineering logbooks contained and how they were used, especially in the engineering domain, with only six studies of aspects of engineering logbook practice being found in the literature, five of which derive data purely from educational courses.

The consequence of this is a lack of rigorous guidance on how best to manage or improve support for logbook information – both for the individual and especially for the wider organisation – although successes in the field of design rationale capture and the logbook's special role in engineering and design both hint at the potential value of such sources. Therefore, despite a number of e-logbooks being developed over the past 20 years (reviewed in Chapter 8) uptake for such tools has been low. Indeed, the sheer number of disconnected tools may actually have increased the problem of "*information fragmentation*" (Jones & Thomas, 1997). With these issues in mind, research questions will now be formulated, and a suitable methodology for their investigation developed.

3 Research Questions and Methodology

The previous chapters outline the rationale for this research and review existing work of relevance. Two areas in-particular have been identified as requiring further investigation; namely, the lack of understanding of the current use and content of existing paper-based logbooks and a lack of strategy and guidance on how current and emerging technologies could be used to best support more effective management of engineering logbooks through electronic alternatives.

To address these two issues, this chapter will begin by describing the framework adopted for designing the research in Section 3.1. This framework will define the structure of the remaining sections, which will tackle the purpose and theory behind the research (3.2), the resulting research questions (3.3) and the methods and sampling strategy employed to answer them (3.4). Finally, a research plan will be outlined in Section 3.5.

3.1 Research Framework

Robson (2002:p82) argues that a good design framework will have high compatibility among purposes, theory, research questions, methods and sampling strategy. These elements are illustrated in Figure 3-1, below:

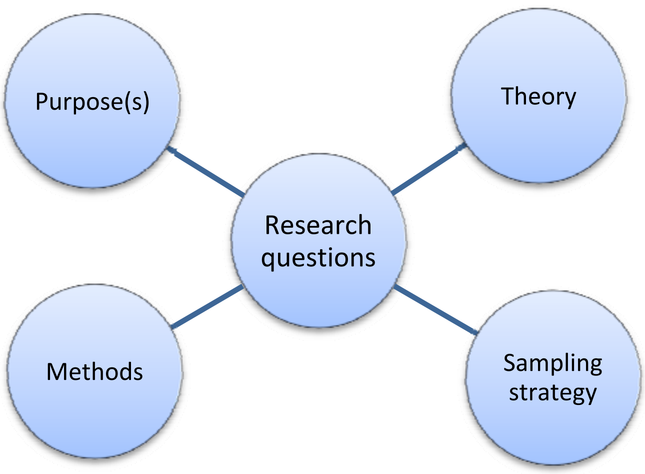


Figure 3-1 – Framework for research design

3.2 Purpose and Theory

As detailed in the literature review conclusions, it was suggested that because keeping a logbook often forms part of an engineers' training, they may contain information that could be useful for both the author and potentially the wider organisation. However, it is noted that despite considerable successes for e-logbooks in other domains and for other personal information management tools and methods, there has been low uptake in the engineering domain. It is argued that this is because there appears to be very little in terms of fundamental research into what logbooks actually contain and how they are used. This makes it difficult for any new e-logbook to be able to fulfil the wide range of roles (both cognitive and social) that other existing personal information collections provide (see Section 2.4.2). The second gap relates to a lack of understanding about how existing and emergent technologies could best support increasing re-use of logbook information.

The overall aim of this research is therefore to investigate engineering logbook use and explore how the information they contain could be managed more effectively through the use of electronic alternatives.

3.2.1 A Note on Theory

As well as identifying a lack of existing understanding in these areas, it is important to consider not just the lack of results, but also what methodology has been traditionally adopted in these studies, and whether they were successful in providing fundamental understanding and, ultimately, useful solutions. This section will therefore briefly review various schools of thought that often lead to the employment of very different methodologies and research outcomes. At this philosophical level, approaches or viewpoints on how phenomena can be understood may be broadly classified into several schools of thought, including positivist and relativist, but also 'hybrid' schools, such as realist and pragmatic approaches. These are now briefly described.

Positivist approaches are characterised by adherence to the 'scientific method' – empirical studies based on largely quantitative data gathered from direct observation. Rejecting such a scientific approach, relativism holds that "*reality cannot be defined objectively but only subjectively: reality is a socially interpreted action*" (Robson,2002:p23). As a consequence, qualitative methodologies are often utilised, "*emphasising the role of language as an object of study and as the central instrument by which the world is represented and constructed…generating working hypotheses rather than immutable empirical facts*" (Robson, 2002:p25).

Realist approaches are hybrid in the sense that they subscribe to elements of both positivist (i.e. there is an external reality) and relativist approaches (that knowledge is a "*social and historical product and "'facts' are theory-laden").* Experiments are designed to understand the mechanism(s) that causes a particular outcome to happen, in the context in which it is studied:

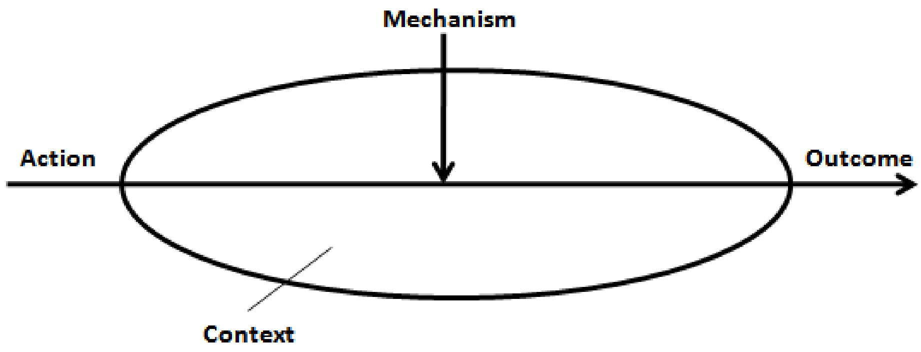


Figure 3-2 – Representation of realist explanation (*from* Robson, 2002)

In a similar vein, pragmatism contends that one is not limited to either strict positivist, quantitative, or strictly relativist, purely qualitative approaches – the focus is on using "*whatever philosophical or methodological approach works best for a particular research problem at issue*" (Robson, 2002:p43).

The question, then, is which of these viewpoints is most appropriate for this project. It is clear from the literature on personal information that research from a purely positivist stance would not be sufficient to fully understand the problem. For example, it is evident from the literature review that there is no 'theory of logbook use' - that is, a number of explanations are offered for why people maintain personal information collections, although these are not theories in the positivist sense but appear to be a complex set of inter-related technical and social factors. For this research, where the purpose is to gain understanding of logbook use to effect a positive change (better management and thus greater re-use of logbook content) it would therefore appear that a substantially realist or pragmatic approach would be most appropriate to understand the phenomena under investigation. This is because (in contrast to many approaches taken in previous e-logbook attempts) these approaches accept of the complexity of the 'real world', and typically mixed-methodology approach to data collection and analysis. With this in mind, research questions are now formulated and discussed in Section 3.3 below, before appropriate methods for their investigation are set out in 3.4 and a research plan discussed in 3.5.

3.3 Research Questions

With respect to the two gaps identified in the literature review in Chapter 2, two research questions and a set of associated objectives have been formulated and are set out below. According to Robson (2002:p59) research questions should be clear, specific, answerable, interconnected and substantively relevant. To ensure these criteria are met, two inter-related groups of questions have been formulated to address the overall purpose of the research stated in 3.1 above.

3.3.1 Research Question One

To address the apparent lack of knowledge about what is in logbooks and how they are used, the first research question is **what information do logbooks contain and how and why are they used?**

To address this question, there are three associated objectives, listed below. The first two are focussed mainly on building fundamental understanding about existing paper logbooks and their relationship to other more formal sources, with the third being focussed on a what insight may be gained from existing e-logbook attempts:

1. Why do engineers maintain logbooks? What do they contain and how are they currently structured, organised and used/re-used?
2. Of the information in logbooks, what are the differences between it and its more formal counterparts? What makes it into the more formal sources and is there any loss?
3. What lessons may be learned from existing e-logbook attempts in both the engineering domain and more generally?

3.3.2 Research Question Two

With many previous e-logbook attempts being made around eight to 10 years ago, the second gap identified relates to the lack of guidance on how current technology can be used to improve the management of logbook information through e-logbooks. The second research question is therefore **how can this understanding be used together with current and emerging technologies to improve the management of logbook information?**

This will be explored through three further objectives, designed to be more convergent and solution-focussed:

1. How can current and emerging technologies be used to best support improved management of logbook information?
2. What are the requirements for the next generation of engineering e-logbooks, to improve information management for the both the individual and wider organisation?
3. How can e-logbooks be demonstrated and evaluated in an engineering environment?

3.4 Strategy, Methods and Sample

The next consideration in Robson's (2002) framework illustrated in Figure 3.1 concerns the methods and sampling strategy employed to address the research questions. This section will therefore begin with a discussion of the overarching strategy adopted for this research in 3.4.1. With respect to this strategy and other practical considerations, data collection methods will then be discussed in 3.4.2 before the overall research that integrates all these aspects is detailed in 3.5.

3.4.1 Research Strategy

As argued in 3.2.1, the multi-faceted and relatively undefined nature of the research topic necessitates that the strategy should be routed in a largely realist or pragmatic viewpoint, which may combine various methods and both quantitative and qualitative data collection and analysis methods.

The relative lack of existing theory on the subject and nature of the research questions and objectives to be addressed also indicates that there must necessarily be some flexibility in the strategy (that is, that the research strategy and methods are not completely pre-defined and that a preceding part of the research may influence subsequent data collection or analysis). Other key considerations of a flexible research strategy (*adapted from* Robson, 2002:p166) are now summarised:

1. Rigorous data collection, using **multiple methods.** Data are summarised (e.g. in tabular form). Detail about how data are collected is recorded.
2. The study is framed within the assumptions and characteristics of the flexible (qualitative) approach to research. This includes fundamental characteristics such as an **evolving design, the presentation of multiple realities, the researcher as an instrument of data collection** and a focus on **participants' views**
3. The study is informed by an understanding of existing traditions of enquiry; i.e. the researcher identifies, studies and **employs one or more traditions on enquiry**. This tradition need not be 'pure', and **procedures from several can be bought together**
4. **The project starts with a single idea or problem that the research seeks to understand, not a causal relationship** of variables or a comparison of groups (for which a fixed design might be indicated). Relationships might evolve or comparisons might be made, but these emerge later in the study.
5. The study includes **detailed methods**, a rigorous approach to data collection, data analysis and report writing. The researcher has the responsibility of verifying the accuracy of the account given.
6. Data are analysed using multiple levels of abstraction. Often, writers **present their studies in stages** (e.g. **multiple themes that can be combined into larger themes or perspectives**), or layer their analyses from the particular to the general.
7. The writing is clear, engaging, and helps the reader to experience 'being there'. The story and findings become believable and realistic, **accurately reflecting the complexities of real life**.

The implications of these considerations are now discussed with reference to data collection methods and other practical considerations such as the sampling strategy that apply to this research.

3.4.2 Data Collection Methods and Other Considerations

There exists a wide range of methods and techniques to collect data, including (*from* Robson, 2002) surveys and questionnaires, interviews, standard tests and scales, a wide variety of observational methods and analysis of documents and other artefacts. In choosing appropriate methods for this research, three main factors have been considered. Firstly, it is noted in the table above that good flexible research designs often use multiple data collection techniques. The importance of this in an engineering design context is underlined by Subrahmanian (1992) who argues that "*One important point that needs to be stressed is that no single method will provide complete information either on the process [of engineering design] or the domain. A number of techniques have to be used in conjunction to create a robust picture of engineering design tasks and environment."* Such sentiment is also evident in the pragmatic approach argued for in 3.2, which advocates (or at least doesn't preclude) the use of mixed-methods. The triangulation provided by such multiple studies also helps to reduce the threat to validity and of researcher and respondent bias (Robson, 2002:p174).
Secondly, another strong theme in the research plan will be the need to focus on participants' views. This is completely compatible with a flexible approach that utilises both user-centred (and largely qualitative) techniques such as questionnaires, interviews and evaluation of concepts as well as more quantitative analysis of the logbooks. User-centred techniques, which focus on the experiences of the user (see, for example, Carroll, 2000) appear particularly appropriate to address the research questions concerned with existing use and how new tools and methods can be evaluated in an industrial context.

Finally, with respect to practical considerations, access is possible to both the engineers working for the industrial collaborators and others with a connection to the university, and their logbooks and it would certainly be pragmatic to gather data from both these sources. The three year term of the research also means it should be possible to revisit the same engineers multiple times (although this cannot be guaranteed). The other relevant practical consideration is related to the nature of the research. The purpose of the research is to both understand and improve the management of engineering logbook information to increase the potential for re-use. It is thus what Robson (2002) terms evaluation research and notes that there are several important points of which to be aware: Firstly, "*issues concerning clearances and permissions, negotiations with 'gatekeepers', the political nature of an evaluation, ethics, the type of report etc.. are not in themselves design issues, but they do set an important context for the choice of design*." Further, it is noted that "*Evaluation is intrinsically a very sensitive activity*". Again, a flexible approach aligns well, as exactly what analysis and reporting of such personal information will be permitted is unclear at this stage. With these points in mind, a research plan has been formulated and is now discussed.

3.5 Research Plan

This section outlines the methods that will be employed to address the research questions and associated objectives, before the overall plan and thesis structure is integrated in Table 3-1.

3.5.1 Research Question 1 – Exploring Logbooks

To tackle the first research question, a two-part approach will be employed. To address the first objective, current paper-based logbook *use* will be investigated via two complementary mechanisms: i) a survey via questionnaire of practicing engineers and ii) exploring logbook use in context through a study of logbooks in the wider personal information management space, and creating a set of detailed scenarios (descriptions of use) from semi-structured interviews with practicing engineers. The survey will be designed to provide a higher-level overview of logbook use/re-use. The personal information study and scenarios will then aim to triangulate the questionnaire results, and also to provide in-depth information on logbook usage not possible to elicit from a questionnaire. The results from both will help to inform the analysis of logbooks, discussed below.

The content, structure and organisation of existing paper logbooks will be investigated through a detailed quantitative and qualitative analysis. They will analysed in terms of the types and format of information they contain, how entries are structured and how the whole logbook is organised. Note that as per a flexible research design, the detailed schema for the analysis of the logbooks will not be predetermined here, but instead informed from the results of the scenario interviews and questionnaire and through preliminary discussion with engineers.

The second objective is concerned with the relationship of logbooks to more formal sources. In order to investigate any potential differences in the information content of logbooks and their more formal counterparts, the information content of a set of engineering project documentation consisting of both the formal (reports) and associated informal (logbook) records will be analysed. It is expected that this will also allow further insight into the role of logbooks and how the information content is used during a project, helping to triangulate the findings from the logbook use survey and scenarios.

To address the third objective of understanding and learning from previous e-logbook attempts, a detailed review of existing e-logbooks attempts and research in both the engineering and other domains will be undertaken. The purpose of this will be to gain insight into factors that lead to the success or otherwise of the e-logbook, and also to see if lessons may be learned from domains that have higher adoption rates for e-logbooks than engineering and design. The criteria for this review will be decided in part through the earlier findings of how and why logbooks are used.

3.5.2 Research Question 2 – Enhancing Logbooks

For the second research question, more solution-focused methods will be used, starting with the exploration of existing and emerging technologies via a literature review and analysis of existing technologies. The second objective will be addressed by the production of a detailed specification for an engineering e-logbook (EEL). This will be developed by deriving requirements from the findings of the descriptive studies undertaken for the first research question and integrating them into a detailed requirement specification. Proposals for the architecture, technologies and standards for EEL will also be made. Finally, addressing the third objective of demonstrating and evaluating the resulting design will involve the creation of an e-logbook technology demonstrator to show how e-logbooks could be implemented on a Tablet PC platform, together with recommendations to industry concerning evaluation and deployment. Recommendations for further research and for industry will also be made.

3.5.3 Overall Plan

How these constituent parts fit together to address the research questions is illustrated in Table 3-1. This table shows the relationship between the research question, associated objectives and the research methods proposed to address them. The chapters in which each part of research is reported are also shown.

<table>
<tr><th>RQ</th><th colspan="2">Objective</th><th colspan="2">Method/Study Proposed to Address Objective</th><th>Cp.</th></tr>
<tr><td rowspan="5">RQ1</td><td rowspan="3">RQ1-1</td><td rowspan="3">Why do engineers maintain logbooks? What do they contain and how are they currently structured, organised and used/re-used?</td><td colspan="2">Literature review</td><td>2</td></tr>
<tr><td>Logbook use survey</td><td>Logbook use scenarios</td><td>4,5</td></tr>
<tr><td>Information content analysis</td><td>Logbook structure and organisation analysis</td><td>6</td></tr>
<tr><td>RQ1-2</td><td>What is the relationship to more formal information?</td><td colspan="2">Logbook use scenarios
Analysis of relationship to formal information</td><td>5,7</td></tr>
<tr><td>RQ1-3</td><td>What lessons may be learned from existing e-logbook attempts?</td><td colspan="2">E-logbook technology review</td><td>8</td></tr>
<tr><td rowspan="3">RQ2</td><td>RQ2-1</td><td>How can technology be used to best support such an e-logbook?</td><td colspan="2">E-logbook technology review
EEL Demonstrator</td><td>8,10</td></tr>
<tr><td>RQ2-2</td><td>What, then, are the requirements for the next-generation e-logbook?</td><td colspan="2">Requirement specification derived from research findings</td><td>9</td></tr>
<tr><td>RQ2-3</td><td>How can e-logbooks be demonstrated and evaluated in an industrial context?</td><td>Technology demonstrator</td><td>Strategy for evaluation and deployment</td><td>10</td></tr>
</table>

Table 3-1 – How the research questions will be addressed

4 Logbook Use Survey

In order to investigate the current use of paper-based logbooks, a survey of practicing engineers was undertaken via a questionnaire. Firstly, the design of the questionnaire and characteristics of the respondents are discussed in 4.1, before the results are presented in 4.2 and discussed in 4.3.

As noted in the literature review in Chapter 2, there has been little prior research into engineering logbook use, and no surveys have been carried out that focus specifically on logbook use in the engineering domain. The surveys and other types of research that do exist usually looked at logbooks from a different perspective, such as sketching (see, for example, Song & Agogino, 2004) or in a different context. For example, Topi et al., (2006) studied the role of informal notes for sharing corporate technology knowhow, but the research was not conducted in an engineering organisation. Therefore whilst still largely relevant to this research, it is expected that because of the specialised nature of engineering activities, differences in note-taking practices and information types will be found. Others have also looked at personal information use in engineering, but usually at a higher level. For example Court et al., (1998) investigated the information seeking practices of engineers, whilst Bernstein et al., (2008) studied the 'information scraps' of knowledge workers, such as post-it notes and other 'back of the envelope'-type sources. Again, whilst these studies are useful to highlight the importance of the topic, they do not specifically consider logbook information use and content in an engineering context.

4.1 Questionnaire Design and Respondent Background

In light of the above, it was decided that the approach for this research should aim to gain a general overview of logbook use and provide pointers for subsequent research, as afforded by the flexible approach adopted in Chapter 3. As well as characterising the organisational (large company, small to medium-size enterprises, SME's or academic) and professional background (the main type of work their job involved, such as design, management etc), the questionnaire included questions about three broad areas. Because of the almost complete lack of literature about engineering logbook use, the list of options for each question was elaborated through consideration of literature related to more general information management (such as strategies for finding information) and initial discussions with a number of engineers. There was also space at the end of the questionnaire for engineers to add other comments about their logbook-keeping practice.

1. **Reasons for maintaining a logbook**, including options such as 'organisational requirements', 'training', 'personal record', 'project record', 'reminder of work in

progress', 'evidence for professional qualification' and 'other'. Other reasons could be specified. Respondents were asked to select up to three reasons.

2. **The format of the logbook**, in terms of its physical format (book, diary, electronic etc.) and whether a single logbook or multiple logbooks were kept.
3. **Information location and re-use**. These questions sought to understand how logbook information was re-found (e.g. contents pages, memory etc), exploring how often and for what reasons information was re-used (memory aid, when answering questions, writing reports etc), whether past logbooks were retained and how sensitive respondents considered their logbook material to be.

It was felt that covering these three areas would give a picture of the reasons for logbook use, as well as more specific data on how the information they contain is actually used. The survey was sent to a range of collaborating organisations for distribution internally and was also distributed with the Mechanical Engineering department at the University of Bath. Respondents consisted of 50 engineers holding various positions within large companies, Small to Medium Sized Enterprises (SME's) and academic institutions. The breakdown of respondent backgrounds is detailed in Figure 4-1:

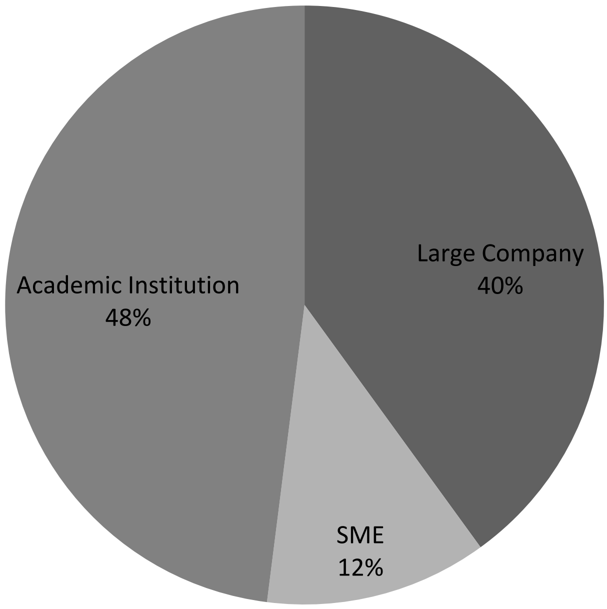


Figure 4-1 – Organisational background of respondents

In terms of their professional role, the majority (60%) of respondents can be classed as working in research and design engineering, or in a management role (20%). In addition to this, it is worth noting that just over 30% of the respondents were engineers trained and working outside of the UK, adding an international dimension to the findings. The backgrounds of the sample are shown in Figure 4-2:

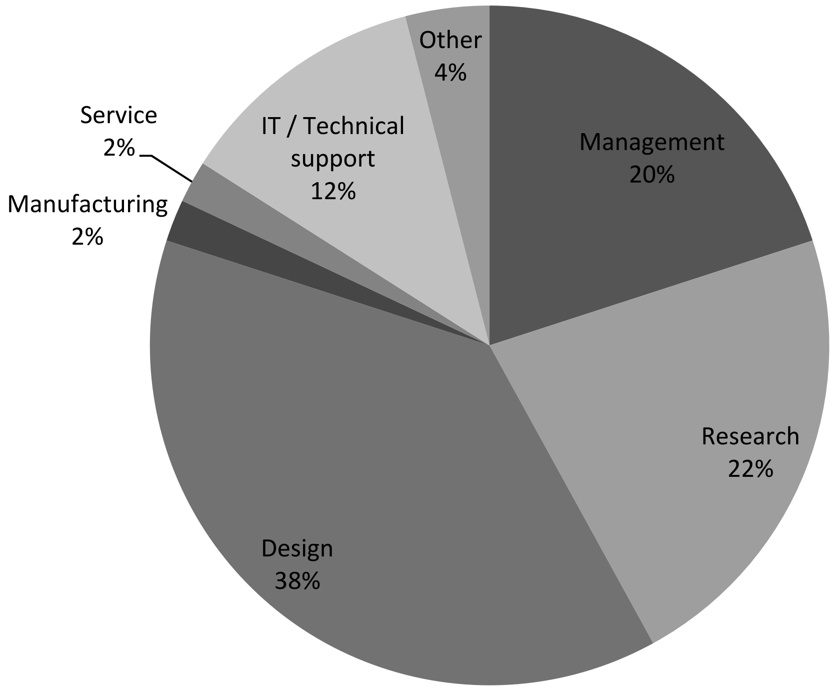


Figure 4-2 – Professional background of respondents

4.2 Results

This section presents the results of the survey in terms of reasons for maintaining a logbook (4.2.1), its format (4.2.2) and information location and re-use (4.2.3). These results are then discussed in detail in Section 4.3.

4.2.1 Reasons for Maintaining a Logbook

The first part of the questionnaire sought to establish the reasons why engineers maintain a logbook. Respondents were asked to select the top three reasons from a predetermined list, as described in Section 4.1. The results are shown in figure 4-3 and highlight the two most frequently occurring reasons: 'a reminder of work in progress' and 'a personal work record' (>70%), although most respondents indicated multiple reasons, reflecting the multiple roles that logbooks appear to fulfil.

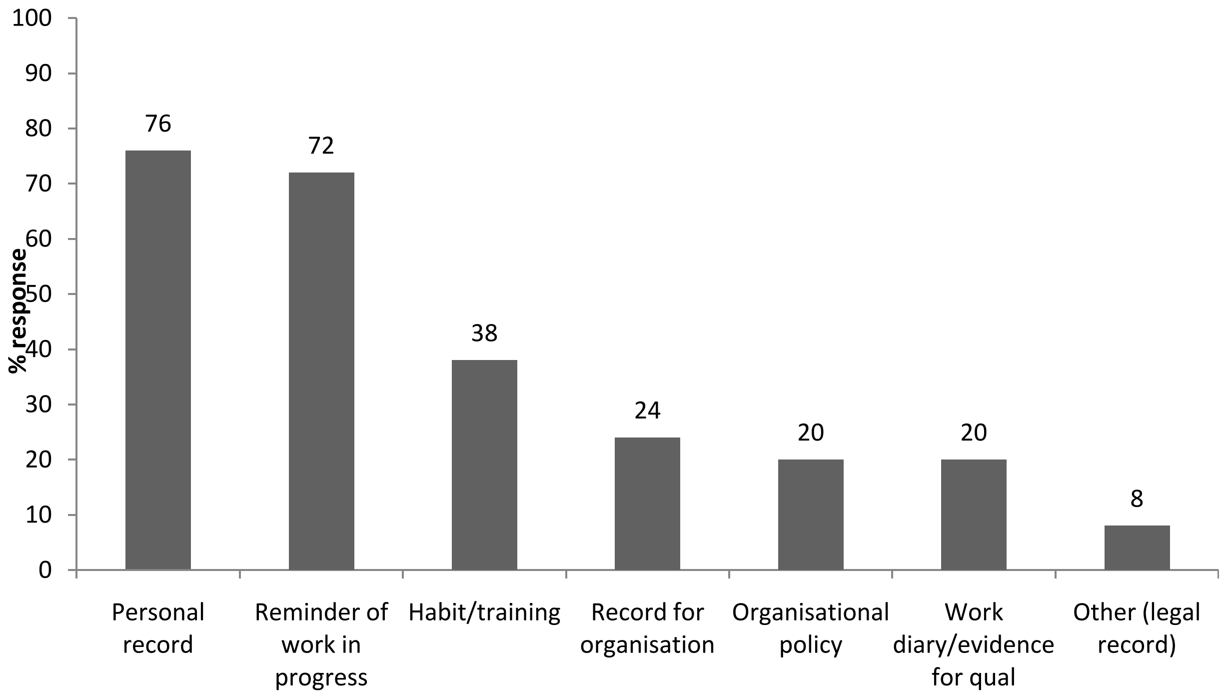


Figure 4-3 – Reasons for keeping a logbook

In contrast, only 20% indicated that their logbook-keeping was because of organisational policy. Alternative reasons given included habit or training (38%), as a record for the organisation (24%) and evidence for qualification purposes (20%). Within the 'other' category, responses included that it was viewed as a legal record (linked being a record for the organisation), used for recording actions, or for the formalisation of creative working sessions, both of which are similar in nature to 'personal record' and 'reminder of work in progress' categories.

4.2.2 Logbook Format

Respondents were asked to specify whether their logbooks were project based, personal or general. The results revealed that the majority of engineers keep a single logbook (51%), although a significant number did keep separate logbooks for different projects (34%), which is consistent with the findings of Boardman (2004), who observed that electronic information was often organised into project folders.

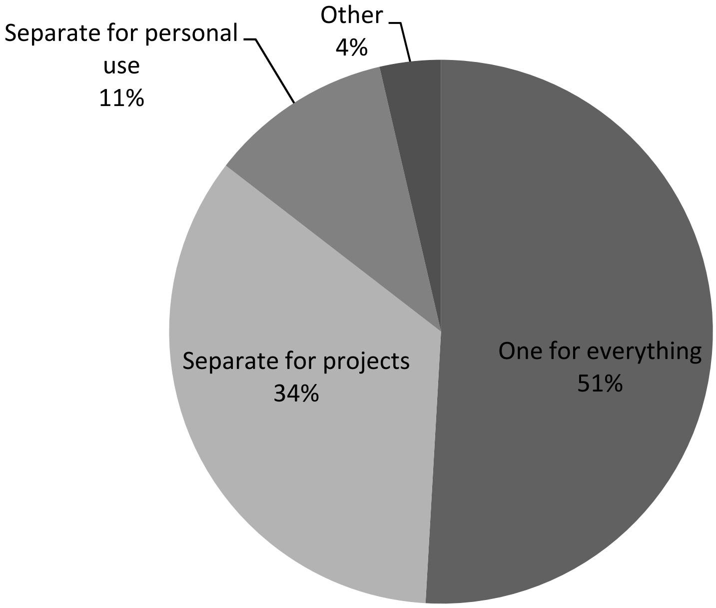


Figure 4-4 – Logbook type

To investigate logbook formats, participants were asked to identify the type of logbook they kept: hardback, bound sheets, diary, electronic or other. Logbooks were mostly hard-backed A4 sized notebooks (61%) and loose sheets kept in ring binders (27%). Of the 50 participants, just two respondents used a laptop computer as a logbook:

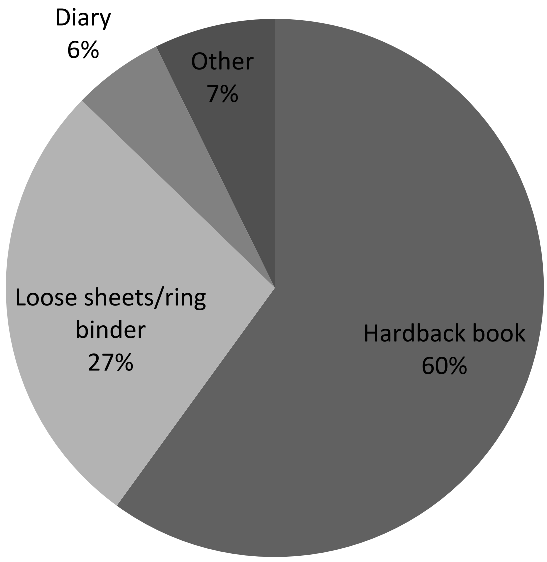


Figure 4-5 – Logbook format

4.2.3 Information Location and Re-use

To allow the investigation of how information was located and to what extent it was re-used, respondents were asked to select the method they used to locate relevant information: 'browsing', 'indexing', 'cross-referencing', 'page numbering', 'memory', and 'other'. These results are illustrated in Figure 4-6:

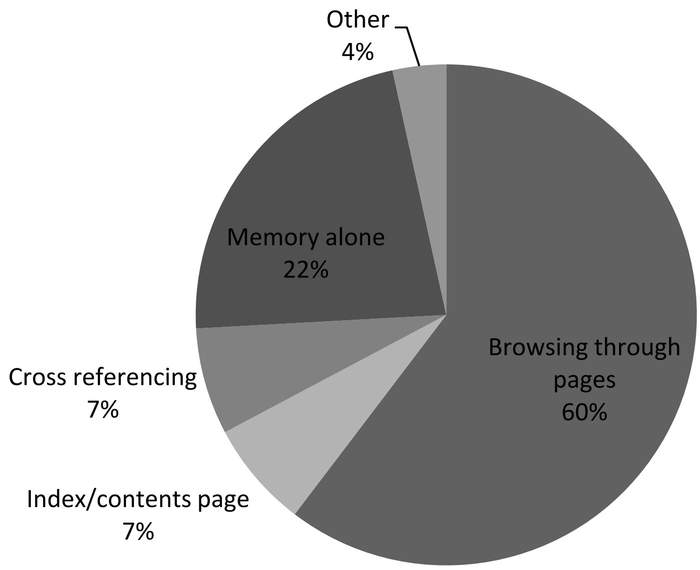


Figure 4-6 – Ways of locating information

Most participants indicated that they generally located information by browsing through pages, or by recalling the approximate date of entry from memory. Only 14% of respondents used a more formal approach such as an index or contents page (7%), or a cross referencing system (7%).

To assess the level of re-use, the frequency of access by the logbook owner was also investigated for the current (active) logbooks. Respondents were also asked if older logbooks were retained and, if so, how often they were accessed. The results are shown in Figure 4-7:

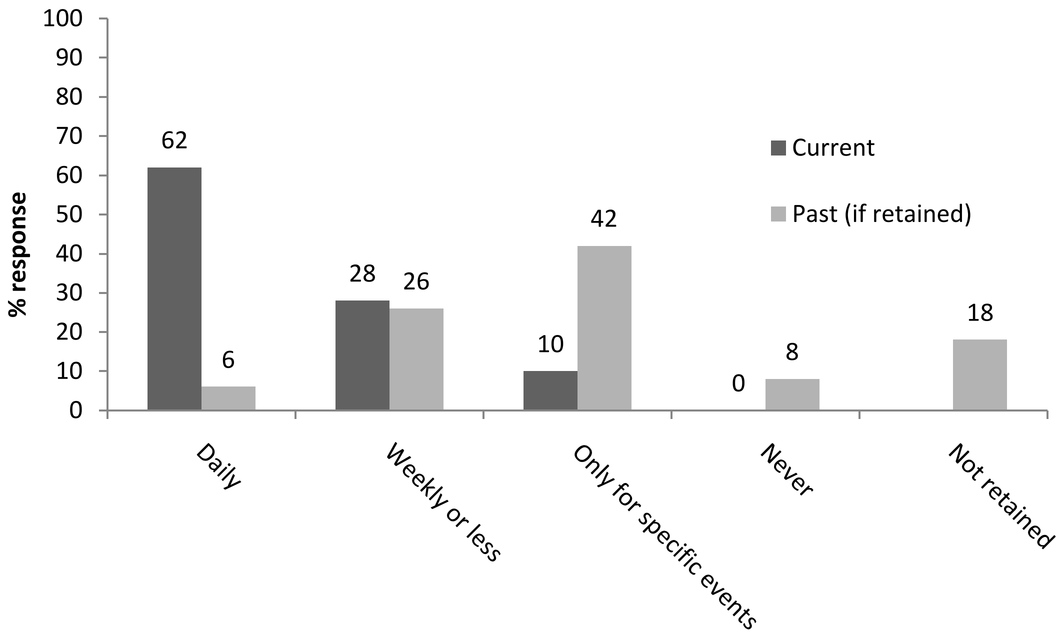


Figure 4-7 – Frequency of use of current vs. past logbooks

It can be seen that 62% of respondents referred to information in their current logbooks on a daily basis, with a further 28% referring to the information on a weekly basis. Just 10% referred to them only for specific events.

In contrast to the respondents current logbook, 18% of those questioned did not retain past logbooks, implying that any useful information they contain will be permanently lost to both the author and the organisation. Of those that did retain their past logbooks, the trend compared to current logbooks was largely reversed, with just 6% referring to past logbooks on a daily basis, whilst the majority (42%) referred to them for specific events only, or on a weekly basis or less (26%). Several possible reasons for these findings are put forward in the discussion in Section 4.3.

In terms of *why* they had a need to locate and re-use the information in their logbooks, respondents were asked to select from a list all reasons that applied. A broad range of answers was given, with the most often cited being to carry on previous work, and similarly, reminding themselves of the status of work, or tasks that were outstanding. The complete results are presented in Figure 4-8:

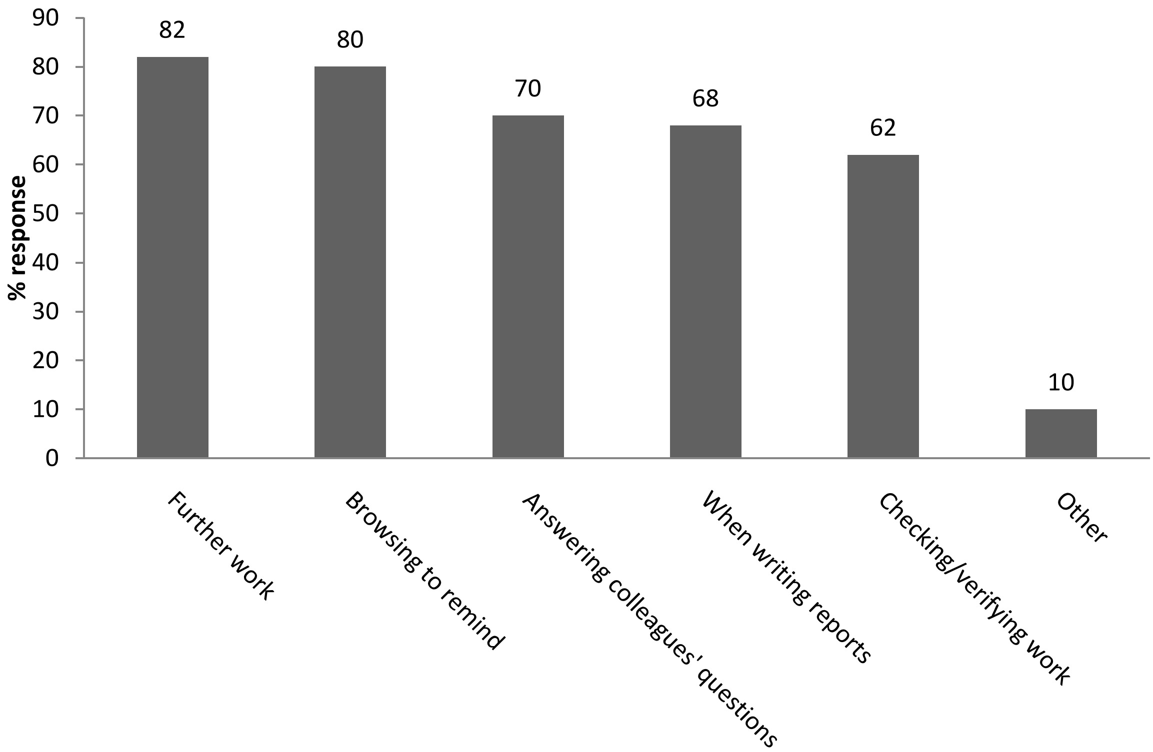


Figure 4-8 – Purpose for information re-use

It can also be seen that logbook information was commonly re-found to help answer questions from colleagues. It was noted by Grudin (2001) that one reason for maintaining collections of personal information (of which logbooks are a part) is because they allow the circumstances of disclosure to be controlled – that is, the individual author can decide who sees what, and knows to whom they have given information. To gauge the degree to which logbooks were considered personal to the owner, respondents were asked whether they would be happy sharing their logbook with colleagues and customers or suppliers (Figure 4-9).

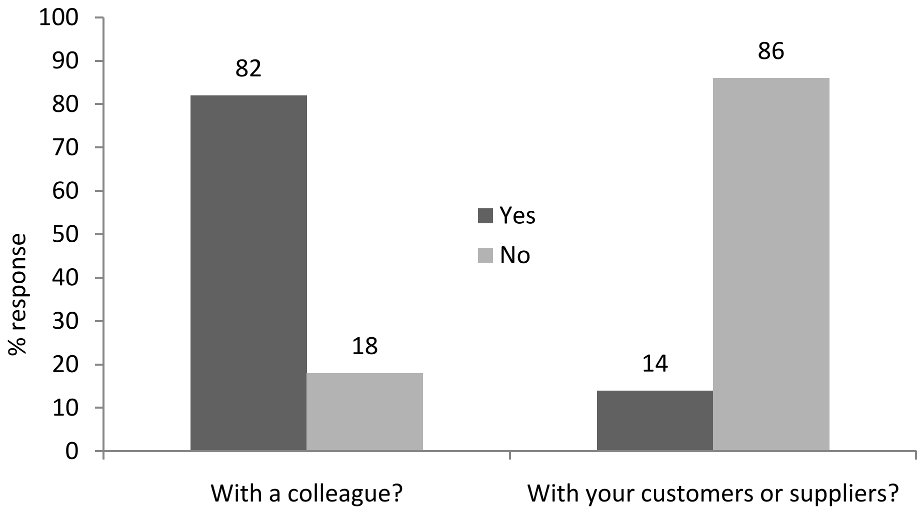


Figure 4-9 – Willingness to share logbook information

Contrary to expectations, most respondents indicated they would be happy for their colleagues to access their logbooks. Unsurprisingly, however, was their reluctance for those outside their organisation (that is, customers and suppliers) to see the information. However, the issue of whether an assessment of the trustworthiness of logbook information could be made without the original author 'mediating' the access is not answered by this survey and will therefore be revisited in later chapters (specifically in chapters 6 and 7).

4.3 Discussion

Firstly, the results presented above will be summarised and discussed in relation to the literature in 4.3.1, before implications for the design of e-logbooks are drawn in 4.3.2.

4.3.1 Discussion of Findings

In terms of *what* logbooks consist, the most common forms of logbook are a hardback, lined, A4 notebook followed by a collection of loose sheets gathered in a binder. Two-thirds of respondents used a single logbook, the remainder keeping a separate logbook for each project in which they were involved. In general, information content was structured chronologically, with information being located by recalling an approximate date and browsing through pages. This broadly supports the findings of Sobek (2002) and Wilcox et al., (1997), which also reveal logbooks have a commonly chronological structure, with entries being separated with lines or by starting a new page and locating entries by memory and browsing. Interestingly, Oehlberg et al's., (2009) finding that an increasing number of 'hybrid' design journals are used (i.e. a combination of paper and digital recording media) is not evidenced here. This could be a consequence of the questionnaire design – That is, for this study, the respondents were only questioned on logbook use, although in reality their 'personal information space' may have included digital sketching tools and other digital tools. It may also have been a consequence of the differing backgrounds of the samples (practicing engineers vs. younger students more likely to adopt new technologies in the study of Oehlberg et al., 2009) and the type of design task undertaken (a variety of engineering and design/research roles versus a product design problem including industrial designers).

In terms of what the results reveal about *how* logbooks are used, Currano & Leifer's (2009) identification of three logbook themes, identified from a study of what are termed 'idealogs' from an undergraduate engineering course provide a useful framework. Three themes or 'modes of use' were identified, with 'ideation' argued to be the most important. Following their definition below, these three themes are used as a starting point with which to discuss the survey findings:

Themes →	**Ideation**	**Communication**	**Documentation**
Activities	Idea generation Concept generation Brainstorm Think of new ideas Develop ideas Refine ideas Visualise	Share Relay Communicate Show	Record Log Document Organise Keep track Review Recall

Table 4-1 – Logbook themes as a framework to discuss results *(reproduced from* Currano & Leifer, 2009)

For *ideation,* whilst the questionnaire did not explicitly question the role of logbooks in ideation or reflection, Figure 4-8 reveals that much of the re-use is in support of 'further work', 'when writing reports' and 'browsing to remind', all of which suggest ideation activities, such as developing and refining ideas. In addition, significant further evidence in support of the role of logbooks in self-reflection is presented in chapters 6 and 7, when the information content of logbooks is explored in more detail and their role in visualising (evidenced by the amount of graphical content) is revealed.

The *communication* mode of use is evident through Figure 4-8, which reveals that a primary reason for re-use was in answering colleagues questions, although the questionnaire alone does not offer any evidence to show logbooks are used jointly, or shown to colleagues, although the majority of respondents would be happy to do this (Figure 4-9). A large number of respondents also indicated that they used their logbooks for 'further work' or 'when writing reports'. As well as being evidence of ideation activities as discussed above, this re-use of logbook information could also be considered communication (sharing and relaying), albeit in an indirect way. How logbook information is used to help create formal reports is investigated in more detail in chapters 5 and 7.

There is also significant evidence in support of the *Documentation* mode of use. For example, Figure 4-3 reveals that engineering logbooks are typically used as a personal work record, whilst 4-8 reveals that they also serve as a reference source for future work and report writing, with engineers referring to current logbooks on an almost daily basis. Whilst it is arguable that this may be more *ideation* than *documentation*, the boundaries between the two may not be as simple and well defined as Table 4-1 suggests. In addition, it is revealed that past logbook are generally only referred to by the author on a weekly basis or less, or for specific events only[5]. The difficulty of locating entries through 'browsing' pages (60%) or 'memory alone' (22%) may mean that it is simply too difficult or time consuming for all but the most important information. The argument could also be made that rather than being too hard to locate, the past information is not accessed frequently because it is not needed for either ideation or documentation. Whilst this could very well be true for at least a proportion of the information such as completed 'to-do' items, this is not borne out by either the comments of the respondents to this survey, or by Wilcox et al.'s 1997 logbook usage study, which found authors generally had difficulty locating information and expressed a desire for better methods to support this activity. As an example, one respondent in this survey remarked that easier access to past logbooks would be a "*distinct advantage"* for their work, while the following comment supporting logbooks as a source of *documentation* was made by a respondent:

"*I used to keep a 'design log', this was used on a number of occasions to directly save the company money. For example, I had details of a job I had done to make an amendment to a drawing. Included as part of this was a set of retrospective actions to bring existing components up to the new standard. Months later I was approached by the manufacturing concessions department about the job as a number of components were made to the wrong standard, the information in the logbook provided enough information to point to the retrospective action that saved them producing concession drawings. Another example was during concept work involving patent work, from it I was able to provide all the alternative solutions envisaged to tighten up the patent as much as possible and the exact dates also required for the application."*

Further, despite Currano & Leifer's (2009) assertion of the role of logbooks or 'idealogs' as *"...not primarily as an information repository, but as a medium for design thinking*", when asked to give their impression of 'idealogging' and its purpose in design projects, the responses were fairly

[5] This supports the findings of Sellen and Harper, (2002) who suggest that a paper document acts as a reminder through its physical presence (which would be lacking if, for example, a completed book was filed in a central store or even in a drawer.)

evenly split between the three themes of ideation, communication and documentation, suggesting that logbooks are at least perceived as having an important role as an information repository and work record for individuals. The relative lack of responses indicating logbooks were kept as a result of organisational policy or as a record for the organisation was not expected, given that maintaining a logbook commonly forms part of an engineers' training and is a frequently cited reason for logbook maintenance in other domains (see, for example Myers, 2003 and Butler, 2005). The implications of these findings for the requirements for an e-logbook are now discussed.

4.3.2 Requirements Arising

It is clear from the above discussion that and the literature review in Chapter 2 that personal information in general (and logbooks in particular) do not exist solely as containers for information, but the reasons for their creation and maintenance include a range of technical and social factors. The results of this questionnaire reveal (in support of several other studies) that logbooks are maintained for a variety of reasons, with the information they contain frequently re-used for a variety of purposes, including (from Currano & Leifer, 2009) *ideation*, *communication* and *documentation*. Further, the re-use of logbook information for a variety of purposes (such as when writing reports and verifying information) shown in Figure 4-8 suggests that logbooks do contain potentially valuable engineering-related information that may be useful to a wider audience.

Secondly, the largely personal nature of logbooks (evidenced by the majority of respondents indicating they are kept primarily as a personal and not organisational record) has implications for the wider re-use of information by the organisation or even a small project team. For example, most respondents (>80%) indicated that they would be happy to share logbook information with colleagues. However, the survey reveals that browsing and memory are the predominant ways of locating information, which strongly suggests it would be much harder for someone with little prior knowledge of what the logbook may contain to locate information without assistance from the author. Indeed, in 18% of cases, past logbooks are not even retained, meaning a total loss of any information they might contain.

In terms of requirements for any future e-logbook, the clear implication is that if the management of logbook information is to be improved to the point where it may be useful to anyone other than the logbook owner, how information is re-found will need to be addressed. In addition, the personal nature of logbooks means that there is a requirement for some type of access control.

The logbook material may also require the ability to be separated by project, with a significant 34% of respondents keeping separate logbooks for each project in which they are involved. The key trade-off inherent in these findings is the need to improve apparent shortcomings of the logbook as a source of documentation, whilst maintaining the unique physical affordances of paper and the role of logbooks as a tool for private ideation and reflection.

However, whilst the survey provides evidence that logbooks *do* support a range of engineering activities, the question of *how* they do it (that is, what features do they have which afford these types of use?) is not answered completely. Chapters 5-7 will therefore build on the understanding gained from the literature and this survey, looking in more depth at the role of logbooks in terms of information flow, content, structure and organisation, and its relationship to formal information.

4.4 Concluding Remarks

This chapter has presented the results of a survey into existing paper-based engineering logbook use. It reveals that logbooks are created for a range of reasons, but are viewed largely as a personal record of work in progress, with the predominant means of retrieval being from memory or simply browsing through pages. Whilst current logbooks are accessed very frequently, older logbooks seem to be accessed less frequently, or not even retained. It is argued that this may be due to the difficulties of locating past information due to the shortcomings of current paper systems, as well as the potential reduction in value and usefulness of older information. Respondents' attitudes towards electronic alternatives or enhancements of traditional paper note-taking (such as searching by keyword) were also found to be largely positive, although the 'affordances' of paper (such as its reminding through its physical presence) are well documented (Sellen & Harper, 2002).

The most important finding that this questionnaire highlights (and the main contribution of this chapter) is the evidence (in support of several pieces of existing work) that logbooks support multiple 'modes of use' – such as (*from* Currano & Leifer, 2009) *documentation* (as a record for the individual or organisation, to keep track of work and tasks), *ideation* (concept generation and refining ideas etc). and *communication* in the form of sharing information and showing work to others.

This led to the first fundamental requirement that future logbooks must improve aspects of use and re-use (in particular for the documentation role), whilst supporting (or at the very least not inhibiting) all the modes of use identified.

It was also noted that whilst the questionnaire was effective in providing previously lacking fundamental information on logbook use and identifying logbooks do fulfil these various roles, *how* they do it and *what* they actually contain was not ascertained from the questionnaire. To this end, the use of logbooks in terms of information flow (i.e. what goes in, why, and where does it end up?) is now explored in Chapter 5 through the creation of a set of detailed scenarios investigating logbook use in context, before an in-depth analysis of existing paper-based logbooks is undertaken from various perspectives in Chapters 6 to 8.

5 Logbook Use in Context

In order to gain additional insight and to triangulate results from the survey presented in Chapter 4, two complementary studies were undertaken: Firstly, a study of personal information use was conducted. This involved questioning engineers about the 'stores' of personal information they used and how they related to each other. The aim was to set logbook use in the wider context of personal information management.

The findings of this study were then used as a starting point to investigate the role of logbooks in more detail. Six semi-structured interviews of practicing engineers and other stakeholders representing both individual and organisational perspectives were carried out. The objectives were twofold: The interviews were firstly designed to shed further light on the existing logbook-keeping practices of engineers in a wider context - specifically in the areas of how and why logbooks are maintained, and to understand the 'flow' of information in terms of where it comes from, how it is recorded and where and how it is then re-used in other information sources. Secondly, suitable participants - from not only the perspective of their own personal information management, but from an organisational perspective - were questioned to gain further insight into the requirements of various stakeholders, not just the individual engineer. For both these objectives, participants were also asked about their current practices, how they envisaged their requirements would change in the future and how these changing requirements could be fulfilled from an information management perspective.

The rest of this chapter is structured as follows: Firstly, the wider personal information space of engineers is investigated in Section 5.1. Following on from the findings of this, the second study is then introduced in Section 5.2 with some background to scenario-based techniques, followed by the rationale for using them and the method used. The scenarios are presented in Section 5.3 and the findings from both the studies discussed in 5.4, with respect to the requirements arising for e-logbooks from both individual and organisational perspectives. Concluding remarks are then set out in 5.5.

5.1 Exploring the Wider Personal Information Space of Engineers

This section describes the method used to gather the information in 5.1.1, followed by the results of the study in 5.1.2.

5.1.1 Method

It has been argued by Bruce (2005) that personal information collections can be viewed in terms of Form (the physical or electronic medium used to hold or transmit the information), Structure (how the information is arranged) and Pointers (how the information is linked to other stores).

Using this as a starting point, a list of topics to be investigated was elaborated, included what types of 'information stores' were used, how they were structured and organised, what contextual information was present and how the information stores linked to each other. Identifying personal information by 'information store' (i.e. the physical or electronic medium used to hold or transmit the information) was considered appropriate because it was easy and more natural for the participants to identify stores and reflect on their personal information use independently from particular media or systems. Six engineers from the University of Bath were questioned about their personal information use in a semi-structured way. The participants were all involved in engineering design research and had at least three years of experience at a post-doctoral level. They were interviewed at their desks to encourage them to talk about the 'information stores' around them. It also allowed the interviewer to see samples of the information and question them in more detail about how it was used. Participants were questioned about how the sources were used and where possible pointers existed, and were asked to show examples if possible. These pointers usually took the form of explicit links between stores or an input to another store. For example, an engineer might make reference to an electronic file store or contact information also found in another store, such as an address book.

The topics of structure and organisation, and context, were chosen because it is arguable that the first two factors dictate to a large extent accessibility (together with being able to physically access the information), which has been shown to the most important factor influencing information seeking (Fidel & Green, 2004). The context-providing identifiers included with the information arguably dictates to a large extent its value or usefulness, as far as it can be influenced (i.e. usefulness is ultimately a judgement by the end-user, all one can do is try to maximise the chances of it being useful by allowing the user to accurately assess its relevance and quality). Note that when collections of information exist, such as a collections of journal papers, their organisation is assessed under the heading 'arrangement' – recognising that collections of formal information can be considered personal information if they are collected for, and used by, the individuals. Furthermore, such personal information stores are frequently arranged in a specific way to add value. For the purposes of this study the levels of structure, organisation and context were assed as being low, medium or high, the definitions of which are given in Table 5-1 with examples:

Category	Definition	Examples
Information Store	The physical or electronic artefact used hold and/or transmit the information	Post-It notes, diaries, logbooks, email, box files, collections of journal papers or books, to-do lists etc.
Form	Characterisation - A brief description of what form the information takes	Paper-based/ electronic, printed/handwritten etc.
Structure	Subjective assessment of how the information entities are structured on the scale of low to high (see examples on right)	**Low** – freeform text that does not follow conventions of written language or graphic representation (no full sentences, paragraphs etc) **Medium** – Follows conventions of written language or diagrammatic representation. **High** – as medium but also in a widely accepted and commonly understandable format for the source, e.g. contact details arranged alphabetically by surname, with fields for address, job role, telephone number etc.
Organisation	Subjective assessment of how the information entities are arranged on a scale of low to high (see examples on right)	**Low** – No apparent organisation other than co-location **Medium** – arranged in an obvious way – e.g. chronologically or alphabetically, by project name, etc. **High** – As for medium, plus in a commonly accepted way for that type or with an index or contents page.
Arrangement (if applicable)	How collections of personal information are arranged/archived (for multiple instances of types only – e.g. collections of journal papers)	As for Organisation, if collections of a type of information exist (a collection of past logbooks or journal papers, for example)
Contextual Information	Assessment of the identifying information or metadata, such as times, dates, project names, descriptions etc that are present, on a scale of none to high.	Dates/times, title, author, description of information, etc. **Low** – Date or brief title etc. **Medium** – As low, plus descriptive title and consistent across entities **High** – As medium plus description of intent or scope of information/additional background, in an accepted, structured format.
Pointers	Explicit links to other types or sources of information, whether personal or not, as assessed by the author and through examples	References to people (i.e. contact details), URLs, papers/books, electronic files, or any information held in other stores.

Table 5-1 – Aspects of personal information investigated

5.1.2 Results

In total, 24 types of personal information stores were identified and characterised with respect to their structure, organisation, arrangement level of contextual information and pointers (Table 5-2):

Form	Store	Description of Form	Characteristics				
			Structure	Organisation	Arrangement (if applicable)	Contextual information	Pointers
Paper-based	Logbook	Hand written, containing a variety of information from many sources	Low	Medium	Low	Low	Computer file stores, URL's, Contacts, Books, Papers, Files/folders, Emails, Diary Entries, meeting action lists
	Diary	Typically a hard-back book with a week-to-view format	Medium	High			Contacts
	Post-it notes	Kept on desks, around computer monitors etc. Very brief unstructured notes, handwritten.	Low	Low	Low	None	Computer file store, Contacts, URL's, Diary entries
	Address book	A4 sheet of numbers and addresses	High	Medium	Low		
	Business cards	Kept in file in alphabetical order	High	Medium	Medium	Medium	Contacts
	To-Do list	To-do list – paper	Medium	Low/Medium		Low	Contacts, Emails, Diary entries
	Noticeboard	In office and used to store information in various formats	Low	Low			Diary entries
	Flipchart	A2 paper chart, used to record ideas etc or during presentations.	Low	Low	Low/Medium		
	Books	collections of reference material kept on or near desk	High	High	None	Low	
	Journal papers	As above	High	High	None/ Low/Medium	Low	
	Files and folders	Various collections of a wide range of reference material	NA/Various	Low	Low None/Low	Low	
	Paper bundle	As above, but stored loose on desk for accessibility	NA/Various	Low	Low	Low	

	Meeting action list	Produced from meeting minutes and used in a similar way to to-do lists	Medium	Medium		Medium	Contacts, Email
	Paper notes	Loose A4 paper notes used as a logbook, but less information from other stores. Still stored chronologically	Low	Low	Medium	Low	Computer file stores, URL's, Contacts, Books, Papers, Emails
Electronic	Diary	As for paper. Variety of programs used, most commonly Microsoft Outlook	Medium	High		Low	Contacts
	Address book	As for paper version, but often more detailed info present	High	Medium		Medium	
	To-do list	As paper, but commonly integrated with email and diary system	Medium	High		Low/Medium	Diary entries, Emails
	Tablet Notes	Used as a logbook by only 1 participant and in a similar fashion to a regular logbook	Low	Medium/High		Medium	Computer file stores, URL's, Contacts, Books, Papers, Emails, Diary Entries
	Email	Variety of programs used, commonly Outlook. Large number of files attached to incoming and outgoing mail	Low to medium	High		Medium	Logbooks, Computer file stores, URL's, Contacts, Diary Entries, to-do list
	Computer file store	Personal files on shared (network) or personal hard drive, containing large variety of information, organised in hierarchical folders	NA/Various	Medium		None/Low	Disk collections

	Browser bookmarks	'favourites' folder used to keep track of commonly used URLs. Often contained 50+ links, but less in engineering organisation	NA	Low/Medium		None/Low	
	Web history	Used in a similar way to bookmarks, above	NA	High		Medium	
	Disk collection	Collections of CDs or other media containing a large variety of electronic files including supplier catalogues and backups	NA/Various	Low	Low	Medium	
Other	Whiteboard	Used to record a variety of brief notes or sketches, often for 'working out' or in a collaborative situation	Low	Low		None/Low	Contacts, Diary entries

Table 5-2 – Characterisation of personal information space

The number of personal information stores used by the participants varied widely, from five to 14, although all participants - even the participant using only five personal information stores - commented that they were still referred to on a daily basis. This shows that personal information was still an often used and important source of information, which is consistent with the results of previous work (see, for example, Topi et al., 2006; Whittaker & Hirschberg, 2001; Lowe, 2002). The information also took a variety of forms, with 14 of the 24 types being paper-based. Of these 14 types, seven were handwritten and the remainder printed. Although the quantities were not accurately measured in this assessment, a large majority of the information was clearly still paper-based, echoing the findings of Lowe (2002).

In terms of structure and organisation, most stores had low levels of structure and were often organised in the most basic ways. For example, the collections or archives were either not organised, or organised in a simple chronological manner, although this may be a consequence of their relatively small size. The exceptions to this were diaries, email systems and to a lesser extent, electronic file stores, which all enforce a pre-defined method of organisation on the user. Contextual information was also limited in most cases. Dates and titles were often in evidence, but often applied inconsistently with, for example, dates lacking years or being in an ambiguous format. The exceptions to this were again largely found in electronic stores such as email. This is because much of the contextual information was generated automatically, or the user was prompted to enter it (e.g. a subject line in an email, which also included the date, time, list of recipients, previous correspondence appended to the reply etc.)

The top four stores in terms of the number of pointers were logbooks and other notes, email, diaries and address books. It is also interesting to note that of these stores, email, address books and diaries are all well developed, with numerous electronic PIM tools with sophisticated organisational functions such as remote access, sharing and collaborating to fulfil these functions. Further, such electronic tools have almost universal use, with only one participant still using a paper-based diary.

In contrast, Chapter 4 suggested that traditional paper logbooks currently have a limited capacity for re-use, being referred to only for specific events once completed, or at the end of a project. This is reflected through the interviews, where participants commonly judged logbooks and other stores with little structure or context to have little or no capacity for re-use by colleagues or the wider organisation, despite containing potentially valuable information. Conversely, email and other more structured sources were judged by the participants to be most useful as personal and organisational stores of knowledge about past projects.

5.2 Logbook Use Scenarios

This section builds on the results from Section 5.1 by investigating logbook use in an industrial context from three perspectives: individual logbook use in terms of the flow of information, and also the organisational perspectives on the role of logbooks both now and in the future.

5.2.1 Rationale for Using Scenarios

Scenarios are essentially descriptions of use, which are used to understand a complex problem from a user perspective. According to Carroll (2000), "*a scenario is a concrete story about use…[they] are a vocabulary for coordinating the central tasks of system development - understanding people's needs, envisioning new activities and technologies, designing effective systems and software, and drawing general lessons from systems as they are developed and used.*"

In contrast to many problem solving approaches in software engineering (and design in general) that seek to control a design by reducing complexity and decomposing the problem into manageable tasks, Carroll asserts that "*scenario-based techniques belong to a complementary tradition that seeks to exploit the complexity and fluidity of design by trying to learn more about the structure and dynamics of the problem domain, trying to see the situation in many different ways and interacting with concrete elements of the situation*". A number of ways in which the use of scenarios can overcome the challenges associated with characterising design are illustrated in Figure 5-1:

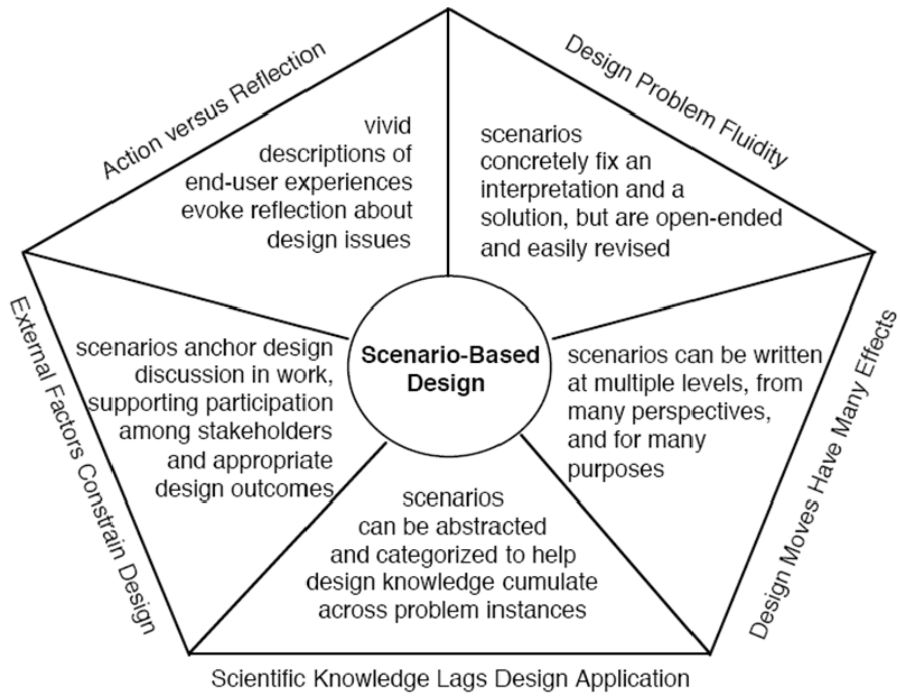


Figure 5-1 – Challenges and approaches in scenario-based design (*reproduced from* Carroll, 2000)

The first challenge is termed "action versus reflection". That is, "*there is a fundamental tension between thinking and doing*" (Carroll, 2000) and that "*reflective activities in information system design often occur decoupled from action*". For this research, scenario-based approaches seek to overcome this disconnect between thinking and doing by allowing the participants to reflect on their logbook-keeping practice, but in the context of their own work and environment in a way that is not possible when answering a questionnaire asking for views on relatively abstract problems or tasks. From the perspective of the researcher, scenarios "*…resolve the paradox or reflection and action by providing a language for action that is ineluctably reflection evoking."* From the perspective of the research methodology discussed in Chapter 3, scenario-based design techniques are compatible with the characteristics of the flexible approach adopted, especially by explicitly focussing on participants views.

Design problem fluidity and the problem of design moves having many effects are accommodated by the fact that scenarios are able to be relatively concrete descriptions of use (e.g. "*I put this type of information in my logbook for this reason, and it ends up in this location, I do this because…"*). However, scenarios are also relatively quick and easy to create and adapt, or look at from a different perspective, or for a different purpose – with Carroll (2000) noting that "*scenarios are…clay mock-ups for the domain of interaction design*". Again, this is a useful attribute as this research is concerned with logbooks not just from the perspective of the individual author, but also the wider organisation.

The forth challenge concerns that fact that scientific knowledge often lags design application – that is, "*designers often work in domains for which certain critical scientific and engineering knowledge is missing"* (Carroll, 2000). This is certainly the case in this research, where there is a limited amount of existing work on which to build. Carroll argues that constructing scenarios helps to resolve this problem by allowing problems to be abstracted, which could, for example, help to identify knowledge or solutions from other domains which could be applicable to this research. Carroll also observes that "*in the large, information technology appears as a co-evolution of tasks and artefacts*." Exploring both current practice and future use through scenarios can ensure that both sides of this cycle are explored.

Finally, Carroll (2000) points out that with some approaches, external factors constrain design – that is, constraints exist externally to the design problem in the form of, for example, the state of technology, individual preferences or past experiences of the researcher or the organisation, or constraints imposed by the design or research process itself. Carroll (2000) notes that "*a design process in which scenarios are employed as a focal representation will ipso facto remain focussed on the needs and concerns of prospective users"* and are therefore less likely to be influenced by these external constraints than when the design work "…*is couched in the language of functional* *specifications"*. In the context of this research and the methodology employed, the use of scenarios again fits well with the characteristics of flexible approaches, particularly in actively involving users.

It is therefore proposed to use scenarios as a way of exploring logbook use in an industrial context, triangulating the survey results, identifying requirements for e-logbooks and indicating areas of particular interest for further research.

5.2.2 Method Used to Construct Scenarios

This section first discusses how the scenarios were created, before the results from each interview are presented in Section 5.3. Scenarios commonly take the form of descriptions of use in a narrative form and generally include four characteristic elements:

1. **Setting** – The physical space, for example an office, cockpit etc.
2. **Agents & actors** – who is involved and who they interact with
3. **Goals & objectives** – Why the person is doing something that way
4. **Sequences of actions & events** – What they are doing, in what order

There are numerous ways to create sets of scenarios including (from Carroll, 2000), ethnographic studies, participatory design techniques, re-use of prior analyses, or generating the "*Cartesian product*" of agents, goals, actions, events or objects. For example, in the case of agents, one could focus on scenarios from an individual, group and wider organisational perspective.

The objectives of this section are to triangulate the results presented in Chapter 4 and build a richer picture of logbook use in terms of information flow, and the types of information they contain, as well as how to better support this type of information from an organisational perspective. It was therefore decided to carry out interviews with both engineers who use logbooks for their individual work and also other stakeholders, to gain this wider organisational perspective on logbook use.

Whilst there are no rules on the number of scenarios needed to be an effective and representative sample, Carroll (2000) notes that "*for high level design, often very few scenarios are enough - e.g. for strategic management, four scenarios are usually enough.*" It is also noted that " *not all scenarios are equally significant*" and the distinction is made between critical scenarios (rare episodes where something surprisingly good or bad happens) and routine or unimportant scenarios. In general, "*scenarios are adequately detailed when they make significant design issues apparent - for example, enabling the identification of claims.*" As the objective of the scenarios is to build on the survey undertaken in Chapter 4 and the characterisation of the wider personal information space described in Section 5.1, it was not felt a large number were needed. Six people in a variety of roles were contacted and interviewed at their place of work. The details of the participants are summarised in Table 5-3:

ID	Job Role	Interview length (hh:mm)	Main perspective
A	Senior test engineer	0:55	Individual
B	Concessions engineer	0:42	Individual
C	Engineer – Dimensional control	0:19	Individual
D	Engineering IS architect	1:00	Individual & Organisational
E	Archivist	0:30	Organisational
F	Technical library manager	0:35	Organisational

Table 5-3 – Details of participants used to build scenarios

The interviews were semi-structured and explored the following topics:

- What their job entails – what are their main activities and how they fit into the organisational structure?
- What types of information they generate and use – how and where is it stored?
- Why are these types of information recorded? How are they used once complete?
- The role of the logbook in that person's job – what they use it for and how they use it? Where does the information come from and how is it subsequently used?

To explore organisational issues - and in particular how the organisation stores and re-uses engineering design information - all participants were questioned about organisational aspects (e.g. whether there was a policy for archiving or retaining logbooks). Further, two interviews with people responsible for maintaining organisational records. The questions covered the following topics:

- What information generated by projects is retained? How is this decided?
- What form does the information take?
- How is it stored and classified?
- How is it used/re-used?

In addition, all participants were questioned about how their role has changed or may change in the future and whether they felt their current practice adequately fulfilled their needs. The full list of initial questions used to structure the interviews is reproduced in Appendix A. The interviews were carried out at the desks of the participants, with access to their logbooks and other relevant artefacts, and were recorded (audio only) for subsequent analysis.

Scenarios may be analysed through a number of methods, including (*adapted from* Carroll, 2000) scanning for causes and effects – e.g. compare 'before and after' scenarios, participatory analysis, systematic questioning or questioning stages of action – for example, with respect to human activities such as problem solving (or in this case logbook use), which provide a framework against which to pose questions. In this case, the stages of action (of logbook use) were questioned, with the framework for questions coming from two perspectives - individual/personal and organisational logbook use, and also an information perspective based on the information lifecycle activities of creating, classifying, browsing/navigating, searching, sharing and collaborating.

5.3 Results

The results from each of the six interviews is now discussed with respect to the framework described above. Each scenario begins with a brief description of the person's role, followed by a description of their current logbook use and any relevant organisational issues. The interviews have been grouped, with the first three more focussed on individual logbook use by engineers and the latter three focussing more on organisational issues.

5.3.1 Scenario A – Senior Test Engineer

This scenario involves a senior test engineer. Their job involves managing a wind tunnel facility – both carrying out experiments and other management activities. This involves reporting findings to various internal stakeholders, as well as liaising with customers and suppliers from outside the company. The results of experiments are communicated in the form of presentations and technical reports. The job involves working at various sites and they are typically involved in several projects at once.

Current Logbook Use

Although working on several projects, one logbook is kept for all of them, as carrying around multiple logbooks was not practical. The logbook is a typical hard-backed A4 book, arranged chronologically. The entries consist of technical information, detailed colour sketches, some written notes and filenames and file paths to test results. Important information elements (such as actions arising from meetings, technical information about, for example, components used in an experimental rig or filenames to test results) are identified by highlighting or other symbols. This aids their retrieval, which is carried out largely by *browsing & navigating* – that is, estimating an approximate date then manually browsing through each logbook page. It is noted that although some information (particularly completed tasks) loses its value once the task has been completed, other information such as filenames and sketches of experimental rig layouts do not, retaining the same potential importance for "*as long as [the engineer is] in that job*". However, in support of the results presented in Chapter 4, past logbooks are not accessed as frequently as the current logbook, because of the difficulty of remembering where it is. The lack of index or contents page means that structured *searching* of entries is not possible. Whilst it was noted that retrieving certain types of visual information such as sketches was easy, locating textual information was more difficult and much more time consuming. In terms of the *cues* used for searching, the most useful were the *project* and *source* of the information (i.e. which company supplied particular components). The project and topic were usually recorded at the beginning of a logbook entry, but not always. The source of the information (i.e. which company supplied the component) was usually listed in a hand-written table, making locating by browsing slightly easier, but still time-consuming for older information.

In terms of the *flow* of information through the logbooks (i.e. where the information comes from and where and how it is subsequently re-used), there are three main sources of information the logbook is used to record from, with four main avenues for re-use. This described below and represented in Figure 5-2. In terms of inputs, the logbook is used to record information from:

1. Experimental rigs, in the form of sketches, hand written notes and calculations, and external technical information.
2. Meetings, in the form of handwritten notes, including tasks and other actions.
3. Collaborative working sessions – usually face-to-face, consisting of handwritten notes, calculations and sketches.

These are then re-used in four ways:

1. Tasks from various meetings are highlighted, serving as a reminder.
2. Meetings notes are transformed into formal, typed meeting minutes and emailed to relevant stakeholders.
3. Technical information, sketches and notes on experimental results are used when preparing presentations and formal reports.
4. Various types of information are used when working collaboratively, commonly for problem solving-type activities. Information is usually shared via email due to the distributed mature of the teams before a telephone call to discuss solutions. Where sketches are needed, they are scanned from the logbook and emailed.

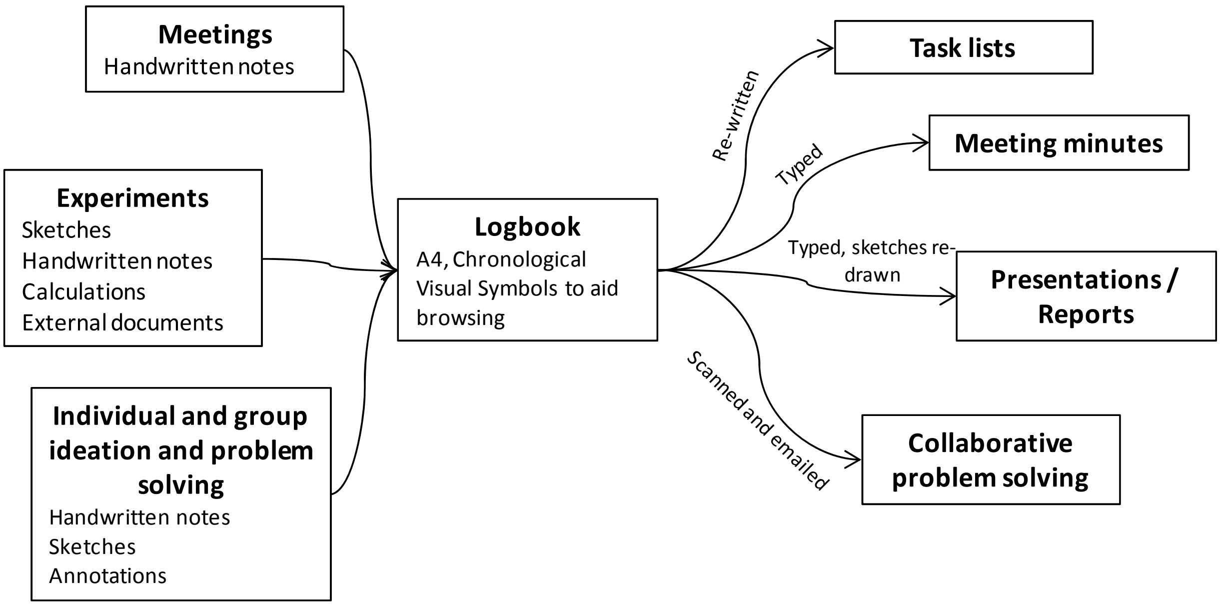


Figure 5-2 – Role of Logbook for Test Engineer

In this scenario the logbook plays a central role between *activities* such as meetings and setting up experiments and the more formal *outputs* such as meeting minutes, presentations and reports. Again, as identified in Chapter 4, the *ideation* (Currano & Leifer, 2009) activities of developing and refining ideas is also evidenced through the use of relatively informal sketches and notes in collaborative problem solving activities. In this case the logbook is used both to record face-to-face collaboration and also to disseminate ideas in the form of sketches for further discussion (albeit in the rather cumbersome way of pages being scanned and emailed to the members of the distributed team).

Group/Organisational Issues

From an organisational perspective, the main issue that became apparent was that despite being an integral part of this engineer's work, the logbook was viewed firmly as a personal resource under their sole control. Whilst it contained only work-related material, the engineer still wanted to retain control over access by having questions directed to them, then answering them by referring to the logbook.

In terms of the formal record, there is both a document management system (arranged by project) and associated paper files. Some engineers submit logbooks to the 'official' file, but this was not policy and most (including this engineer) did not. This was because they were too valuable to be stored somewhere inaccessible and because the engineer believed that the lack of a means of searching and a lack of contextual information would make re-use by others difficult. In this case, it was noted that using the logbook in conjunction with the email records (where most of the collaborative problem solving occurs, often with reference to scanned logbook sketches) could be a solution.

However, the more fundamental issue of *information fragmentation* was clearly evident – there were several formal stores, including paper records, a group DMS, several network locations, an intranet site, wiki and the ubiquitous email system. There were few links between them and this was a source of frustration as it made finding and sharing information harder, requiring frequent transformation to different forms resulting in duplication and unnecessary processing.

Requirements Arising

There were six requirements elicited during the interview:

1. Easier transformation of logbook information into other forms – particularly sketches to be shared electronically with distributed teams, which is currently a time-consuming process of scanning and emailing.
2. Better integration of electronic information and logbooks – the example of being able to include CAD screenshots was used, along with technical data about components from various suppliers and links to test data.
3. Better ways of searching information than relying on memory/browsing – with the project, topic and source of information being the most useful ways of searching.
4. The ability to group certain types of information in more flexible ways – mainly tasks and information on projects which is currently scattered throughout the logbook.
5. More effective ways of working collaboratively on logbook content, but with the option to retain control.
6. More comprehensive links with other sources of information such as DMS and email.

5.3.2 Scenario B – Concessions Engineer

The concessions engineer is responsible for providing support to manufacturing in cases where parts cannot be (or have not been) produced to the specification indicated. For example, a hole may be slightly larger than specification and it is the job of the concessions engineer to authorise a 'concession' – effectively either to allow the change, or produce a solution, such as using a bush to reduce the size of the hole to meet the specification. Several product lines are supported by the engineer, and around 80% of the cases are fairly 'routine' such as oversized holes. The other 20% are more complex and require liaising with various stakeholders such as experts in stress calculations, or materials and processes to produce an acceptable solution. Increasingly, routine concessions are also outsourced to an approved contractor, but it is up to the engineer to gather the required information.

Current Logbook Use

The logbook is again a hard-backed A4 book, arranged chronologically. It is used in conjunction with a camera to record details of the problem on the manufactured part. This takes the form of sketches, measurements and a small amount of written notes. Digital pictures are also taken, and relevant documents such as material data and stress calculations are gathered. This information is used to generate a solution. Again, the logbook may be used to develop ideas, carry out calculations or work through problems with colleagues. The final concession is stored in a document management system via a pro-forma. This details the solution and has attached any supporting information such as pictures. The logbooks in this case were not retained when they were full and in general the engineer believed the usefulness of most of the information was very time-limited. Most concessions are dealt with within a week. This means that that the predominant mode of retrieving information was via memory and browsing, although logbook entries were usually marked with a date or very short description. The engineer did keep information relating to some particularly unusual examples in a personal folder for quick access. This was mostly constructed from the final, formal record, but could contain logbook information – particularly sketches. It was noted that the very informal nature of the notes and the lack of contextual information meant that logbooks records were of limited use to anyone but the original author. The links between, for example, photographs, a logbook entry, associated documentation and the corresponding formal entry in the DMS were largely held in memory.

In terms of information flow, the logbook information came from inspecting and measuring parts being manufactured, and also from talking to relevant specialists, such as stress or materials engineers. The entries were then used, together with photographs and other paper and electronic information to create an entry in the DMS. This is represented in Figure 5-3:

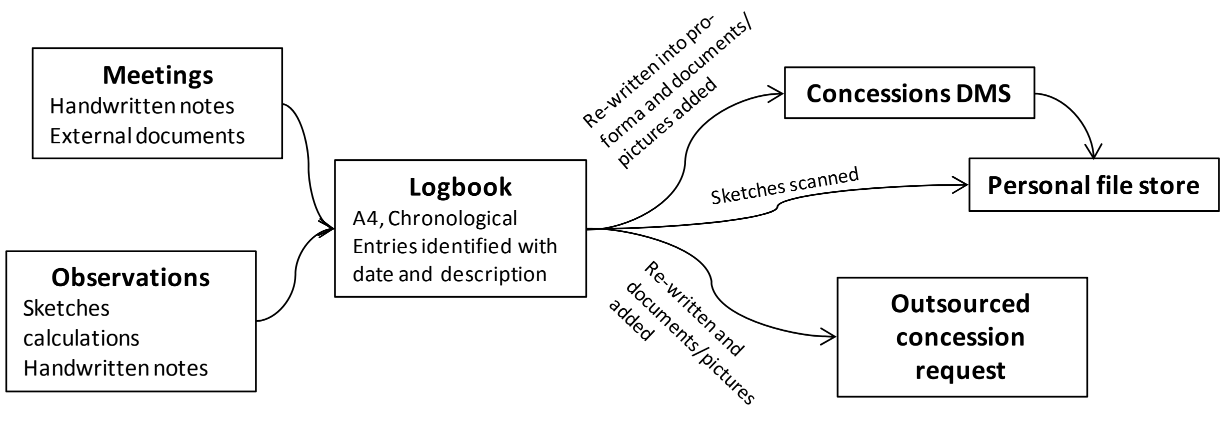


Figure 5-3 – Role of Logbook for Concessions Engineer

It is again evident that the logbook plays an important mediating role between the observations of the manufacturing problem and the final, formal report produced and stored in the DMS. The two main modes of use are also similar – namely undertaking some kind of individual engineering work, and secondly, some kind of collaborative activity – usually taking notes in meetings aimed at solving problems.

Group/Organisational Issues

From an organisational perspective, two factors were evident: The first is that in this case, logbooks are usually discarded once full. In addition, the formal records in the form of an entry in the DMS do not contain all the logbook information, which is used instead as a reference for the individual. For example, the original sketches will be re-drawn, and some measurements or photographs may also not be recorded in the formal record.

This could arguably impact the level of re-use of past solutions and the dissemination of good practice. Arguably because of the limitations of the formal record, the engineer kept their own records of 'special' cases in personal folders. These were based on the formal record, but supplemented by other informal information such as logbooks sketches. These consisted of unique knowledge, but because they reside locally, their wider re-use relies on knowing who to talk to and who is available. If, for example, a member of the team was not available that week, or one was unaware they had previous experience of a specialist concession, this information would be completely unavailable.

Secondly (although related to the first issue) information fragmentation is again evident. In this case, the principle sources of information are from logbooks, photographs and other documents, which are in both paper and electronic form. These are often communicated via email. Because of the time-critical nature of many of the concessions, it is considered too time consuming to, for example, print pictures for including in logbook entries, or reference external sources of information. This means there is a general lack of contextual links between information sources, with the engineer relying on memory to maintain links between, for example, a logbook sketch and a photograph of the part sketched. Together with the relatively informal nature of logbook entries, this makes re-use by anyone but the original author problematic, and, for anyone outside the small concessions team, almost impossible.

Requirements Arising

The requirements elicited during the interview were in four areas:

1. Better integration between various types of paper/electronic sources – specifically between logbook entries, photographs and other paper and electronic documents.
2. There was also a need for easier sharing of logbook and other paper-based information between distributed teams, particularly as some concessions were now outsourced.
3. There was less need in this case for more structured ways of locating existing logbook information for the individual author, due to the short timescales over which each concession was active. However, because of the dissatisfaction expressed with re-finding past concessions, it was suggested that by allowing access to logbooks and other informal

records, the dependency of accessing information through "*knowing who to talk to*" could be reduced.

4. Finally, because details are often gathered from the manufacturing facilities, a need for portability and a reasonable level of ruggedness of the logbook was considered essential.

In terms of how the job was anticipated to change in the future, new products contain a much higher proportion of composite components that cannot be re-worked in traditional ways, meaning the number of traditional concessions would reduce. This means that there would be a greater number of concessions that would involve machine control issues. Whilst the engineer felt that this would make the job more desk-bound, information from a wider number of sources would be required. It was also felt that the amount and complexity of work outsourced could increase, meaning there was an increasing need to share information such as sketches electronically.

5.3.3 Scenario C – Dimensional Management Engineer

Dimensional management involves liaising with both design and manufacturing functions in order to optimise Design for Manufacture (DfM). This requires an understanding of how the use of tolerances impact upon, for example, stress constraints and manufacturability. The aim is to make the manufacture more efficient and faster, and to reduce concessions (where there is a problem manufacturing to specification). In a similar fashion to the Concessions Engineer described in 5.3.2, their work consists of numerous, often quite short, projects.

Current Logbook Use

Somewhat unusually, in this case two artefacts that could be considered to be logbooks were evident. Firstly, a small A5 notebook is used to record meeting notes, sketch concepts and record ideas or tasks. However, unlike the previous engineers, the contents of the logbook are almost always immediately formalised – either into electronic meeting notes or drawings, presentations and reports. The engineer is sure all information from the logbook is transferred in this way. Once this has been done, the handwritten logbook is not referred to again and they are discarded once full. The entries are typically very brief aide memoirs with little or no metadata. Meetings may have a date or title, but other entries are simply started on a new page. The second logbook consists of a collection of external documents, such as reports, presentations and emails and represents a record of the finished project. It is essentially a collection of printed electronic files that are centrally stored, but arranged in a particular order. It is arranged by project and has a comprehensive contents page with a short description of each project.

This logbook is maintained as both a record for professional development (and is 'signed-off' by their manager each month) and also as a quick reference of projects for re-use. The re-use consists of both re-visiting past projects when, for example, a design is updated to check whether it needs to be modified, and also when similar issues are encountered in a new project. Whereas the handwritten logbook is accessed on a daily basis, the collection of external documents is accessed several times per month. Whilst the contents are duplicated in an electronic form, the paper version is easier and quicker to access, and links between documents easier to maintain. This flow is represented in Figure 5-4:

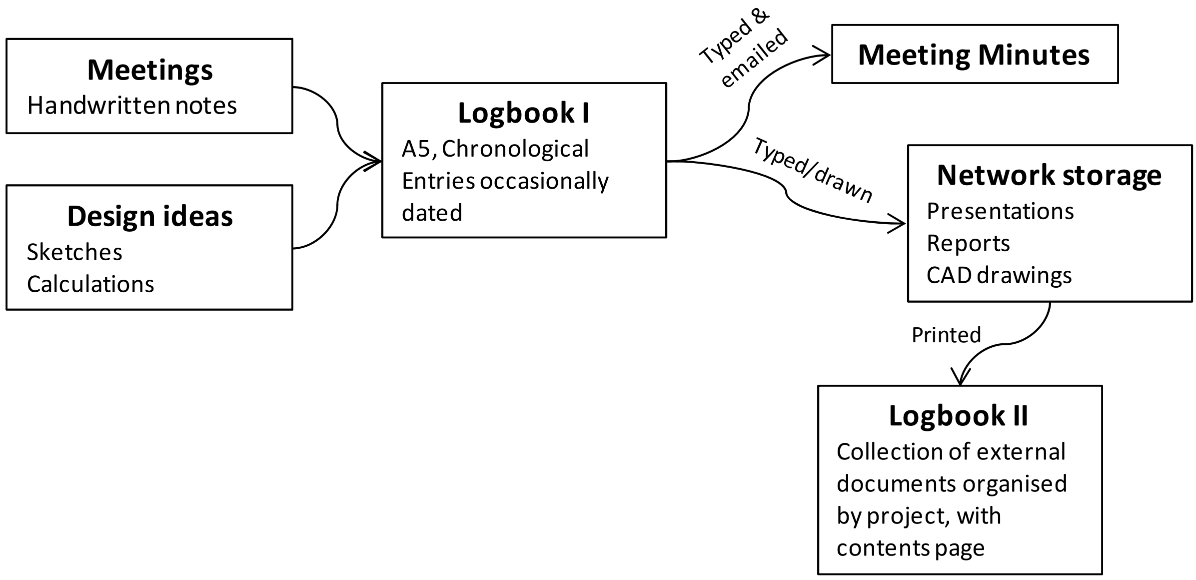


Figure 5-4 – Role of Logbook for Dimensional Control Engineer

Group/Organisational Issues

Whilst the first handwritten notebook was judged by the engineer to be of very limited use to the group/organisation, they felt that the second logbook was a comprehensive account of the projects, including rationale for decisions etc. This is because in this case, the final reports went through a comprehensive validation procedure and were very detailed. The addition of a contents page with descriptions also meant that the engineer felt colleagues would have little difficulty accessing the information in his absence. In a similar fashion to the previous scenarios, the links between the paper-based notes and records and their electronic counterparts were largely held in memory, with no clues in the second logbook as to whether the information was the most recent, or where one might find the electronic file.

Requirements Arising

The engineer felt that their current note-taking practice worked reasonably well and because of their very short useful life-span, did not feel a more structured approach to their written notes was necessary. However, they felt that it would be better to maintain a single, electronic record. This was not done because the paper logbook afforded very quick access and, crucially, easy links between files that were hard to maintain on the central networked storage. The requirement was therefore expressed as being able to keep a single, easily accessible electronic version that could maintain links between files and have some type of 'contents page'.

Their second (perhaps more fundamental) comment on how the current situation could be improved was to have more consistency between individuals' logbook practices. For example, while they were confident that the collection of external documents with a contents page formed a useful record, they had not received any training or formal guidance and felt practices varied widely, making sharing more difficult. The desire was therefore for consistent guidelines for keeping personal records.

5.3.4 Scenario D – Engineering IS architect

Although their background was in engineering, this person is responsible for investigating and deploying new IT services in support of various engineering functions. They are typically involved in several longer-term projects (in this case the development and deployment of Wiki technology) as well as shorter-term tasks. The wider team is transnational and they communicate regularly via twice-monthly telephone meetings and less frequent face-to-face 'review' meetings.

Current Logbook Use

In a similar fashion to the dimensional management engineer described in 5.3.3, two artefacts that could be described as logbooks are used. The first was the common, handwritten A4 paper-based book. This was described as "80% a *cache memory"*. It was used to record meetings and actions, individual problem solving activities that usually involved sketches and diagrams and also collaborative communication and problem solving sessions, where the logbook would be used for two participants to discuss ideas through sketching. In terms of re-use, the short-term nature of many of the projects (often two to three weeks) meant that the content of the entries was often used to write emails, or as the basis of presentations. Important actions arising from meetings were handled slightly differently, being collated and re-written at the back of the logbook as a 'quick reference'. This, together with the very unstructured nature of the notes (no index or contents page, some dates and titles for meetings) meant that again the predominant mode of re-finding information was via memory and browsing pages. Some entries were identified as very important and did get referred to multiple times over longer periods. The low number of such pages meant that they could be easily identified with visual symbols such as highlights or a bookmark.

The second type of logbook, in response to the limitations of their paper-based logbook, was a laptop computer used together with the mind-mapping software, MindManager™. This was described as an e-logbook and was used for two specific scenarios: Firstly, it was used to take notes during formal review meetings. A 'pro-forma' was created with agenda points and then populated by typing into it directly during the meeting. Secondly, it was used during a conference to record notes from presentations. The reasons cited for taking notes in this way were twofold. Firstly, the flexible structure of the MindManager software made it easier to group things that were not presented in a linear fashion. For example, the participant commented that people speaking often jumped around topics, not presenting points in a linear fashion. In a similar way, notes could easily be re-arranged after the event, which is not possible on paper. Secondly, it was easier to transform the electronic content into other forms, such as emails and presentations without having to re-type it from hand-written notes. The relationship between these two logbooks is shown in Figure 5-5:

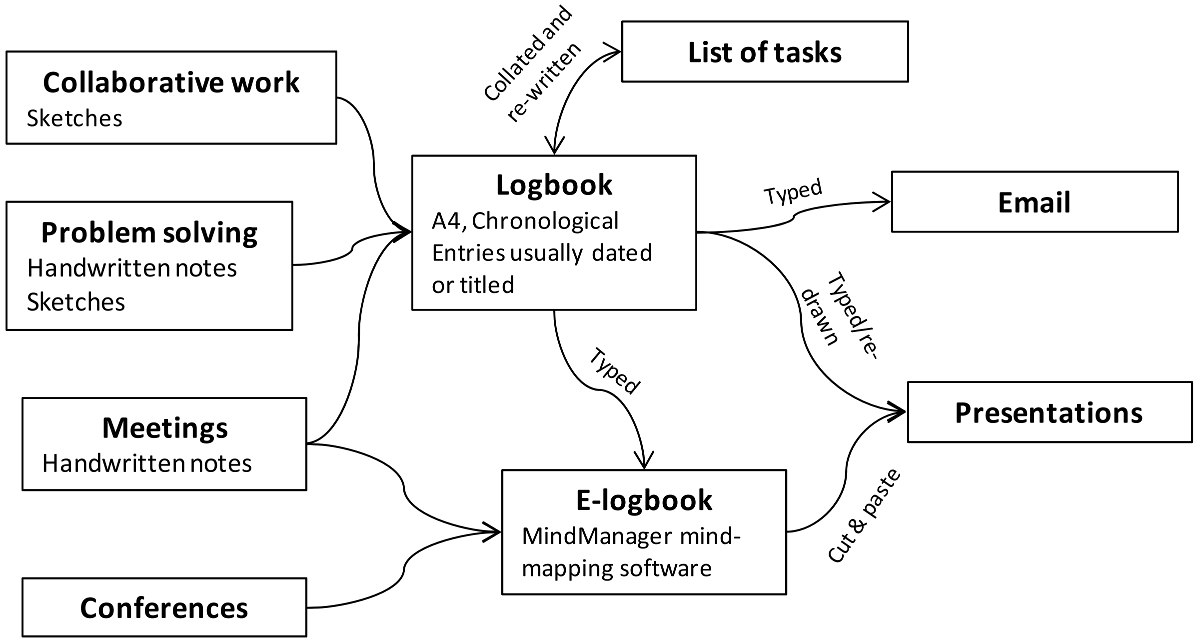


Figure 5-5 – Role of Logbook for Engineering IS Architect

Yet again, it can be seen that despite the use two types of what could be categorised as logbooks, the mode of use in both cases is similar, acting as a temporary store between very informal information (often verbal information or internal thought processes) and the formal record.

Group/Organisational Issues

From an organisational perspective, even though long-term re-use was very rare, the logbooks were all retained. This was because although they were "*not a knowledge base",* the participant viewed them as evidence of work for professional qualifications, as a legal record and "*not doing any harm, so why get rid of them?"* However, like the previous scenarios, the lack of contextual information in the logbook entries (both handwritten and MindManager software) means that the potential for re-use is limited. For example, it was remarked that the value of the collaborative problem solving or idea generation sessions in the form of sketches was the process, not the actual sketch itself, which meant little on its own, even to them. It was also noted that the lack of users of MindManager™ meant that sharing of notes in their 'native' form was not possible, although their electronic format made sharing via, for example pasting into emails and presentations much easier. In terms of links between the informal logbook content and the resulting more formal records, links were again not explicit, existing solely in the memory of the participant.

In terms of other organisational issues, the participant was responsible for investigating and implementing new computing technologies. The current focus of their work was on wiki's, which were being widely deployed in a variety of forms to aid collaborative work. It was noted that uptake of this new technology has depended on customising the Wiki to individual business units' requirements. It was also noted that there has been a general move to more electronic sources, with information such as that found in, for example, newsletters. now distributed electronically.

Requirements Arising

A number of requirements covering both individual and organisational aspects were expressed:

1. Sketching and free-form entry were essential for problem solving.
2. Screen quality and resolution for sketches was important. Inadequate electronic replacements for sketching was the main reason why paper a logbooks was still used.
3. Easier transformation into electronic form for formalisation and sharing – indeed, this was the main motivation for using MindManager™ alongside a conventional paper e-logbook. One suggestion was to 'label' content to aid re-use. The example of labelling actions in meetings was given.
4. It was further suggested that this labelling of content could also allow dynamic re-arrangement of content to, for example, automatically collate actions from meetings, which is currently done manually. It was noted that this would also replicate what is possible with MindManager -i.e. easy spatial re-arrangement of notes.
5. Their experience from the current projects indicated that a very clear and quick payback for additional effort during note-taking was essential for adoption within the company.
6. The separation of personal information (shopping lists, for example) was expressed as being essential, as was having control over the circumstances of disclosure (i.e. who can see the notes).
7. Finally, it was noted that one shortcoming of MindManager was its low usage within the company. A desire for a 'common' universal solution was therefore viewed as necessary to achieve the full benefit.

5.3.5 Scenario E – Archivist

Although personal logbook use is covered in this case, the main focus of the interview was the organisational issues surrounding archiving, and particularly the archiving and storage of logbook material, both currently and in the future. This person is responsible for managing the archives of technical material, such as formal reports, calculations, presentations, specifications, approval documents etc. and also less formal information such as logbooks. Their daily work consists of meeting internal customers to discuss archiving requirements, dealing with new material submitted to the archive and developing and ensuring compliance with, for example, retention periods and other future archiving standards.

Current Logbook Use

Their personal logbook is in the form of an A4 hand-written diary. They used previously used a plain logbook, but found the page-per-day diary helped them locate entries faster and suited their working style, focussed around daily task lists. The portability and speed of creation was noted as a valuable feature of the logbook, with the archivist commenting that they often used it when they had *"five minutes spare before a meeting...to writes notes to remind me of things that need doing".* The logbook is used to record a daily task list, meeting minutes and actions arising from those meetings. Entries had a date by virtue of the page it was written on, and usually a brief description.

The notes and tasks were re-found by recalling an approximate date and then browsing pages. Whilst it was noted that this worked well for entries up to a few weeks old, it was harder and more time consuming to retrieve older entries. Past logbooks were retained, but referred to infrequently.

In terms of how the information was re-used, the meeting notes were sometimes used to create formal meeting minutes, which were then shared via email. Meeting notes were also accessed to either remind the participant of something, or in response to a question (e.g. from a customer clarifying a point or action raised in a previous meeting). When tasks were completed, they were 'crossed off' the list. Uncompleted daily tasks were frequently 'carried over' to a new day by re-writing them. Tasks and actions were also transferred to an electronic form in Microsoft Outlook™ by re-typing them. This was usually done for important or longer-term objectives. The content of the logbook was completely work-related and as such the participant would readily share logbook content if necessary. This is illustrated in Figure 5-6:

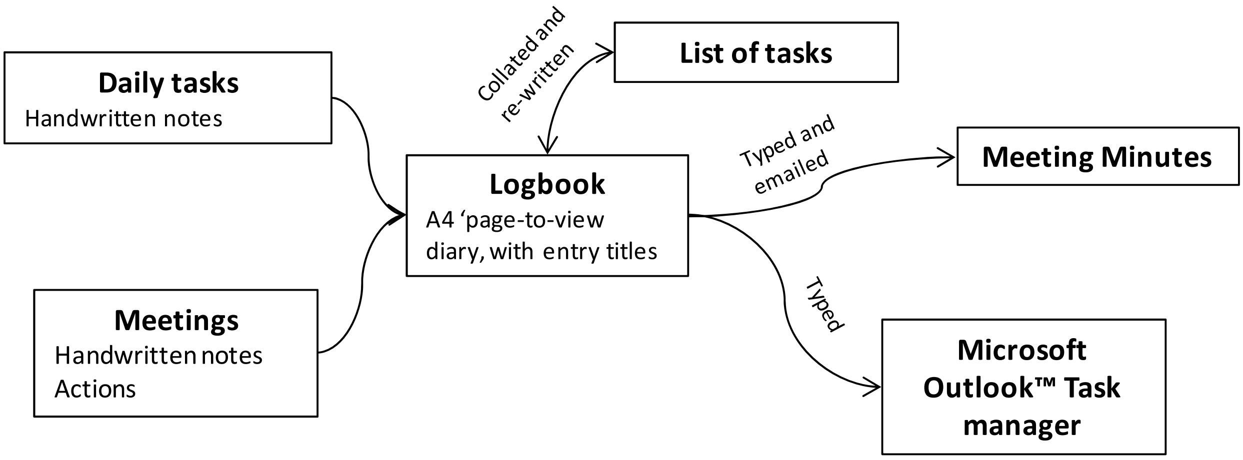


Figure 5-6 – Role of Logbook for Archivist

Whilst the personal logbook use of this participant is interesting insofar as it is very similar to the practices of the engineering scenarios presented in previous sections (c.f. the role of the logbook in acting as a task-manager and as an intermediate store between verbal exchanges in meetings and the formal minutes of the meeting), the main focus of this interview was on the organisational issues surrounding the current and future role of logbooks as an organisational resource accessed through the archives, discussed below.

Group/Organisational Issues

In terms of current practice, the archives of this company site alone contains in the region of 1.3 Million documents, organised by department and product type. There are estimated to be many more millions held at other sites. Any type of document with technical content is retained. Submission of documents is generally the responsibility of each department. There is an official document retention policy, which for most types of information with technical content (including logbooks) is for the life of the product to which they refer plus 99 years.

Logbooks are currently submitted to the archive, although it is the responsibility of the individual to include logbooks in the archived material. There are thus comparatively very few logbooks compared to other sources of information, and "*the few that we have, have never been looked at*".

More recently, in response to increasing numbers of documents, there is also an off-site archive, in which material is held chronologically in numbered sections, with a comprehensive searchable index. The index is created by scanning all paper-based documents and using optical character recognition (OCR) to allow keyword searching. Logbooks are also included in this archive. They are converted into an electronic form, and are associated with the more formal material insomuch as they are archived in the same physical location. However, they have to be added manually to the searchable index as OCR cannot be used. This means they are also less searchable than other more formal information. It was commented that the logbooks may not always be useful on their own, but together with the other material may have some use, especially in a legal context, where *"they want to know who was responsible for a decision, and logbooks could tell them that"*.

In what format material is archived was also raised as a concern and some archived material has become inaccessible because of changing file formats and obsolete equipment. Current material is stored in relatively open formats including the near ubiquitous image formats of TIFF and JPEG. Their curation policy is to migrate data to newer storage formats as they emerge, as well as trying to archive the technology required to read some formats. They are also exploring the use of the archival standard of Adobe's Acrobat™ portable document format, termed PDF-A for future use and have an ongoing project exploring how to archive the large amounts of raw data produced by, for example, finite element analysis software and also the various digital mock-ups (DMU's) created at various stages of the design process. How these various aspects can be connected is not yet clear, although it is their intention that re-use of archive material can be made much more widespread by making searchable, integrated digital records available directly to engineers via their computers 'on demand'.

Requirements Arising

In terms of individual logbook use, the requirements elicited included a logbook of at least A4 size, with portability and quick recoding of notes important affordances. There was also a desire expressed for a more effective way of tracking tasks, especially over longer time-scales, where using memory and browsing pages becomes ineffective. There was also a wish expressed for more training in personal information management, as they felt although they "*managed"* with the existing tools, there was "*a better way of doing things"* of which they were not aware.

Organisational requirements were aimed at more effective integration of logbook material into the archive, to support the future vision of making available integrated, searchable archive material 'on demand': Firstly, a requirement for current training material to be expanded to include record-keeping. Currently, such training does exist, but is limited to topics such as standard templates for reports and document validation procedures. Related to this was the desire to see more consistency across such informal records, to make them quicker and easier to archive. It was also commented that keeping logbooks electronically could encourage submission of such records to the archive, as well as making indexing, cataloguing and integration with other sources easier. The lower cost of digital storage was also mentioned as a benefit of electronic records, although the requirement for open file formats and continued management or curation of the archive was emphasised.

5.3.6 Scenario F – Technical Library Manager

The final scenario also deals predominantly with organisational issues and was intended to complement the scenario presented in 5.3.5. Again, although current individual logbook use is covered, the main objective of this scenario was to understand how the organisation deals with current information access, and how this may change in the future. Their role is to manage the technical library, which involves dealing with requests for both printed material such as journals and product-related electronic resources, as well as developing strategy for more effective use of such information.

Current Logbook Use

In common with the other scenarios and previous results, the main mechanism for managing personal, informal information was an A4 handwritten book, arranged chronologically. It was used predominantly to record notes during meetings and actions, as a reminder. Notes and actions were re-found by relying on memory and browsing, with most entries having a date and title. Some notes were then communicated to the immediate library team verbally. Whilst all logbooks were retained, they were only referred to very infrequently, usually for a particular name or telephone number in response to a request. This is illustrated in Figure 5-7:

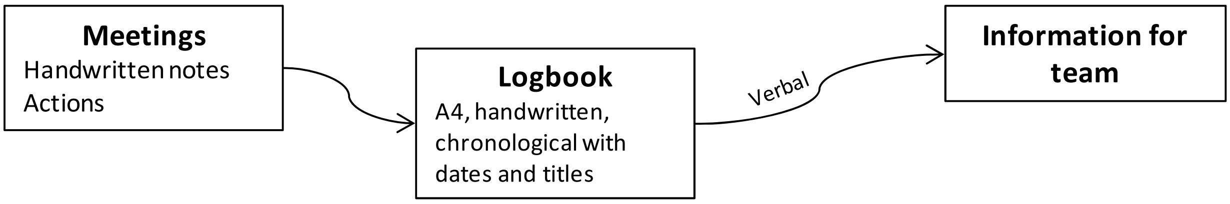


Figure 5-7 – Role of Logbook for Technical Library Manager

Group/Organisational Issues

In terms of future information storage and retrieval from the perspective of the organisation, there were two strong trends, which echo those found in the previous scenario discussing the archivist. The first was the gradual move to electronic sources, with the comment that the Internet in-particular "*has changed the way that we work*". Although the library still issues significant numbers of books and journals, other technical publications are accessed almost exclusively online. The second (related) trend was a pressure to reduce the cost of providing such material, which was being partly met by integrating and centralising the acquisition and storage of such sources at a transnational level and across a group of companies. This has only been made possible by moving to electronic sources.

Requirements Arising

In terms of individual logbook use, the very simple requirement for recording and disseminating meeting notes was met well by the paper logbook. No desire for more sophisticated search technology, or electronic formats was expressed, as was the case in previous scenarios. It was commented that the main requirement for personal note-taking was portability and ease/speed of use. From an organisational perspective, the requirements evident from these trends were similar to those expressed by the archivist, namely more widely available information, delivered 'on demand' to engineers, in an integrated, electronic format.

5.4 Discussion

This section discusses the main findings from the two studies presented in this chapter, and summarises the key requirements arising from both the individual and organisational perspectives.

5.4.1 Logbook Use in Context

Firstly, in terms of the role of logbooks in the wider personal information space, Section 5.1 explored the *form, structure* and *pointers* that existed in the personal information collections of six researchers, all with an engineering background. Of the 24 types of personal information identified, it was found that logbooks were amongst the most widely used stores and have the greatest number of pointers to and from other types of personal information. For example, an engineer would record in their logbook the file paths to CAD models, or paste a print-out of results in their logbook to annotate it, or that they would record messages on Post-it™ notes before transferring these to another store such as their diary, with one complementing the other. Whilst it was noted in Chapter 2 this use of multiple sources may hold benefits such as providing enhanced redundancy (Whittaker & Hirschberg, 2001), it can also cause *information fragmentation* (Jones & Thomas, 2007), making information harder to find and re-use.

The other feature of the personal information collections explored were their low levels of structure and organisation, and especially contextual information such as dates, subjects, the name of the author, their purpose etc. This, together with the almost complete lack of indexing of logbooks revealed in Chapter 4 means there is little scope for any structured searching. Arguably, this relative lack of structure, organisation and context was the reason why the capacity for re-use of most of the sources (including logbooks) was judged to be limited, especially by people other than the original author.

The second part of this chapter expanded the investigation of logbooks in the context of engineering work. Six interviews were carried out with practicing engineers and other colleagues in a large engineering organisation. In terms of logbook use, similar trends to those found in both Section 5.1 and also the logbook use survey presented in Chapter 4 were evident: For example, all the participants questioned used a logbook, most typically a handwritten book, arranged in a chronological format. Similar levels of structure, organisation and context also existed, with five of the six participants indicating that re-use by other people would be very limited. Similar reasons (such as being a reminder of work in progress) were cited, and memory and browsing was the predominant mode of re-finding information in all cases.

The other main feature of logbooks that is evident in both the studies is their role not just in ideation, communication and documentation (identified by Currano & Leifer, 2009 and discussed in Chapter 4), but also in collating various types of formal and informal information, before it is transformed into other (more formal) types such as reports. This is referred to here as the role of *mediating* between various types of activity and information types. Whilst information management strategies varied considerably with the complexity of the person's role, the logbooks of all six participants in the second study described their logbook use in a similar manner, commonly being used to collect and collate information from various sources, before being transferred out, typically as more formal, structured documents.

Whilst the concept of the mediation role exists on a somewhat different level than the three roles identified by Currano & Leifer (2009), it does provide a useful additional perspective from which to understand logbook use as part of a wider workflow. This perspective therefore has important implications for the requirements that must be supported for any future logbook to be successful, not all of which would be evident from considering logbook use in isolation. The requirements arising from these two studies are now summarised with respect to the individual and the wider organisation, across the information lifecycle.

5.4.2 Individual Requirements

In terms of creation, all the participants questioned valued their paper logbook as a quick, easy and portable way of recoding entries. The concessions engineer (5.3.2) noted that the nature of the manufacturing environment meant that a degree of ruggedness was required of the logbook. One of the main affordances of paper appeared to be its flexibility, with many types of information being recorded. These included sketches, calculations, handwritten notes, contact details and various types of documents such as printed emails and test results. There is therefore a corresponding requirement to allow the recording of these types of information. In particular, the ability to sketch in a free-form manner was considered an essential requirement by all the engineers. The ability to collate various types of external document is also essential to support the important role of logbooks in mediating between informal and formal information, as discussed in 5.4.1.

Browsing and navigating entries was the predominant mode of re-finding information. Whilst it was argued that the relative lack of structure and organisation means the options for more systematic searching of logbook material was not possible, the very short-term nature of much of the work undertaken by the engineers meant that 'browsing' was an effective strategy to support much of their day-to-day work.

Despite browsing entries being the predominant form of re-finding, some engineers interviewed expressed a desire for a more effective search capability, to support the occasions where older information was required. Information cited as hard to find via browsing was older information in past logbooks, usually very specific pieces of information such as information on past experimental rigs, the supplier of certain components, or contact details. There was therefore a requirement for more effective searching for these types of information. Three participants elaborated on how they would like be able to search their logbooks. One wanted to be able to 'label' pieces of information specifically actions) that they knew were important or were likely to be needed again. The other two wanted to be able to search logbooks using various criteria - by project, topic or source of information (e.g. supplier of a component) in the case of the test engineer, and by topics.

In terms of re-use and sharing, it was clear that in most cases, a significant proportion of logbook material is translated into other forms, both within the logbook and into more formal representations such as meeting minutes, presentations and reports. Several participants also expressed a need to be able to collate various types of logbook information (and in particularly actions), that were currently distributed throughout the logbook. For example, the engineering IS architect used their logbook to record actions from various meetings, but periodically had to collate and rewrite this list. Two other participants performed a similar action, collating tasks either within the logbook, or as a separate list. This was partly a consequence of keeping one logbook for all projects and types of information, but also because paper did not allow any type of re-arrangement. Indeed, this was the main motivation for one of the participants to use mind-mapping software as a logbook (Section 5.3.4).

The other commonly encountered frustration with paper-based logbooks was the difficulty in transforming logbook information into other forms, for both re-use in formal electronic documents such as presentations and reports, but also in sharing information to facilitate problem solving in distributed teams, in which most of the engineers worked. Again, easier and quicker transformation of meeting notes into more formal minutes was cited in 5.3.4 as a reason for using an electronic logbook, and the test and concessions engineers both expressed a need for an easier way of sharing sketches and other unstructured information with distributed team members. Three participants also expressed a desire for more consistent note-taking practices and training across the company.

5.4.3 Group/Organisational Requirements

The requirements arising from an organisational perspective centred mainly on the need to adapt to several future trends in the wider organisational information management space. For example, in terms of current practice, there was some concern that very few logbooks were submitted to the archive, despite the archivist finding that the ones that were often contained technical information recognised as useful both in terms of content for re-use and also as a legal record.

The scenarios also revealed that the links between informal logbook information and its formal counterpart was usually implicit or held in the memory of the author – that is, it would be very difficult for anyone but the original author to relate formal information such as a report to the logbook entry from which it was created. The logbooks that are submitted to the archive are loosely associated with the formal record, but significant manual effort would still be required to understand the link - whilst the paper logbooks are digitised, their hand-written content cannot be made computer tractable and is hence not easily searchable. Further, the participants questioned from an organisational records perspective all identified strong future trends towards increasing use of electronic sources of information, stored in an integrated manner and searchable 'on-demand' by engineers. The clear implication is that future logbooks require more explicit links to other types of record, to ensure better compliance with legal requirements, reduce information fragmentation and enhance their potential for re-use. Related to this, several participants indicated a desire for more guidelines/training, with none of those questioned having any formal training in personal information management or record-keeping.

Finally, privacy issues were raised by several participants, who, whilst logbook entries were almost always work related, did wish to retain control of the logbook and its content. They were still viewed very much as a personal store and there is a clear requirement to balance the needs of the organisation in terms of record keeping obligations with this view of logbooks as a personal resource.

5.5 Concluding Remarks

This chapter has presented two related studies aimed at setting logbook use in a wider personal information management and organisational context. The first study consisted of identifying the range of personal information stores and - using the framework suggested by Bruce (2005), characterising the form, structure and pointers between them. 24 types of personal information store were identified, with the most commonly used being logbooks, email, diaries and address books. Of those, logbooks had the most pointers (links) with other personal information types. It was also found that almost all the sources had low levels of structure, organisation and contextual information, making their re-use by anyone but the original author problematic.

Building on the results of this study, the role of the logbook as part of a wider workflow in a large engineering organisation was then explored through six semi-structured interviews with practicing engineers. The interviews were used to create scenarios describing in detail current logbook use from both personal and organisational perspective. These scenarios revealed that while the job roles of those interviewed varied significantly, logbooks were used in surprisingly similar ways in most cases.

They key finding from the perspective of logbook requirements was that logbooks currently fulfil not only previously identified roles of ideation, communication and documentation, but also ***mediation*** between various types of work and informal and formal source of information. It is argued that viewing existing logbook use in the wider context of the work they are used to undertake is essential for the success of any future e-logbook.

Finally, it must be noted that whilst the two studies presented in this chapter are accurate representations of the information management of the engineers interviewed and present a detailed account of logbook use in context, the relatively small sample size means that the types of information recorded in logbooks and their level of structure and organisation, has been gathered from interview, not quantitative studies of complete logbooks. To address this, the next chapter presents a comprehensive quantitative analysis of actual engineering logbook content, structure and organisation.

6 Logbook Content, Structure and Organisation

Both the survey (Chapter 4) and studies of logbook use in context (Chapter 5) have provided a detailed picture of how logbooks are used and a good indication of the types of information they contain and the roles they fulfil. This chapter explores in a more detailed and quantitative manner the information types contained in existing paper-based engineering logbooks, and then assess how they are structured and organised. This will be achieved through a detailed analysis of a number of actual engineering logbooks.

First, the details of the logbooks sampled, the methodology and the unit of analysis selected are discussed. The results of the analysis in terms of the information types found, quantities and breakdown by the job role of the author is then presented in Section 6.2, before an assessment of the structure and organisation, including an analysis of the metadata used to identify the logbook entries is carried out (6.3). The results are then discussed in detail and implications for the design of future e-logbooks are elicited in Section 6.4, before conclusions are drawn in 6.5.

6.1 Sample and Methodology

26 engineering logbooks were obtained from a range of engineers working as researchers and in various types of engineering industry. Sixteen were provided from the same group as the Chapter 4 survey respondents, six from the set of documentation used for the comparison of formal and informal information (described in Chapter 7) and a further four were obtained from engineers working in the sponsoring company. For clarity, various terms used in this work are now defined below. For the purpose of this study an 'entry' in a logbook is defined by two dates or a date and a terminator. A terminator could be a ruled line or an empty portion of a page. In practice, entries were clearly defined with little room for misinterpretation. Full definitions of the other terms used are given in Table 6-1:

Term	Definition
Logbook Entry	An entry in a logbook, which may consist of a number of information types, started by a date or title etc. and terminated by a ruled line, empty space or start of a new entry.
Information Type	Specific forms of information: examples include note, 2D sketch, calculation, pie chart etc – any type of information that could be identified for later grouping into classes (see below)
Class	A group of particular information types. For example, photographs, CAD drawings, brochures etc. have been grouped into the class 'External documents'
Occurrence	The number of times a particular class is present in a logbook, expressed as a percentage of total information content
Amount	The proportion of a logbook represented by a class of information, expressed as a percentage of the total number of pages.

Table 6-1 – Definitions of terms used

6.1.1 Information Content

The types of information were first determined by recording as many different types of information as possible in the logbook sample. These were then grouped into 'classes' of information, before two different methods for recording the information content in detail were compared and the most appropriate method selected. The full sample of logbooks was then analysed for the occurrence of the information classes, and the results analysed with respect to the author's job role.

6.1.2 Structure and Organisation

The 13 information classes produced for the analysis of the content was re-used as a framework with which to characterise the structure. This characterisation of structure involved identifying the metadata associated with each information class. These items of metadata included, for example, titles, dates and locations and are termed 'identifiers' for this research. These were almost always located in the heading for an entry (for example, entries often have a title and date), or by a specific class of information (for example, the source of an external document or title of a sketch). An example of an actual logbook entry and its associated identifiers are shown in Figure 6-1:

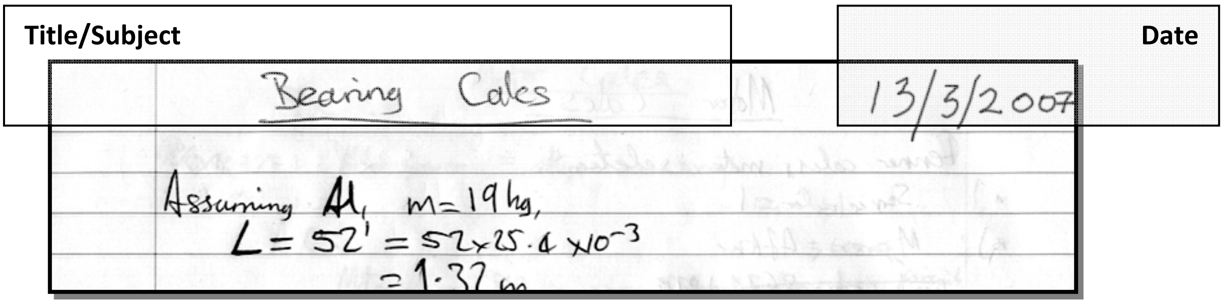


Figure 6-1 – Example of identifiers

To characterise how engineering logbooks are organised, three aspects were explored: the relative order and sequence of entries, the cross referencing of related entries, and the partitioning of entries. These findings were then used as the basis for characterising a number of common approaches for organising the entries of the logbook and helped to identify the limitations of current paper-based logbooks.

The methodology employed for the two aspects of this study (the analysis of content and the assessment of structure and organisation) is summarised in Figure 6-2:

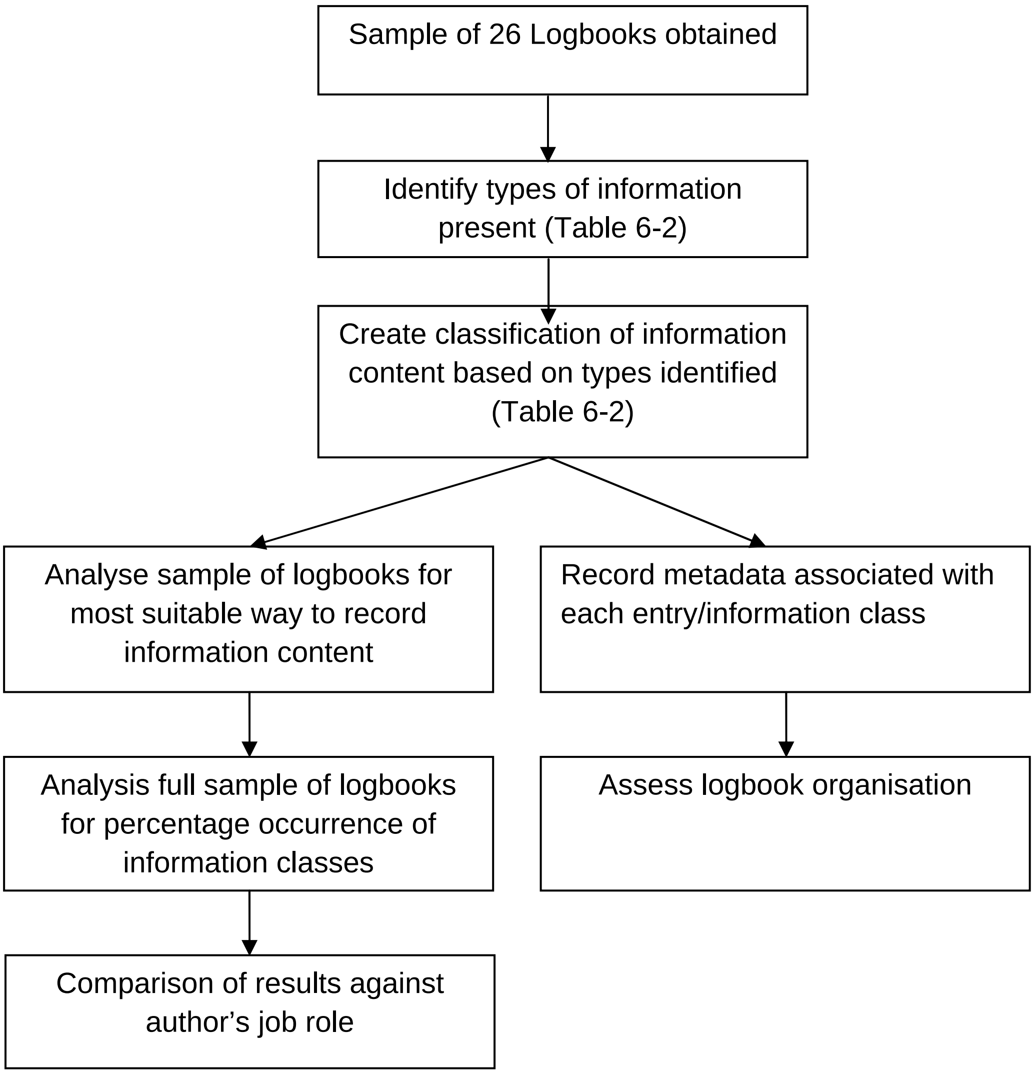


Figure 6-2 – Summary of methodology

6.2 Analysis of Information Content

The initial list of information representations from the sample of 26 logbooks revealed 29 separate types. From these information types, thirteen fundamental classes emerged through a process of combining related types in a brainstorming session. The 29 types and resulting 13 classes are defined in Table 6-2, below. The 13 classes have also been grouped according to two fundamental information formats – textual (6), graphical (3) or a combination of both (4):

Format	Class	Description	Types
Textual	**Written Notes**	Personal notes made by the engineer in an individual or collaborative work session.	*Writing* *Computer Code*
Textual	**Meeting Notes**	Notes taken as a result of a meeting	*Meeting Notes*
Textual	**Contact Details**	Names, phone numbers and email addresses etc	*Contact Details*
Textual	**Calculations**	Hand calculations, from simple to complex	*Simple Numerical* *Matrices*
Textual	**Tables of Figures**	Hand drawn	*Tables of Figures*
Textual	**Completed Forms**	Usually completed by service engineer on-site	*Completed Forms*
Graphical	**Sketches**	Hand drawn, from pencil scribbles to 3D representations with colour	*Simple line (2D)* *3 Dimensional* *(above) + Colour* *Diagrams/Mindmaps*
Graphical	**Graphs/Charts**	Hand drawn	*Line Graphs* *Scatter Graphs* *Pie Chart, Gantt Chart*
Graphical	**CAD Drawings**	Printed and pasted into the logbook	*CAD Drawings*
Text & Graphical	**External Documents**	Sections from reports, product info, photos etc, pasted into the logbook	*Product Brochure* *Printed Tables of Figures* *Graphs/Charts* *Data Sheets* *Photographs* *Drawings* *Sections of Formal Reports*
Text & Graphical	**Annotated External**	As above, but altered or marked up by hand	*As External Documents*
Text & Graphical	**Annotated CAD**	As CAD Drawings, but altered or marked up by hand	*Annotated CAD Drawings*
Text & Graphical	**Memorandums**	Added information in the form of 'post-its', 'sticky notes' or symbols in order to highlight important information or elements to keep in memory.	*Memorandums*

Table 6-2 – Types and resulting classes of information

CAD drawings have been identified separately from other external documents due their relatively large number and special importance in the context of engineering design. Annotated documents were also defined separately as these annotations are an important part of the information selection process for designers.

6.2.1 Comparison of Metrics for Analysis

The second step was to determine the most appropriate way to measure the occurrence of these information classes. Therefore, prior to analysing the information content of the 26 logbooks in detail, the first 16 logbooks were analysed for both the occurrence (how many) and amount (how much space they occupy) of information classes in order to determine the most suitable measure. This preliminary analysis revealed that a significant proportion of the most frequently occurring information classes also represented the greatest proportion of the total amount of information. Although for some classes of information there was not such a direct correlation, the relationship was not worse than 2:1 (for example, 32% of occurrences and only 17% of amount). During this analysis it was observed that some logbooks contain a large number of blank pages. These blank pages can constitute a significant proportion of the logbook (up to nearly 50% in some logbooks, with an average of 23.2%). A summary of the result is shown in Table 6-3:

	% by occurrence	**% by amount (page volume)**
Most common class	47.0	45.2
Two most common classes	74.2	72.4
Two least common classes	5.6	3.8

Table 6-3 – Comparison of criteria used to present results

Whilst both metrics provide a useful description of information content, it was felt that occurrence was the most suitable measure as it is independent of the length of entries and amount of blank pages and thus the results are less likely to skewed by an individual's information recording style. Consequently, the number of occurrences of an information class was selected as the metric for comparing and characterising information composition of the logbooks.

6.2.2 Full Analysis

The full set of 26 logbooks was then analysed for the occurrence of the 13 classes of information identified in Table 6-2, the results of which are now presented.

In order to reduce subjectivity it was important to apply a consistent and unambiguous strategy for identifying such occurrences. At the highest level, an occurrence may represent a complete entry, i.e. between two dates or a date and a terminator, such as a line or a blank portion of a page. However, many individual entries are composed of a number of information classes. For example, a single entry comprised of a 'written note' followed by a 'graph' then another 'written note' on an unrelated topic would constitute two separate occurrences of 'written note', even though they may be contained in the same entry. Therefore each entry had to be analysed in some considerable detail, which whilst time-consuming presented very little room for subjectivity. For this reason it was decided that using multiple coders to ensure inter-coder reliability was not necessary in the application of this coding. The results are shown in Table 6-4, whilst the original data used to produce this table are reproduced in Appendix B.

% Occurrence
<10%
10-20%
20-40%
>40%

Role \ Class	Logbook ID	Written Notes	Meeting Notes	Sketches	Contact Details	Calculations	Table of Figures	CAD Drawings	Annotated CAD	External Documents	Annotated External Documents	Memorandums	Graphs/Charts	Completed Forms
Management	3	20-40%	>40%	<10%	<10%							<10%		
	4	20-40%	>40%	20-40%	<10%	<10%						<10%		
	5	>40%	<10%	20-40%	<10%	<10%	<10%	<10%		<10%				
	6	20-40%	>40%	10-20%	<10%		10-20%							
	10	20-40%	>40%	<10%	<10%		<10%					10-20%		
	19	>40%	20-40%	10-20%		<10%	<10%						<10%	
Design	1	<10%		<10%		10-20%	<10%	20-40%	<10%	10-20%				
	2			<10%				>40%	10-20%	20-40%				
	8	>40%	<10%	<10%		<10%	20-40%				<10%		<10%	
	9	>40%		<10%			20-40%						<10%	
	17	20-40%	10-20%	20-40%		<10%	<10%							
	18	>40%	<10%	20-40%		10-20%				<10%			<10%	
	20	>40%	10-20%	20-40%		<10%	<10%	<10%		<10%			<10%	
	21	>40%	10-20%	20-40%	<10%	10-20%	<10%			<10%	<10%		<10%	

	22													
	23													
	24													
	25													
	26													
Research	11													
	12													
	13													
	14													
	15													
	16													
Service	7													

Table 6-4 – Contents (by % occurrence) of each logbook

Although there appears to be a large variation in the information content, there are a number of similarities: None of the logbooks contained more than eight information classes (from the 13 defined earlier), with the average being six. The most common classes of information were written notes, meeting notes and sketches. Note also that the class 'completed forms' occurs only in the service engineer's logbook. Although a 'special case', it was felt that it should be included as it represents a common type of logbook and as such is important to consider in the creation of any future logbook strategy.

6.2.3 Impact of Author Role on Information Content

In order to provide further insight into the information composition of the 26 logbooks, each was evaluated against the author's job role. For the purposes of this work, four broad organisational roles were used as the basis for analysis: Management (6 logbooks), Design (13), Research(6) and Service engineer (1). These were determined by asking the logbook authors which role they considered best described their main job activities. Table 6-5 shows the average percentage occurrences of each class grouped by the author's role. Note that the service engineer's logbook is omitted, as it contains only completed forms.

Author's Role	Average % (by occurrence) of information class											
	Written Notes	Meeting Notes	Sketches	Contact Details	Calculations	Tables of Figures	CAD Drawings	Annotated CAD	External Documents	Annotated External	Memorandums	Graphs & Charts
Management	35	38	14	1.7	1.8	3.7	0.2	0.5	1.4		2.1	0.5
Design	38	10	19	1.1	10	5.1	6.6	1.6	5.4	0.8		2.3
Research	34	11	21	5.8	19	2.7			4.5	0.8	0.5	4.7

Table 6-5 – Average (by % occurrence) of each class, grouped by job role

It can be seen that 73% of the occurrences in the logbooks of those in a management role are either written notes or meeting notes. In contrast, designer's logbooks contain a similar proportion of written notes (38%), but they record a broader set of other activities. Sketches, calculations and tables of figures are much more prevalent (34% total), as are external documents such as CAD drawings and component specification sheets, making up a further 14% of designers logbook on average. Like designers, the research engineers also favoured written notes (34%) and sketches, calculations and tables of figures (43% total), although recorded fewer meetings than those in management roles (11%). These 'profiles' show that while the contents of a logbook are somewhat dependent on the engineer's role and the work they do, there are also some strong similarities between different roles. Written notes are the main method of recording work in all roles and account for just over one third of occurrences across all job roles. Similarly, with the exception of the service engineer, sketches consistently make up around 18% of all logbooks.

6.3 Structure and Organisation

To assess the overall structure and organisation of the logbooks, the identifiers associated with each information class were recorded. Again, whilst time consuming, there was little room for subjectivity, so a single coder was used.

6.3.1 Structure

In total, thirteen identifiers were present in the 26 logbooks characterised. These are listed and defined where necessary in Table 6-6:

Identifier	Description
Date	The date on which the entry was made
Title/Subject	The title or subject of the information class, e.g. "*meeting about cost estimates"*
Description	Further elaboration on the purpose of the information or background to its creation
People present	Who was present when the entry was made, commonly used in meetings
Location	The place at which the entry was made; at a customer site, for example
Page number	The physical page number on which the entry was created in the logbook
Revision/version	Denoting the revision number or version of the entry according to a recognised system, such an issue number on a CAD drawing,
Source	The source for the information in the entry or a reference, e.g. reference to a textbook etc.
Author	Who made the entry, or annotation on an entry
Name of contact	
Telephone number	Information comprising contact details
Email address	
Organisation	Company or other organisation associated with the information

Table 6-6 – Identifiers present in logbooks

It can be seen that the identifiers are largely simple, general and self-explanatory in nature. Descriptions and titles were typically short (a few general keywords) and the names of people present at meetings were often abbreviated to initials. Engineering domain-specific language was very rarely used, although project names were unsurprisingly more domain-specific, often relating to the products of that company. Table 6-7 shows which identifiers were associated with each information class and – as a measure of consistency of the application of the identifiers – the percentage of each class that used them.

Information Classes / Identifier %	Written notes	Meeting notes	Sketches	Contact details	Calculations	Tables of figures	CAD Drawings	Annotated CAD	External docs	Annotated External	Memo's	Graphs and charts	Completed forms
Date	100	100	92		95	100	100	100	88	100		100	100
Title/Subject	96	89	79		63	100	100	100	88	100		69	100
Description									100	100			
People Present		68											
Location		5											100
Page number	8				5				38	14			
Revision							100	100					
Source	4				16		100	100	50				
Author	16		13				100	100	50				100
Name of contact				100									
'Phone number				100									
Email address				50									
Organisation		47		42			100	100					100

Table 6-7 – Identifiers associated with each information class

It can be seen from Table 6-7 that a broad range of identifiers were applied, in an often inconsistent manner. For example, whilst dates are used fairly consistently, only 42% of the logbooks containing contact information included what organisation the contact was from, and the source of external documents was typically only recorded in 50% of logbooks. This was not unexpected after the previous findings in chapters 4 and 5 revealed a wide variety of reasons for maintaining logbooks and very different personal styles. The implications of this are discussed in detail in Section 6.4.

6.3.2 Organisation

Three aspects of organisation were qualitatively assessed in the full sample of 26 logbooks – i)the order and sequence of entries, ii)cross referencing of related entries, and iii)any other features of interest related to the organisation of the information.

All the logbook entries were arranged in chronological order, although a few started at both the front and back of the book as a way of separating two projects or types of work (e.g. analysis and meeting notes). The front or back pages were sometimes used as a quick reference for contact details, filenames, passwords etc. and as a 'container' to store frequently used or current external documents such as data sheets and printed emails. Entries were usually separated by their identifiers or a line. For example, a new entry would begin with the date or a new subject. Entries that consisted of less than a page in length were frequently terminated with a ruled line, or the rest of that page was left empty, with new entries starting on a new page.

Only two of the 26 logbooks sampled had numbered pages and only one used an index page. Post-It™ notes (self-adhesive yellow labels) were used in three logbooks as a form of rough indexing and highlighting. Several other logbooks used visual cues such as folded page corners and highlighting with a marker pen. These visual cues were usually for important information such as a to-do item or something else that needed to be accessed frequently or remembered. Very little cross referencing was evident. Entries occasionally referred to previous entries by type or date, but without a page number, in the style of "*see previous meeting with Mr Jones on the 14th*". Only one logbook cross-referenced entries to another in a systematic way, referring to numbered equations.

The findings from this study are now discussed with relation to the findings of previous chapters, before the main shortcomings are identified and requirements for a future e-logbook proposed.

6.4 Discussion

The detailed analysis of information content has provided an understanding of what types of information are contained within engineering logbooks and the classification based on these types of information (i.e. the form in which it is represented, such as written notes or a bar graph) is discussed first, followed by the influence of the author's job role. The findings from the assessment of structure and organisation and the key limitations are related to previous chapters before the requirements arising for a future e-logbook are presented.

6.4.1 Information Types

In total, 13 classes of information were found to exist in the 26 logbooks analysed. The sample represented logbooks from various types and sizes of organisation, giving more confidence in the validity of the results than if, for example, the logbooks were from a single organisation or people in a particular job role. The information content was analysed by number of occurrences (that is, the number of times a particular class of information was found in the logbook), which revealed that the most frequently occurring class were written notes and meeting notes.

The variety of information types also provide more evidence that logbooks fulfil a wide variety of roles and exist for a range of purposes – again consistent with the survey and scenarios presented in chapters 4 and 5. The analysis of information types also highlights the wide range of information sources used for design work, as evidenced by the instances of external documents. This echoes previous findings that suggested around a quarter of an engineers' time is spent acquiring and disseminating information (Marsh, 1997). However, it was also apparent that these sources, whilst important, were not well supported by current paper logbooks: Virtually all the instances of external documents were from electronic sources such as print-outs of test results, CAD drawings or printed emails etc. These obviously required additional effort required to print, then paste into the logbook.

There is also evidence supporting what are referred to as the 'ideation' and 'documentation' modes of use (Currano & Leifer, 2009) discussed in Chapter 4, especially through the presence of annotated external documents, suggesting elements of ideation such as *refining ideas*. The many other design notes and large volumes of sketching also support the notion of ideation and also the role of logbooks for "*self explanation and problem solving"* (Trafton & Trickett, 2001).

Ultimately, this diversity reflects the range of activities that engineering design and its management encompasses. This suggests that a 'one size fits all' approach to enhanced management of logbook information may be hard to achieve and may even be misguided. However, the classification of logbook content into just fundamental 13 information classes (together with the fact that logbooks contain no more than eight of these classes) also suggests that while logbooks are used in very diverse ways, their content is ultimately manageable.

6.4.2 Influence of Job Role

Although just over half of the logbooks were sourced from academic institutions, there was no significant difference in the logbook use or content patterns of engineers undertaking the same main job role in academia or industry. Overall, the most commonly occurring elements were written notes, meeting notes and sketches. When considering different job roles, the study revealed that, for managers, written notes and meeting notes were the two most common entries. In contrast, for design and research engineers, the range of information types found was more evenly distributed over the 13 classes, although written notes, sketches, calculations and tables of figures were generally the most frequently occurring. Written notes and sketches consistently made up nearly half of logbook content across all job roles, except in the case of the service engineer. The lack of more clearly identifiable of logbooks for various roles was not expected and may be a consequence of the sample size (although the findings of the analysis and the survey reported in Chapter 4 are self-consistent). It is also possible that the contents are dependent on a more detailed classification of roles than those adopted in this research. For example, design and research activities are diverse in nature, with much overlap. Many organisations also make extensive use of inter-disciplinary project teams. In this case, engineers may be involved in several projects at once, undertaking different roles in each, but recording everything in a single logbook. The keeping of a single logbook for multiple roles or projects is also supported by the survey findings in Chapter 4, with just over half of respondents indicating they use one logbook for everything, and 34% maintaining logbooks for each project.

6.4.3 Structure and Organisation

It is clear that the wide variation in structure of individual logbook entries will significantly affect the extent of potential re-use. For example, descriptions were generally lacking and titles and names of people present at meetings were often abbreviated. Of particular concern from a re-use perspective was the observation that sources of information were rarely identified, and the authors of annotations were never identified. As this information is often critical for allowing a judgement of trustworthiness to be made (Lowe, 2002) its absence means that even if barriers to finding the entry were overcome, the lack of context would mean the ways in which it could be re-used would still be limited. For example, an entry containing information about a component without the manufacturer or part number may still be useful for the logbook owner, or possibly for audit or intellectual property purposes, but is unlikely to be of much use from a design re-use perspective, or if the information is to be shared with the wider project team.

In terms of organisation, all the logbooks sampled were arranged chronologically, as would be expected for a paper document that in many cases serves as a diary-like record. The lack of cross-referencing observed may be a consequence of several factors: Firstly, the effort involved may be too high for the benefit, or there may simply be little need to cross-reference in most cases. This is consistent with the finding in Chapter 4 that logbook information is typically located by browsing or memory alone. Similar reasons likely exist for the lack of contents page or indexing, which is also likely to be a contributory factor to the very low re-use of past logbooks noted in the survey in Chapter 4 (42% only for specific events, 8% never, 18% did not retain logbook).

The use of visual cues such as post-it notes, folded page corners and highlighted words is also consistent with previous findings, in-particular the patterns of use discussed in Chapter 5, in relation to the prominent role of the logbook as a task manager. It also supports the 'browsing to remind' strategy identified in Chapter 4 and the Documentation activities of 'organise', 'keep track and 'review' identified in Currano and Leifer (2009). For similar reasons the front of logbooks were commonly used to record details such as telephone numbers, file paths, passwords and other frequently needed or important information.

It could be argued that the incompleteness of identifiers, the wide variation in structure and basic levels of organisation observed reflect the informal nature of logbooks and their use for quick recording of notes and ideas. This is consistent with the finding in Chapter 4 that they are often viewed as a personal resource (76% of respondents), not designed or set up as a shared information resource. Despite this, it was apparent from the study that at least a proportion of the information they contain could be useful from both personal and organisational perspectives. The results from this chapter are now summarised in 6.4.4 and requirements to overcome some of the apparent short comings are discussed in 6.4.5.

6.4.4 Summary of Findings

This table summarises the main findings from this chapter and relates them to what has been found in the previous chapters and literature:

Aspect	Main Findings	Relation to Previous Chapters and Literature
Content	• 26 types of information, grouped into 13 fundamental classes • Most common were written notes, meeting notes, sketches and calculations • Wide variety of information types reflects range of reasons for use • Average of 6-8 classes of information in typical logbook • Little variation by job role, but managers have more meeting notes • Importance of external documents and annotations emphasised	• Survey (Chapter 4) reported varied reasons for use so not unexpected to see variety of information types • Scenarios (Chapter 5) find prominent role of logbooks in mediating activities (e.g. sketching before formalising in CAD, written notes typed into formal meeting record etc) • Sketches, calculations, meeting notes and calculations etc support concept of logbooks supporting Ideation and documentation (Currano & Leifer, 2009) and self explanation and problem solving (Trafton & Trickett, 2001)
Structure	• Entries identified with metadata (termed 'identifiers') • Most common were dates, titles and subjects, and project names • Descriptions generally lacking • Project titles and people present often abbreviated • Authors of annotations usually not identified • Sources of external documents not identified	• Survey (Chapter 4) reports majority of respondents regard logbooks as personal store of information, not intended for use by third parties. • Predominant mode of searching by memory or browsing (Chapter 4), supporting the existence of simple identifiers
Organisation	• Chronological • Very limited cross-referencing • Very limited use of contents pages, no index • Visual cues to highlight particular activities • Front page used as store for frequently used information such as contact details, passwords etc.	• Browsing to remind predominant mode of re-finding information (Chapter 4) so visual cues useful. • Quick access needed to important information, especially tasks (Chapter 5) • Similar findings to those reported in Wilcox et al., 1997.

Table 6-8 – How logbook information types support modes of use

Whilst some aspects of logbook use seem to be very well supported by current paper logbooks, it is apparent that there are a number of features and characteristics of logbook use and content which limit their ability to be re-used effectively as a source of design information. For example, Section 6.4.1 notes that integrating external content into logbooks requires additional steps and Section 6.4.3 argues that the wide variation in the types of metadata recorded with entries is a barrier to re-use by anyone but the original author. With this in mind, six core information-based logbook activities, forming an 'information lifecycle' (creating, classifying, navigating, searching, sharing and collaboration) have been used to summarise the key limitations affecting re-use. These are presented in Table 6-9:

Logbook Activity	Key limitations
Creating	• Inconsistent structure and organisation of entries • External documents require significant additional effort and only represent single, static viewpoint
Classifying	• Lack of identifiers (metadata), inconsistently applied in personal style
Browsing/Navigating	• Often relies solely on memory of original author • Lack of cross referencing combined with inflexible organisation of entries • Visual cues personal to author and do not reflect interest of other potential users
Searching	• Manual activity with few logbooks containing an index or contents page • Often hard to identify author or purpose of logbook to aid searching collections of books
Sharing	• Source of information often not identified • Lack of description or rationale • Inconsistent structure and organisation makes systematic sharing hard
Collaborative use	• No means to individually identify contributors

Table 6-9 – Key limitations affecting re-use

The key limitations of current logbook activities summarised above give rise to a number of corresponding requirements, representing how the limitations may be overcome. It is important to note, however, that this involves more than simply providing functionality where this is none (e.g. enforce consistently applied identifiers to all entries, mandate a single structure that must be used etc) – that is, there must be some evidence of a need for a requirement other than the current absence of that feature.

6.4.5 Requirements Arising

In terms of creating content, the first and arguably most important requirement that is apparent from the findings above is that any logbook must be able to support the full range of information classes identified in the analysis, even information that makes up a very small percentage of the logbook (such as contact details or graphs and charts), as its scarcity does not necessarily reflect its importance. This is particularly true of external documents, which are important in supporting the mediating role of the logbook, yet at present require a significant additional effort. It is therefore also necessary to support the creation in the logbook of any type of external information in any form (e.g. CAD, images, photographs, data, emails etc.)

In terms of the wide variation in the way the content of entries is structured, and the unique visual cues used by the author, the primarily personal nature of logbooks as a quick recording tool means that there is a trade-off to be made between the ease and flexibility of use and the ease of re-use by both the original author and other stakeholders such as the project team or organisation. It is argued that flexibility in logbook entry structure is an inherent and useful affordance of current logbooks and should be retained as a requirement.

However, for classification and subsequent browsing/navigating, the inflexible nature of the *ordering* of entries exacerbates the problem of locating relevant entries. For example, just over half of the respondents in the survey in Chapter 4 kept one logbook for all projects, and the scenarios in Chapter 5 revealed that considerable effort is often needed to retain coherent records of information such as tasks or actions arising from meeting notes that become scattered throughout the logbook. It is therefore argued that there is a need not only to retain the flexibility of how entries are structured, but provide flexibility for the organisation of entries that is not currently possible.

To support this, it is argued that the inconsistent application of metadata to entries presents a fundamental barrier to re-use, as evidenced by the search strategies for engineering logbooks and low levels of re-use of past logbooks revealed in Chapters 4 and 5. Therefore the forth requirement arising is that a future e-logbook should support the application of consistent, relevant and defined metadata. This will aid the retrieval and subsequent re-use of entries, reduce the dependence on memory for re-finding entries and permit more flexible entry organisation. It could also facilitate the creation of indexes or contents pages should this prove useful or necessary.

The current limitations of searching, sharing and collaborative use listed in Table 6-9 could also be significantly reduced by the requirement to consistently apply defined metadata identifying the sources of external information, the authors of annotations and a purpose or description for entries. In a similar vein, often the author or purpose of the logbook is not identified. There is therefore a requirement that the author and purpose of the logbook must be made explicit to aid searching and sharing collections of logbooks.

6.5 Concluding Remarks

It was argued in Chapter 2 that whilst considerable work has been undertaken that deals with the improved management of formal information sources, comparatively little effort has been directed at improving the management of informal information sources such as logbooks. To address this, a detailed analysis of the information content, structure and organisation of engineering logbooks has been undertaken. This chapter therefore presented a detailed analysis of 26 existing paper-based engineering logbooks, comprising nearly 3000 pages of engineering-related content. It has revealed the types of information they contain and how this relates to the role of the authoring engineer. Twenty-six types of information were recorded in total. These 26 types were grouped into 13 classes and analysed by the number of occurrences in the logbook sample. The most common classes were written notes, meeting notes and sketches. The analysis also revealed that some classes of information were more common in specific job roles (such as the predominance of meeting notes in managers logbooks).

In terms of structure and organisation, the analysis also highlighted the difficulties of identifying and organising information content due to its highly unstructured nature and the inconsistent application of metadata to entries. The most common metadata (termed identifiers in this research) were dates and titles. Whilst these were used in a high proportion of entries, other types of this context-giving metadata were far less consistently applied. For example, the source of external documents was hardly ever recorded, the names of people present at meetings were commonly abbreviated and dates were written in various formats. However, it is arguable that by classifying the information into classes and showing that the typical logbook contains at most only eight of these information classes, the content is ultimately manageable.

The overall results of the work build on the survey and exploration of logbook use in context presented in Chapters 4 and 5 respectively, and provide a unique insight into the content of engineering logbooks – a topic that has not previously been investigated in this way. Further, it is argued that the understanding gained through this analysis is essential for the development of improved techniques and methods for the more effective management of such unstructured information.

The requirements arising therefore centre on the need to retain the nature of the logbook as a means of recording information in a flexible and quick manner, whilst improving the management of the resulting information to reduce the reliance on memory as the primary means of locating information, therefore making the content more accessible to both the individual engineer and other stakeholders. The two most important requirements concern the ability of any future logbook platform to be able to support the recording of the full range of information types, and to permit the consistent application of metadata to entries, to aid searching, sharing and re-use.

However, whilst a detailed picture of the *types* of information has been presented, the potential of logbooks to support design re-use and other business activities has thus far been largely presumed or anecdotal (although the types of information and frequency of re-use of current logbooks do provide some empirical basis for this assumption). To address this, Chapter 7 now presents a detailed assessment and comparison of logbook content to more formal sources, with the aim of establishing two aspects of logbook information: the *usefulness* (i.e. demonstrably understandable and relevant to engineering design) and the *uniqueness* (i.e. such information does not exist elsewhere in formal records).

7 Relationship Between Formal and Informal Documentation

Even the most routine engineering design projects generate large volumes of formal and informal information, from an ever-increasing variety of tools and systems. In one example, the average number of documents in a typical design project in Rolls Royce was around 40,000 (Marsh, 1997:p.75). During the design process, the efficient creation and transformation of this information is critical to the success of the project. However, at the end of the design process there is a requirement to prepare formal project documentation necessary to support manufacturers and customers, and conform to legislation. This includes elements such as CAD models, specifications and manufacturing data. In the process of preparing this documentation, only a small proportion of the information generated is captured – if only because of limited resources. It is therefore unclear whether potentially valuable design information could be omitted from this formal record and eventually lost. This is because whilst the previous chapters have strongly suggested that informal information can be important to the individual and is of a type (such as calculations and other design information) that could support better traceability and wider re-use (Chapter 6), it has also been seen that it is recorded in a largely personal style, with inconsistent use of metadata and basic methods of structuring and organising. Whilst Chapter 5 showed that logbook information is often used to prepare formal documentation, it is not clear how much of this information is transferred into the corresponding 'formal' project record and whether anything 'lost' from the formal project record can be found in a usable form in logbooks.

This final part of the investigation of current paper-based engineering logbooks is therefore concerned with determining the information content of logbooks from a different perspective and addresses two important questions: Firstly, is the information logbooks contain demonstrably *useful*? – that is, do logbook entries contain understandable and re-usable accounts of engineering design activity useful to either the engineer who created them or to the wider organisation? Secondly, is the information they contain *unique*? – clearly there is little point going to considerable effort to better exploit logbook information if it is largely replicated in formal sources that are already well managed and widely accessible.

In order to explore these two questions, a comparative study of documentation from an engineering design project has been undertaken. Following an outline of the rationale for the study and a description of the methodology in sections 7.1 and 7.2 respectively, the results are presented and discussed in detail in Section 7.3. Section 7.4 builds on the results with a discussion and two illustrative examples. Section 7.5 then discusses these results with respect to their implications for the design of a future logbook to potentially enhance the design record, before conclusions are drawn.

7.1 Rationale

It is argued that to document even a relatively small engineering project in a way that is complete and allows efficient re-use of the information for future work is a considerable challenge for two reasons. Firstly, it is complex because of the sheer variety of ways the information is stored, with a recent survey finding 105 electronic file formats in use between just 40 engineers (Hicks et al., 2008). This multitude of types and data formats exist partly because each has been developed to support different aspects of the design process particularly well. For example, CAD tools afford precise representations of very complex designs to be created and communicated quickly, whilst at the other end of the spectrum, logbooks afford the quick recording of ideas through notes, sketching and quick calculations.

Secondly, the problem is compounded as much of this information is not formally managed in a way that facilitates re-use or even retrieval. This is particularly true of the associated informal information, with links to the associated formal records often not explicit, being held in memory only (Chapter 5) or discarded completely at the end of a project (with nearly 20% of engineers questioned in Chapter 4 not retaining past logbooks).

It was seen in Chapters 4-6 that logbooks in-particular contain a rich variety of informal design-related information including sketches, contact information and meeting notes. The literature also shows evidence of logbooks being used to support design activities considered important, such as self explanation and problem solving (Trafton & Trickett, 2001), sketching (see, for example, Purcell & Gero, 1998) and being able to provide evidence of thought processes and rationale (see, for example, Grenier & Schmidt, 2007). However, it was noted in Chapter 2 that they remain a "*largely untapped resource*" (Topi et al., 2006) for engineering organisations, with little research what they contain and in-particular how they differ from the formal record. It is argued that such an understanding is necessary, as the need for e-logbooks that afford better management of engineering is lessened if all the useful information they contained is reproduced in the formal project record. Such formal sources are generally assumed to have higher levels of structure and organisation, as they are often designed primarily to communicate. Such records are also much more likely to be computer tractable and more recent records of this type are usually stored in some kind of document management system with its associated search and retrieval functions.

This lack of research into the nature of - and differences between - informal logbooks and formal project records forms the motivation for this study. The objective is to draw lessons for the requirements for an e-logbook that could make the design record more complete and arguably more useful.

7.2 Methodology

This section starts with an overview of the dataset used in 7.2.1. The classification schema created to analyse the dataset covered both the type of information and its nature, and is discussed in detail in 7.2.2. How the analysis was performed is then discussed in 7.2.3.

7.2.1 Data Set

The documentation used in this study was generated by six engineers studying mechanical engineering at the University of Bath. The documentation consisted of logbooks, reports and CAD drawings and was generated during a three-month project carried out in conjunction with a large UK-based engineering organisation. The logbooks were also used in the analysis of logbook content reported in Chapter 6. Whilst this analysis also utilised logbooks from engineers in management and research roles, the group here reflected reasonably well the wider sample. Whilst they predominantly undertook engineering design work, there were both elements of research and a project managers logbook, which recorded their responsibilities in terms of organising the other team members and tasks/meetings etc.

The sponsoring organisation's role was as the customer: they gave the team a design brief, and provided resources and access to facilitate the project. The brief was to re-design a module for a large packaging machine in order to reduce changeover times. The six team members had all previously worked for one year in a variety of engineering organisations. This project was chosen for three reasons: Firstly, the dataset was relatively complete and self-contained. Whilst there were some associated emails and work on a whiteboard, it represented a large proportion of the physical record. Secondly, the engineers did not know in advance that the documents would be analysed, which was essential if meaningful comparisons were to be drawn. Finally, it represented a 'real' industrial problem, with engagement from a range of stakeholders and tasks spread across various design stages – from defining the problem to relatively detailed design. It is therefore believed to be an accurate reflection of a common engineering design scenario.

7.2.2 Classification Schema

Following lessons learned from a previous attempt (reported fully in McAlpine et al., 2006b) a new information coding scheme was adopted, which had originally been developed at the University of Bath to classify engineering email content. In summary, the previous approach used a coding scheme originally developed to illustrate information loss in design review meetings (Huet et al., 2006). The scheme had four categories: rationale, lessons learned, decisions and actions, and was used to produce visual maps centred around topics. However, whilst it was used very successfully to analyse the discourse in design review meetings and compare it to the formal minutes, it was difficult to apply it to logbooks and reports. Fundamentally, the information in logbooks did not correspond to single parts of the formal documentation, which meant that comparing the maps (and thus exploring potential information differences) was almost impossible.

The coding scheme was created from an extensive review of the literature on classifying information in various fields, including engineering design, sociology and organisational behaviour. The categories attempted to comprehensively cover *How* the information is presented, *What* it is about (whether it is product or process-related) and also *Why* it is being created (in terms of problem solving activities and intent of the communication). This approach was taken because of the relatively unknown nature of the problem under investigation. By not restricting the scheme to a particular aspect of the logbook content (such as information type), a richer picture of the differences between the formal and informal documents could be gained. The detailed rationale for the selection of the terms is also discussed in detail in Wasiak et al., (2008) and the full coding scheme is presented in Table 7-1:

How	What			Why	
Information classes	**Product**	**Project**	**Organisation**	**Problem Solving**	**Communication**
Written note **Meeting note** **Sketch** **Table of figures** **Calculation** **Contact Information** **Graph/Chart** **External Document** **Annotated External** **CAD** **Annotated CAD** **Memorandums** **Completed Forms**	**Functions** Things the product must do, e.g. 'Be fast' **Performance** How well the product achieves its functions **Feature** The quality or characteristic with which the function is achieved **Operating Environment** Objects that interact with the product **Materials** Materials selection and characteristics **Manufacturing** Consideration of manufacturing, assembly and transport **Cost** Consideration of costs particularly unit costs **Ergonomics** User Interaction with product	**Risk** Assessing likelihood and weighting implications **Planning** Management of phases, activities and tasks **Team** Team selection and development **Quality Management** Quality, standard or expectations **Cost** Financial arrangements at the level of the project, rather than specific component costs **Time** Timescales, deadlines	**Stake Holders** Share holders, customers, directors and their culture and politics **Economic Issues** Costs and efficiency, market and product selection **Human Resources** People, availability, allocation, training etc. **Physical Resources** Ranging from offices to equipment **Financial Resources** Cash, Assets, Borrowing **Knowledge Resources** Current ability and stored information **Tools and Methods** Specific testing and modelling techniques **Practices & Procedures** Accumulated by the company, often developed through experience	**Goal Setting** Identifying where the design is, and to where it needs progressing **Constraining** Imposing boundaries with requirements and desirables **Solving** Encompasses one or more of the following stages: searching, gathering, creating and developing solutions **Evaluating** Judging the quality, value and importance of something **Decision Making** Considering key factors from evaluation and possible compromises to form a decision	**Clarifying** Clearing up mis-understandings (both requesting and in response). **Debating** Discussing opposite views **Informing** Sharing, presenting or distribution information with others. No response is required. It is passive **Exploring** Discussing possibilities and ideas, invoking suggestions **Digressing** Discussing irrelevant material **Managing** Includes arranging, directing and instructing. Implies action (such as a response) needs to be taken

Table 7-1 – Information Coding Scheme (*adapted from* Wasiak et al., 2008)

For the purposes of this research, two modifications were made: Firstly, the analysis included the 13 information classes (written notes, meeting notes, calculations, sketches etc.) previously identified from logbooks in Chapter 6. It was felt that this would allow more insight to be drawn about the differences in types of information as well as their nature. Secondly, the coding scheme originally included a 'communicative acts' category. This was intended to classify the type of interaction where two-way communication between people was involved (e.g. meetings or emails) and covered the way in which language was used in dialogue – for example, if the author of an email used language that agreed or disagreed with another team member. It was thus not appropriate to include it for this research, where the communication was essentially one-way (team member to logbook or report) and not expressed in the form of dialogue that could be analysed in that way.

Whilst the exploratory nature of the research means that certainty about the completeness of the coding scheme cannot be claimed, it has been used extensively to mark-up other design documentation (primarily emails) covering a variety of types of design projects, and has been through several iterations to ensure reasonable completeness of coverage with respect to the aims of the research. For this study, virtually all entries were coded with at least one term from each top-level category and all entries could be classified into one of the 13 previously identified information classes (Chapter 6).

7.2.3 Analysis

For the purposes of coding the documents, the information was split into appropriate 'chunks'. Logbooks were split into entries in exactly the same way as they were for the content analysis in Chapter 6. Again, entries were generally headed with a date or subject and ended with a terminating line, or the start of a new entry and were very easy to identify. The reports were split according to their numbered sub-sections. Whilst not perfectly analogous, it was felt that report sub-sections did correspond to logbook entries, as they both dealt with one aspect of the design or process, thus making the mark-up more manageable and the analysis meaningful. If, for example, the reports were analysed by entire sections, or logbooks in week-long chunks, so many terms from the classification would likely apply as to render any meaningful analysis unlikely.

The inter-coder reliability for the coding scheme was not formally assessed in this case due to time constraints and because the reliability of the schema had already been assessed when applied to other documentation (Wasiak et al., 2008) Although this assessment found levels of agreement between coders at the lower-level terms did vary, there was "*near perfectly consistency*" between coders at the higher (product, project, organisation) categories. A further, larger study of an email corpus with the same classification schema carried out at the University of Bath revealed that the inter-coder reliability for two coders as measured by the kappa co-efficient, was greater than 0.7, which is considered acceptable for exploratory studies of this type.

As well as the percentage of entries or report sections containing the 13 information classes, the actual number of sketches, calculations and CAD drawings (representing discrete information types that could be compared directly in a meaningful way) were also counted. The results for the information content categories (product, project, organisation, problem solving and communication activities) are presented as the percentage of entries that contain each category and sub-category. For example, if 50 of 100 logbook entries contained some aspects of product performance, the percentage of entries would be 50%. As entries can (and often did) contain multiple categories of information content, the graph percentages do not add up to 100%. This methodology is summarised in Figure 7-1:

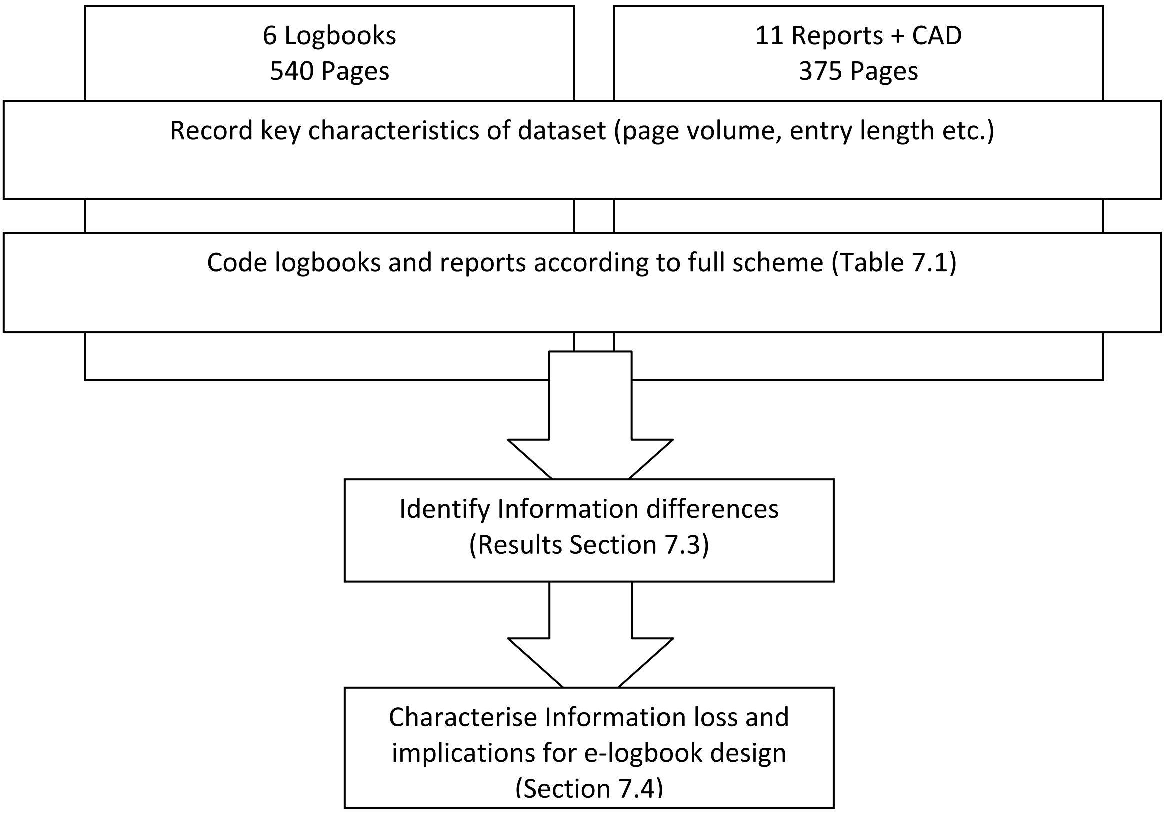


Figure 7-1 – Summary of Methodology

7.3 Results

This section presents the main results from the study. First, the key characteristics of the documents are presented, before the top level schema categories are examined. The detailed results from the lower-level schema terms are then presented. The data is also reproduced in Appendix C.

7.3.1 Information Types and Top-level Categories

Table 7-2 shows some key characteristics of the documents analysed, along with the number of instances of sketches, calculations and drawings:

	Logbooks	Reports
Number of logbooks/reports	6	11
Total page volume	540	375
Total Entries	372	405
Average length of entry (pages)	1.45	0.93
% of entries with 2+ info types	33%	18%
Average info types per entry	1.45	1.21
Number of Sketches	124	34
Number of Calculations	52	21
Number of CAD drawings	0	30

Table 7-2 – Key characteristics of dataset

It can be seem that the number of entries (as defined above) is very similar, with less than a 10% difference. However, the average length of logbook entries is higher, reflecting the less compact and structured nature of the logbooks entries As expected, the logbooks contain many more sketches than the reports, whilst the reports contained many more formal representations in the form of CAD drawings. The differences in the distribution of information classes is illustrated in Figure 7-2. Where the information class was present in less than 5% of the entries, they have been grouped into 'all others' for clarity of presentation. The full data is available in Appendix C.

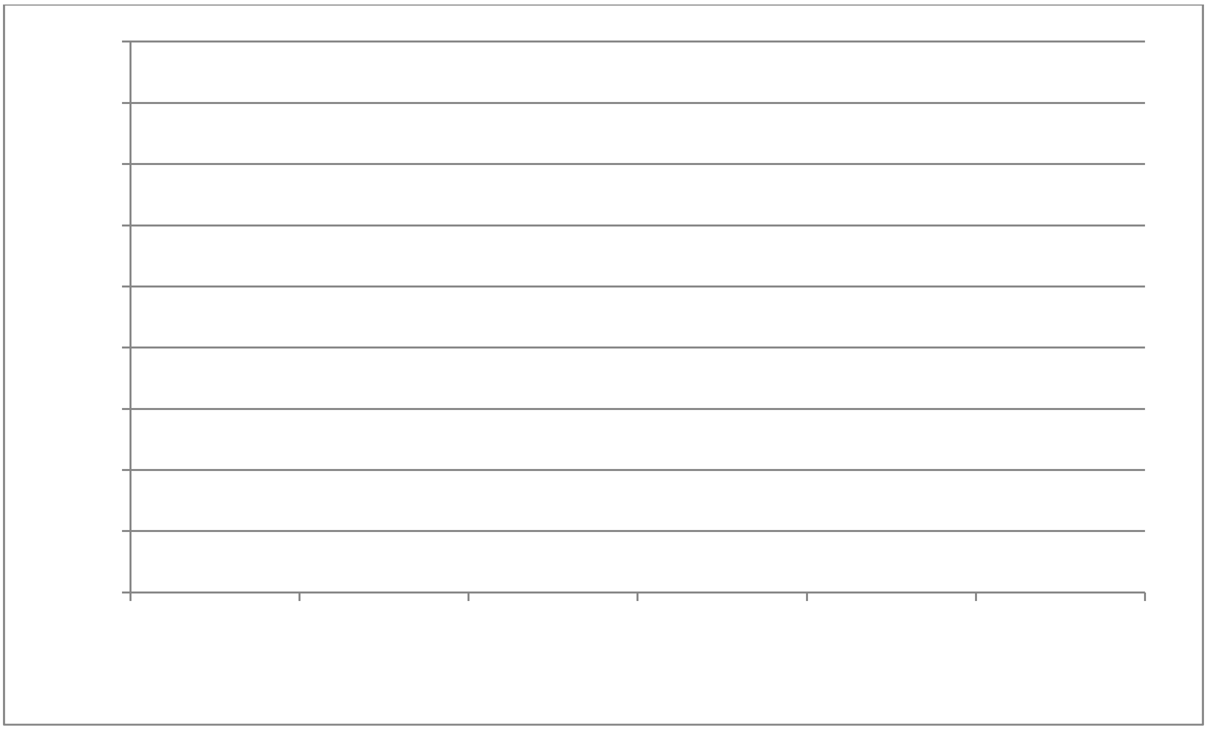


Figure 7-2 – Percentage of entries containing various information classes

It can be seen from the above table and graph that there is a complete absence of meeting notes in the reports (compared to over 20% of logbook entries being meeting notes). Other significant differences can be seen in the number of sketches (although arguably many of the sketches will be manifested in the CAD drawings) and amount of entries containing calculations. It was observed that tables of figures were used more often in the reports to summarise the results of calculations, and this is manifested in Figure 7-2 above, although this of course means the method used and any possible errors are not apparent in the reports. The ‘richness’ of the entries also differed significantly, with many more logbook entries containing two or more information classes (33% vs. 18% for reports). This is also evident in the figure for the average number of information types per entry (1.45 vs. 1.21 for reports).

However, these statistics alone do not afford a full understanding of the differences between the logbooks and reports. Starting with the top-level terms from the schema, the percentage of entries that contain these terms are shown in Figure 7-3:

Figure 7-3 – Percentages of entries containing top-level categories

From this, it would appear that the trends between the logbooks and reports are remarkably similar, with the exception of the relative lack of project-related information in the reports, 55% vs. just 15% of entries for reports. As can be seen in Table 7-1, project-related information cover topics associated with the *process*, such as managing risk, planning/task allocation, timescales etc. Therefore, it is necessary to drill down into each of these categories to give additional insight into the reasons behind these trends.

7.3.2 Sub-categories

Taking each top level category in turn, Figure 7-4 first shows the breakdown of product sub-categories:

Figure 7-4 – Percentage of entries containing product-related information

The trends across the sub-categories are broadly similar for both logbooks and reports, although proportions of performance and ergonomics related entries (which are related to performance) are significantly higher in the reports. This is not counter-intuitive, as the traditional role of formal reports is to describe the final design (including its performance), whereas logbooks have a greater role during the emergence of the design. The product cost information was observed to be present in both logbooks and reports. However information related to ergonomics was virtually absent from the logbooks, suggesting this was only considered at the end of the project.

The breakdown of project sub-categories also reveals more detail about the large differences in the number of project-related entries mentioned above, as illustrated in Figure 7-5:

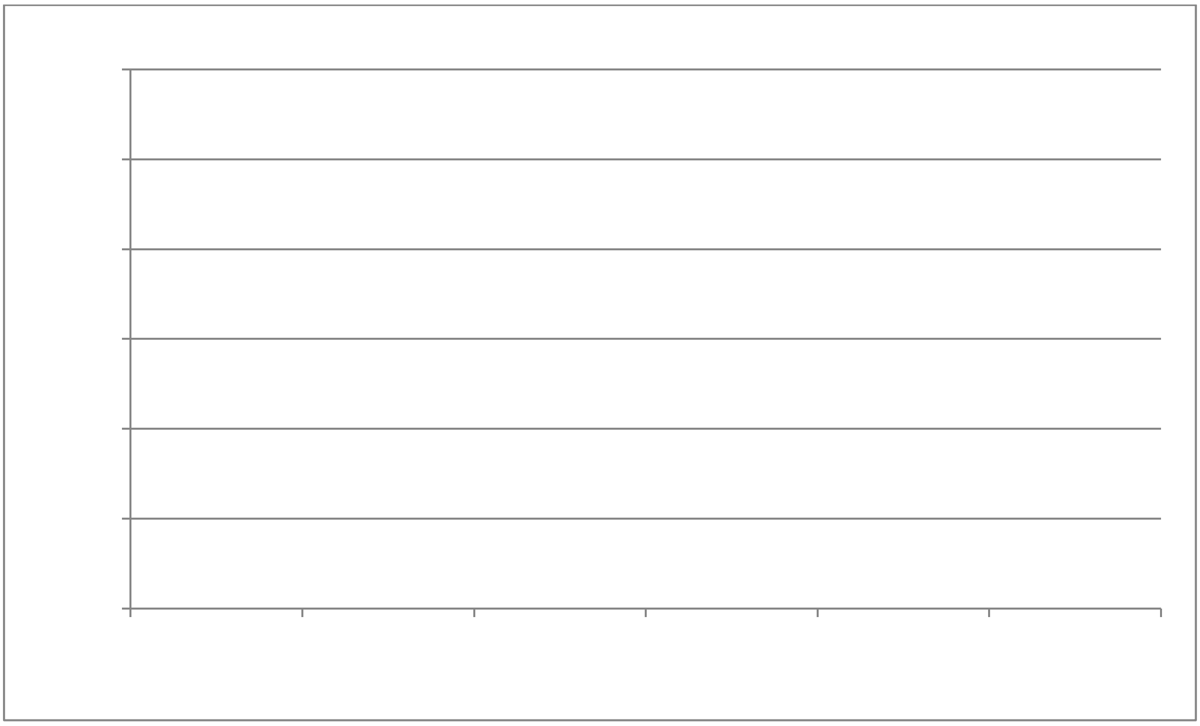


Figure 7-5 – Percentage of entries containing project-related information

It can be seen that most of the difference arose from the relative absence of 'planning', 'team' and 'time' entries in the reports, with nearly 50% of logbook entries containing some elements of planning, compared to only around 7% of report entries. These differences can be attributed to the following factors:

- A significant amount of planning and task allocation (referring to team members) was recorded in meeting notes, which were completely absent from the reports (20% vs. 0%).
- Logbooks were all chronological and often resembled a diary. Thus the logbook was effectively a living document, making planning an integral and natural part of many entries.
- Logbooks were frequently used to track tasks outstanding for the individual in 'to-do' style lists at the beginning of entries.

Similar trends existed for organisational-related entries. Economic information was present in both logbooks and reports, as such information was provided by the stakeholders in a relatively clear form during meetings and simply copied from logbook to report. For example, the target cost of the machine was communicated to the engineers in the meeting, and was then transferred in to the formal requirement specification. There is also a clear loss of human resources (HR) related information. Such information was often very similar in nature to 'team' information (i.e. dealing with issues related to team members and their roles) and was therefore absent for similar reasons - namely that such issues were often discussed in meetings, records of which are absent from the formal reports:

Figure 7-6 – Percentage of entries containing various organisational information

Moving to the problem solving sub-categories (Figure 7-7) it can be seen that entries containing ‘goal setting’ and ‘constraining’ activities are at broadly similar levels. However there are significant differences between the amount of entries containing ‘solving’ and ‘evaluating’:

Figure 7-7 – Percentage of entries containing various problem-solving activities

The majority of ‘goal setting’ was observed to be in the requirement specification and scoping section at the beginning of the logbook, which are also repeated in the reports, hence these percentages are very similar. The significant differences in the proportions of entries containing elements of solving and evaluating are probably for a similar reason as the difference in performance-related entries shown in Figure 7-4, namely that logbook entries are more likely to contain elements of solving – i.e. search, gathering and developing solutions in the earlier stages of design, whereas the reports emphasise the final design, including its evaluation.

The overall percentages for entries containing the top-level ‘communication activity’ (Figure 7-3) was, unsurprisingly, almost 100%. This is simply because virtually all entries can be classified as communicating something. However, drilling down into the sub-categories reveals that the nature of this communication differs significantly between the logbooks and reports (Figure 7-8):

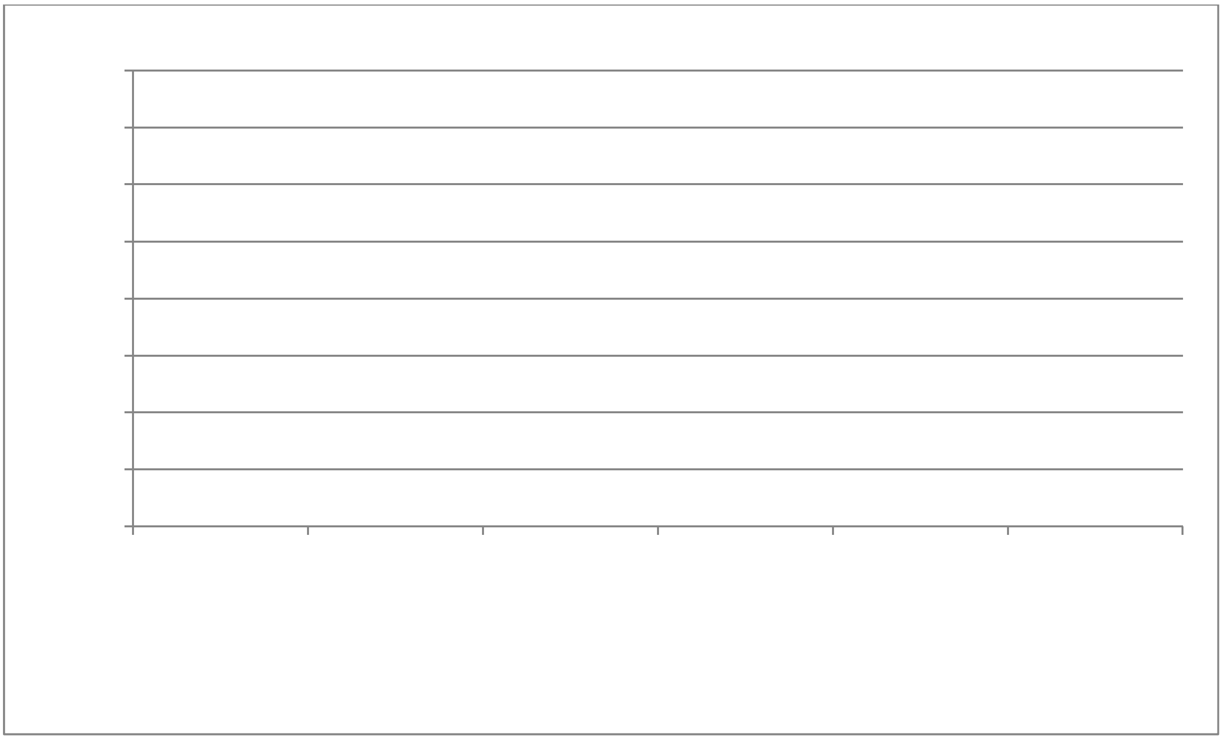


Figure 7-8 – Percentage of entries containing various communication activities

Firstly, there is a lack of ‘clarifying’ and ‘managing’ in the reports. In a similar trend to the planning categories, this may be explained by the observation that clarifying and managing often occur during collaborative work. Such sessions would be recorded in logbooks as meeting notes, which are absent from the reports. The other significant difference is the contrast between entries that are informative in nature (27% for logbooks vs. 74% for reports) and those which are exploratory, where the trend is almost exactly reversed (64% for logbooks vs. 24% for reports). ‘Informative’ in this context means that the entry states one position, and does not consider options, alternatives or the rationale for the statement, whereas exploratory entries do consider alternatives. Section 7.4 now discusses these findings with respect to the implications for the design record and requirements for future logbook designs.

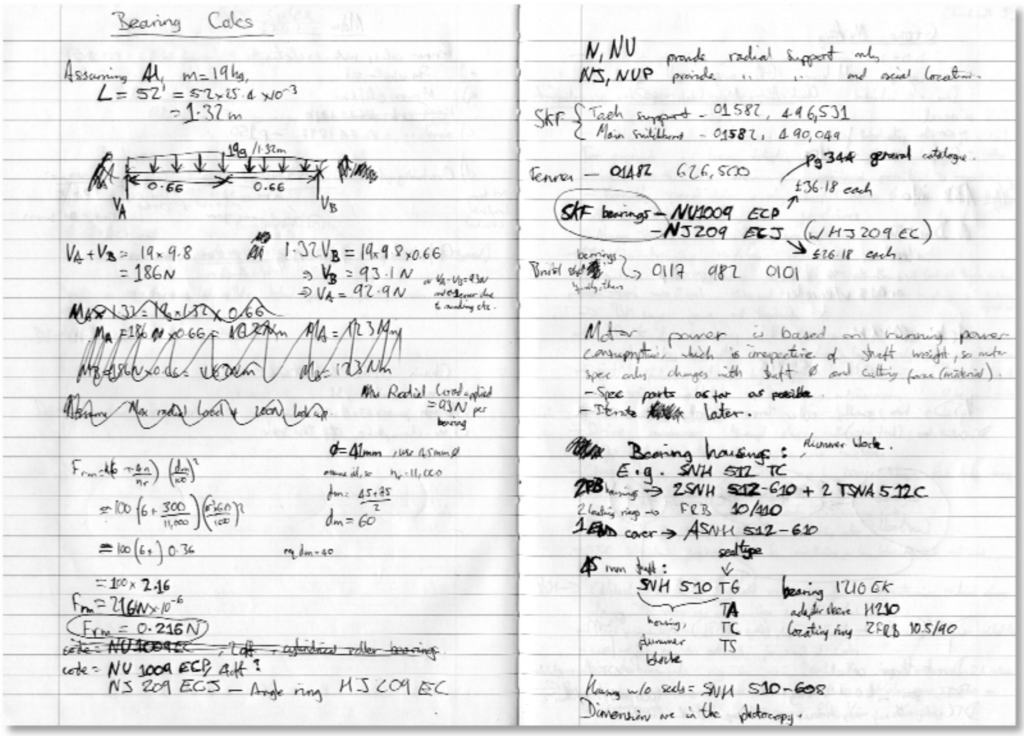
7.4 Discussion

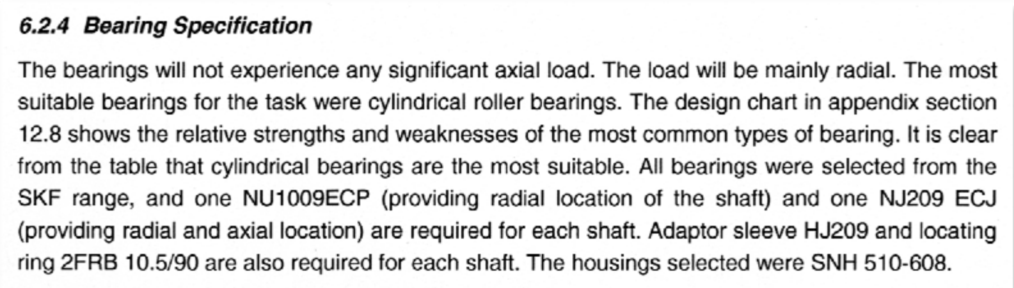
This study is unique in that it has presented a detailed analysis of the nature of engineering logbook information, with a comparison of logbooks to formal reports – a topic previously absent from the literature. Further, the flexible coding scheme used makes possible comparisons between other types of information such as email. Two illustrative examples of logbook entries and their formal counterparts are now presented (Section 7.4.1), together with a description of two possible re-use scenarios (7.4.2), illustrating how the findings of this study can be used to inform requirements for improved management of logbook information (7.4.3).

7.4.1 Comparing Entries

There were clear indications of potential 'information loss' in terms of information classes, and in-particular the numbers of sketches, calculations and meeting notes in this dataset. In the case of meeting notes, much of what was lost was project or organisational-related information (specifically planning, team/HR and managing activities). Other categories or information classes ('product', for example) did not appear to show much of a 'loss'. Indeed, some types of information such as those related to product performance and evaluation, were more prevalent in the formal reports. It is suggested that the greater proportion of entries related to performance and evaluation could be attributed to such activities naturally occurring later in the process when reports are being written, and also that it is the function of a report to concentrate on the final design – and particularly evaluating its performance. This is further supported by the observation that significant differences still exist in the *nature* of these entries, with informal logbook entries containing performance or evaluation aspects still more likely to be exploratory in nature, or relating to the performance of alternatives and not the chosen solution.

Overall, then, logbooks appeared to show more of the emergence of the design, as manifested through more logbook entries containing elements of 'solving' and 'exploring'. They were also richer in terms of the number of types of information, the amount of rationale, and especially the amount of project and process-related information. In contrast, reports – as one might expect – placed more emphasis on the evaluation of the performance of the final product/artefact, largely through factual, textual description, tables summarising information and CAD drawings. These differences are clearly illustrated with a representative example in Figure 7-9, which show corresponding entries from the logbook and the report:





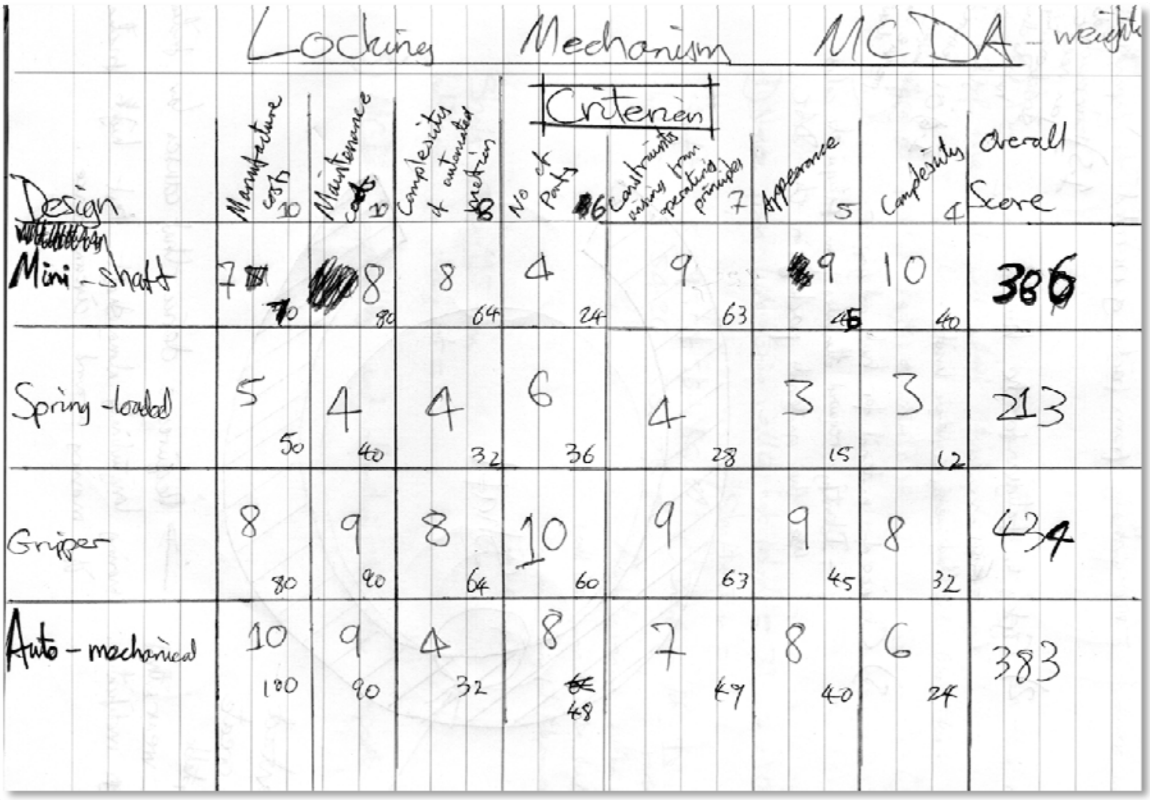
6.2.4 Bearing Specification

The bearings will not experience any significant axial load. The load will be mainly radial. The most suitable bearings for the task were cylindrical roller bearings. The design chart in appendix section 12.8 shows the relative strengths and weaknesses of the most common types of bearing. It is clear from the table that cylindrical bearings are the most suitable. All bearings were selected from the SKF range, and one NU1009ECP (providing radial location of the shaft) and one NJ209 ECJ (providing radial and axial location) are required for each shaft. Adaptor sleeve HJ209 and locating ring 2FRB 10.5/90 are also required for each shaft. The housings selected were SNH 510-608.

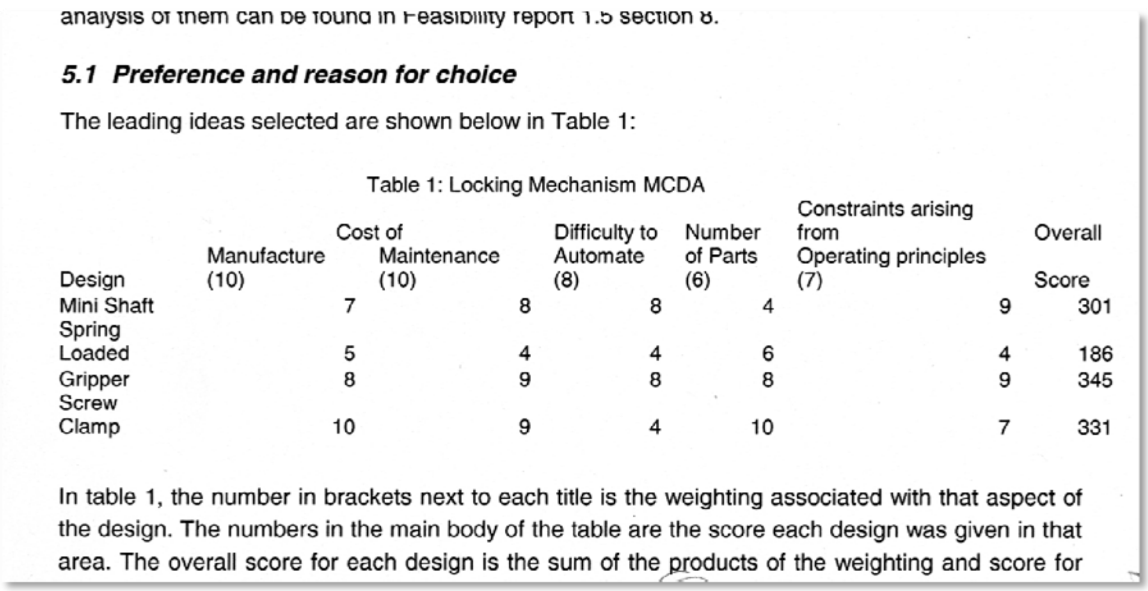
Figure 7-9 – Example of difference in nature of corresponding entries

Here the interwoven nature of logbook entries can clearly be seen, with text, calculations, cost information, contact details and sketches all present. In contrast, the corresponding report entry is purely textual and presented in a factual manner. Whilst it is easier to follow than the relatively ‘messy’ logbook entry, no alternatives are offered, no calculations are shown and the rationale for the assumptions made for the analysis are not apparent.

Figure 7-10 illustrates another logbook entry and its corresponding report section, which are the output of a multi-criteria decision analysis (MCDA). This is a weighted table that is designed to compare various criteria in order to select from a number of alternative locking mechanism designs:



Design	Manufacture costs 10	Maintenance costs 10	Complexity of automated operation 8	No of Parts 6	Constraints arising from operating principles 7	Appearance 5	Complexity 4	Overall Score
Mini-shaft	7 70	8 80	8 64	4 24	9 63	9 45	10 40	386
Spring-loaded	5 50	4 40	4 32	6 36	4 28	3 15	3 12	213
Gripper	8 80	9 90	8 64	10 60	9 63	9 45	8 32	434
Auto-mechanical	10 100	9 90	4 32	8 48	7 49	8 40	6 24	383



analysis of them can be found in Feasibility report 1.5 section 8.

5.1 Preference and reason for choice

The leading ideas selected are shown below in Table 1:

Table 1: Locking Mechanism MCDA

Design	Manufacture (10)	Cost of Maintenance (10)	Difficulty to Automate (8)	Number of Parts (6)	Constraints arising from Operating principles (7)	Overall Score
Mini Shaft	7	8	8	4	9	301
Spring Loaded	5	4	4	6	4	186
Gripper	8	9	8	8	9	345
Screw Clamp	10	9	4	10	7	331

In table 1, the number in brackets next to each title is the weighting associated with that aspect of the design. The numbers in the main body of the table are the score each design was given in that area. The overall score for each design is the sum of the products of the weighting and score for

Figure 7-10 – Example of discrepancies in corresponding entries

Whilst it can be seen that in both cases, the 'Gripper Screw' design achieves the highest overall rating, the numbers differ (434 vs. 345 in the formal report). This is due to the 'Appearance' and 'Complexity' categories being omitted from the table in the final report, as well as a transcription error in the 'Number of parts' column (8 vs. 10). This shows that (as in the previous example and findings in previous chapters) logbooks are used to 'mediate' design activity – that is, they are used to integrate data and information from various sources, allowing that information to be reflected upon, iterated, and finally transferred into a formal report. Elements of this type of use also further supports the concept of ideation from Currano & Leifer (2009).

7.4.2 Re-use Scenarios

The above analysis clearly shows that there are significant differences between the formal and informal project records (i.e. that logbooks records are *unique*) and that the informal records are related to the project and often coherent enough to be readily understandable (i.e. they are also *useful)*. This gives rise to the argument that in a significant number of cases, neither the informal nor the formal records are likely to represent a complete record on their own. Reading the formal reports alone (the usual scenario) may lead to an over-emphasis of the performance of the chosen solution, at the expense of rationale about decisions on, for example, the merits of alternatives and the process by which a solution was arrived. There are two main scenarios where a more complete record could be useful:

1. Information retrieval from an organisational perspective – for audit or to support other business processes.
2. Re-use of design information by engineers, either during the project or for another project in the future.

From an organisational perspective, the more complete records of planning and team/HR information are clearly useful for audit and intellectual property management purposes, even in their current form. Such information is particularly significant, as even where meetings are formally minuted, it has been shown that there is a large loss of information, and specifically actions arising (Huet et al., 2006). This means that the informal records are often the only source of much of this information and could provide vital evidence of, for example, who was present at meetings, who was responsible for a particular task, or when a certain method or solution was first discussed. It could also be used to support other more routine business processes such as project and knowledge management activities. For example, the project categories presented in Figure 7-5 shows that information related to ergonomics was largely absent from the logbooks. Whilst this could just be a consequence of the nature of this particular project, routinely identifying such differences could be used to pro-actively identify possible deficiencies in the decision making process. Figure 7-10 illustrates the role of logbooks in allowing the identification of errors and omissions made during the design process, which may be useful in audit situations and also for design re-use, which is now discussed.

For the second scenario (re-using design information either during or after a project) being able to assess its value and relevance is a critical factor, which is in turn made possible by being able to understand the context in which it was created. It is arguable that logbooks can provide such additional context - and particularly assumptions and models on which the analysis depends - as illustrated in Figure 7-9. Therefore, as well as being useful during a project to ensure the reports are an accurate, balanced reflection of the work done, re-use of information from past projects could be considerably improved. This is because of the potential for better access to the product context and rationale contained in informal sources, as well as through learning lessons from the process, which is impossible with the reports alone.

Linking informal records to their more formal counterparts would then appear to be a sensible way forward. However, the richness of logbook entries, combined with their very different nature makes the direct linking of one entry to another in a report problematic – as does the relative inconsistency in the presentation of informal records. This issue and other requirements arising for the design of a future e-logbook are now discussed, before conclusions are drawn.

7.4.3 Requirements Arising

Firstly (and in direct support of the requirement to support all information classes from the content analysis in Chapter 6) it is apparent that the large numbers of sketches (as seen in Table 7-2) requires explicit support – that is, pen input is an essential requirement.

This study also reinforces the previously stated requirement to support the various 'modes of use' that existing logbooks support so well – in particular, the *ideation* role from Currano & Leifer, 2009 (including idea and concept generation, brainstorming, developing, refining and visualising ideas). For example, there is considerable evidence of such ideation-type activities in the logbooks in this study:

- Figure 7-7 shows significantly higher levels of 'solving' activities in logbooks compared to reports, which includes searching and comparing possible solutions
- Figure 7-8 also shows that logbooks contain many more entries that are 'exploratory' in nature, as opposed to the high levels of informative entries in the formal reports.
- Many of the aspects of ideation can also be seen in Figure 7-9, which shows assumptions being made, ideas tested and alternatives considered.

In addition, it has previously been shown in the literature that personal information such as that found in logbooks has a role in "*self-explanation and problem solving*" (Trafton & Trickett, 2001) – which is essentially what searching and exploring involves. It is also clear from previous chapters that logbooks support this type of use through the quick and flexible creation of multiple types of information. For example, the participants interviewed to create the scenarios Chapter 5 often made reference to the utility of the logbook to quickly record thoughts, ideas and other *aide-memoires*. Further, Sellen & Harper (2002, p.50) identify a number of similar "*affordances*" of paper including reminding through its physical presence, allowing a flexible spatial layout, the interweaving of reading and writing and the ability to annotate.

It is therefore argued that there is a fundamental requirement to retain these characteristics of existing paper logbooks that support these types of ideation activities so well. However, the re-use scenarios outlined in section 7.4.2 above and the requirement for more a more consistent structure and application of metadata introduced in Chapter 6 may be viewed as fundamentally at odds with the quick, flexible nature of logbook entries. It is therefore important to ensure that any requirement for more consistent structure and identification of entries is fulfilled in such a way as not to affect the quick and flexible nature of creation.

There is also further evidence in this chapter of the role of the logbook in *mediation* (discussed in Chapter 5) – that is, logbooks being used as a temporary store for gathering and integrating many types of 'information scraps' (Bernstein et al., 2008) that are then moved or transformed into calendar entries, CAD drawings, more formal reports, presentations or other electronic personal information management tools. For example, Chapter 5 reveals users view logbooks as central in this activity, and Figures 7-9 and 7-10 both show that logbook information is subsequently re-used in formal reports. This is also consistent with the finding in the survey in Chapter 4, with 68% of respondents re-using logbook information when writing reports.

It is argued that this mediation role should be supported by affording easier transformation of logbook material into other forms and allowing the linking of logbook entries to their more formal counterparts. For example, identifying tasks in logbooks could facilitate their transfer to a task manager and being able to identify all the entries belonging to a particular project or person. The requirement is therefore to identify logbook content in such a way as to facilitate links with more formal sources, allowing easier transfer or transformation of this content.

7.5 Concluding Remarks

The aim of this chapter was to investigate two aspects of logbooks: the *usefulness* (i.e. the content is demonstrably understandable, relevant to engineering design tasks and could be useful) and the *uniqueness* (i.e. such information does not exist elsewhere in formal records). To this end, a detailed comparative study has been carried out on complete set of representative documentation from a design project concerned with reducing changeover time for packaging machinery. It comprised of six logbooks and 11 corresponding formal reports, plus CAD drawings, amounting to nearly 1000 pages of information. These documents were classified against a comprehensive coding scheme covering information types, product and process-related categories, problem solving and communication intent, developed at the University of Bath and applied successfully to evaluate other document types.

The results suggest that logbook content does fulfil both the usefulness and uniqueness criteria, with the analysis revealing a number of significant differences in the *content* of the logbooks compared to the reports: There was evidence of both loss of some specific types of information such as sketches, and virtually all planning, team/HR and task information. The content in many cases was also of a form that could be readily understood, although the personal nature of logbooks and their role for quick recording of ideas meant that this was not true of every entry. Importantly, there were also significant differences in the *nature* of the entries, even when it appeared that the information was present in the formal reports. For example, logbooks were much more 'exploratory' in nature (where more than one option was considered), with an emphasis on 'solving' activities such as searching for solution principles, problem solving and evaluating. In contrast, the reports were much more concerned with factual evaluation of the design's performance, with elements such as explanatory sketches, assumptions and alternatives considered but not chosen, often missing. The clear implication was that access to both sources would produce a more complete - and arguably more useful - design record for both individual and project/organisation re-use.

However, it was noted that it is the personal nature and unique affordances of paper logbooks in supporting the *ideation* and *mediation* modes of use were what allowed the creation of this type of record. In contrast to previous attempts at e-logbooks, this research has attempted to follow a largely user-centred approach to the design of logbooks. The requirements arising from this chapter are therefore focussed on the apparent trade-off between the flexibility of paper logbooks to allow the creation of such rich records, with the need for a more consistent structure and means of identifying entries identified as a requirement in Chapters 4 and 6. The main requirements are that the features of logbooks that support ideation and mediation should be retained (flexible pen input, sketching, unconstrained layout of entries, interweaving of information types etc.) and that logbook entries should be structured in such a way as to facilitate their linking to – or transformation into – more formal records.

8 E-logbook Technology Review

Despite Blemel's (1989) assertion that the "*automation of engineering logbooks should be simple and easy"* and almost every other aspect of engineering design being transformed by digital technology such as Product Lifecycle Management (PLM), CAD/CAM and other specialist computational systems, the "*myth of the paperless office"* (Sellen & Harper, 2002) still persists. The literature review in Chapter 2 argued that the lack of research into informal and personal information (including logbooks) and the subsequent lack of fundamental understanding into what they contain and how they are used has contributed to the low uptake of new tools and methods to better manage such information. Further, where specific knowledge about, for example, the affordances of paper did exist, technology was not sufficiently advanced to offer a viable alternative.

This notwithstanding, over the past decade a variety of electronic logbook technologies have been developed. These have mainly been aimed at the pharmaceutical and natural sciences, but attempts aimed at engineering domain do also exist. Myers (2003) provides a useful general summary and Taylor (2006) provides an overview of Electronic Laboratory Notebooks (ELNs) for chemistry and biology. Taylor notes that "*interest in ELNs was subdued until 2004*", although a resurgence in interest since then (mainly in the pharmaceutical industry and life sciences) has led to around 30 vendors offering solutions. It is also a rapidly expanding market, with a growth of 30-40% and sales of around US$50m (£30m) in 2006 (Elliott, 2006). This growing interest can be attributed to legislative and regulatory changes (including the greater acceptance of electronically signed documents in courts of law), more advanced technology and more specific solutions being offered (Elliott, 2006).

This chapter therefore presents the results a technology review of existing e-logbooks, with the aims of identifying the characteristics of the existing solutions from engineering and other domains, and factors contributing to their success or otherwise. The rest of this chapter is structured as follows: Section 8.1 classifies existing e-logbook attempts into three broad areas, before they are reviewed in detail in 8.2, with respect to a typical information lifecycle. The characteristics of these existing e-logbooks are discussed with respect to the findings and subsequent requirements arising from the previous chapters. More general observations not relating directly to the solutions are discussed in Section 8.3 before conclusions are drawn in 8.4.

8.1 Overview of E-Logbook Types

This chapter reports on a review of existing electronic logbooks and associated technologies. The information has been gathered from both the academic literature and also commercial vendors of such systems. Schraefel et al., (2004) classify e-logbooks along two dimensions, the *artefact ownership* (i.e. whether the logbook is controlled by an individual or a group) and the *medium* (in relation to traditional paper logbooks). The medium can seek to *replicate* (paper-based, but with customised pages)*, augment* (again paper, with some method of increasing the functionality, such as scanning pages to make them searchable etc)*, supplement* (make creation of paper-based logbook entries easier) *or replace* paper-based logbook altogether, with desktop computer systems. This classification is illustrated in Schraefel et al., (2004) and populated with logbooks used in the Chemistry field. It is reproduced in Figure 8-1:

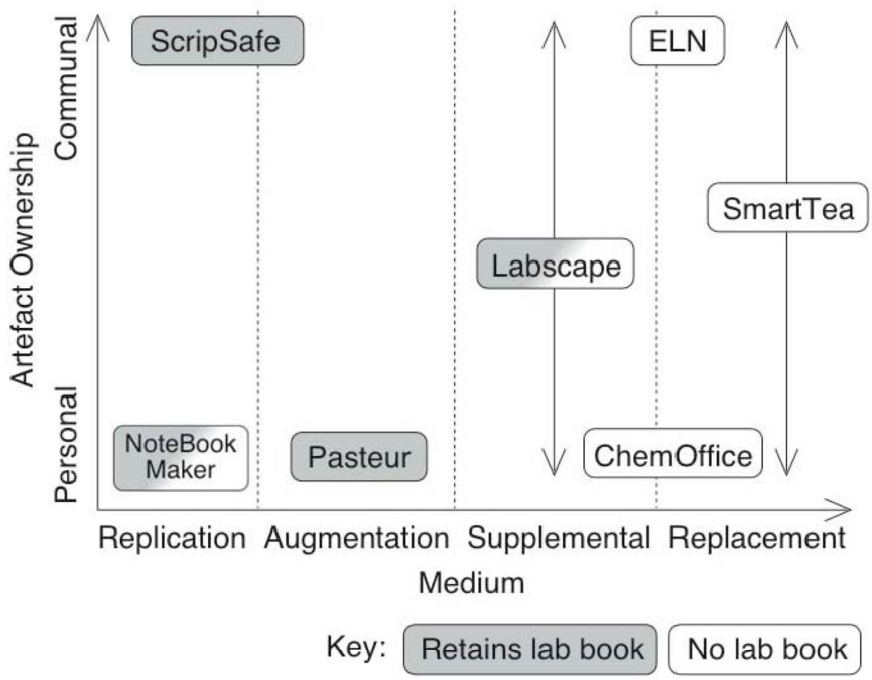


Figure 8-1 – Classification of lab books (*reproduced from* Schraefel et al., 2004)

For the purposes of this review, the classification has been modified to reflect more the aim of reviewing different types of electronic logbooks only, meaning the *replication* category is of less relevance. Whilst the distinction made between personal and 'communal' logbooks made above is also a valid one and will be considered, it again does not explicitly support the aims of this chapter. The e-logbook systems reviewed below have therefore been broadly split into three categories, based on the principle technology employed:

1. Enhanced or augmented paper-based logbooks (*augmented)*
2. Computers with pen based input *(supplemental/replacement)*
3. Keyboard- or web-based logbooks (*replacement)*

It must also be noted that the following overview of these three areas is not intended completely exhaustive, but instead focuses on more recent or particularly significant implementations. This is because many essentially similar offerings exist, particularly in the pharmaceutical and natural science fields. This review is therefore intended to represent a broad cross-section with the aim of drawing lessons and insights into the key characteristics of such technology, whether it would be able to fulfil the particular requirements of logbook use in the engineering domain and whether any other lessons or possible research directions are apparent.

The sections below first summarise the types of system in each of these three areas, before their features and capabilities are discussed in detail in section 8.2.

8.1.1 Augmented Paper Approach

Several technologies have been developed that provide for the electronic capture of handwriting as it is written on to paper. These 'pen based' technologies track and record their own movements as digital coordinates via a sensor placed under a pad of paper (see, for example, the 'Digimemo' from Acecad, 2004). This basic approach is also taken by the a-book project (Mackay et al, 2002), but is particularly novel, as it uses a combination of paper placed on a sensor and a small Personal Digital Assistant (PDA). The PDA acts as an 'interaction lens' when placed on the notebook, providing links to other pages, dynamic content such as computer models or video, and even physical objects by tagging them. This is illustrated in Figure 8-2, reproduced from Mackay et al., 2002:

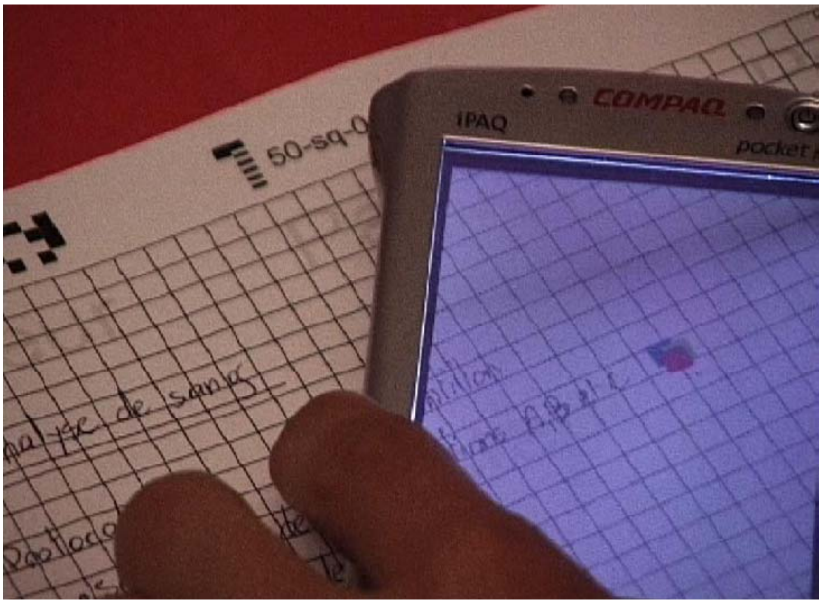


Figure 8-2 – The a-book (*reproduced from* Mackay et al., 2002)

The other main approach to augmented paper systems uses Anoto functionality (Anoto, 2007), which is a combination of a digital pen and specially encoded paper. It is unique as the sensor and recording technology are integrated into the pen itself, which must be used in conjunction with paper printed with a fine grid pattern that is almost invisible to the naked eye. The complex grid pattern allows the pen to identify not only its position on a page, but the page number and even the type of notebook used[6]. The system also has a limited paper-based interface to, for example, classify notes into types or indicating that a particular function is to be carried out – such as the note being emailed to a recipient when downloaded from the pen. Current implementations of the Anoto system include not only conventional notebooks, but, for example, Post-it™ notes and diaries. One recent implementation (Livescribe, 2009) also allows some tasks to be processed by the pen itself, such as simple calculations and recording and synchronisation of audio to the written notes in a similar fashion to Dynomite (Wilcox et al. 1997) discussed in Section 8.1.2.

8.1.2 Pen Computing

Personal Digital Assistants (PDA's) and other pen-based computers are an increasingly common method of recording personal notes. As well as the general feature-set (drawing, typing, diary functions, email and web browser applications), some also have audio and video functionality and can also communicate via wireless networking protocols such as Bluetooth and Wi-Fi. There are several main examples of specialist logbook software designed for PDA's and pen-based computers and can be seen largely as replacements for paper logbooks.

Firstly, Dynomite (Wilcox et al., 1997) incorporates pen input and classification of items via simple 'markers' such as 'to-do', 'contact' or 'URL'. These can then be searched or used to dynamically re-arrange the pages. In feedback, users commented that they were generally happy with the markers, but wanted to be able to define their own to better fit their note-taking habits. Dynomite is further augmented by permitting the linking of recorded audio to written notes, which although received positively by users in a pilot study, was not demonstrated to have any particularly beneficial effect on note-taking or levels of re-use.

The SmartTea project (Schraefel et al., 2004) also seeks to replace paper logbooks used by chemists, with the goal of "*a digital lab book that affords the functional and experiential qualities of a paper-based one, while transparently introducing additional benefits for lab practice available in a digital system*". The design of the SmartTea e-logbook was derived from studies of practice including interviews, ethnographic observation and task analysis. An approach the authors called 'Making Tea' was also employed, which sought to elicit and understand the working practices of chemists through analogy – in this case documenting an experiment to make a cup of tea.

The logbook runs on a Tablet PC platform (Microsoft corp., 2005) and provides a range of features in the form of modules aimed specifically at supporting the recording of experiments by Chemists. These include free-form sketching for representing experimental set-ups and also more structured input of, for example, weights and measures, which are then passed between the

[6] The Anoto grid pattern is unique to around 60,000km^2, with various vendors licensing sections of the pattern (Anoto, 2009)

modules as needed to reduce replication. They are also automatically backed-up on a central server. The evaluation of this e-logbook consisted of three chemists using the logbook over a period of one week, recording four experiments in total. The evaluation criteria consisted of whether the chemists could carry out all the *processes* they needed to in the course of the experiments, whether it provided the *outcome* they expected, and whether it *positively affected* their perceptions of recording experiments using an e-logbook. The goal of the e-logbook becoming 'transparent' in use after 10 minutes was met, and the chemists appreciated the safety and availability of the recorded data.

Anquetil et al., (2004) also use the Tablet PC platform to create a laboratory notebook, noting that whilst the platform had shortcomings, it "*offers a more efficient way to collect and record scientific information while allowing researchers to convert their work to a paper-based medium when needed".* More recently, Microsoft has released several non-specialist e-logbook type applications for Tablet PC's (Microsoft corp., 2007). In addition to the audio synchronisation features of systems such as Dynomite (Wilcox et al. 1997), Tablet PC's also provides handwriting and speech recognition and collaborative tools in a device much more powerful than a PDA. The main note taking applications currently available are Microsoft Journal and Microsoft OneNote (Microsoft corp., 2007). OneNote allows the insertion of image files and other attachments, synchronised audio and video capture and some integration with aspects of the Microsoft Office suite, such as the task manager in Microsoft Office Outlook. A Tablet PC is illustrated in Figure 8-3:

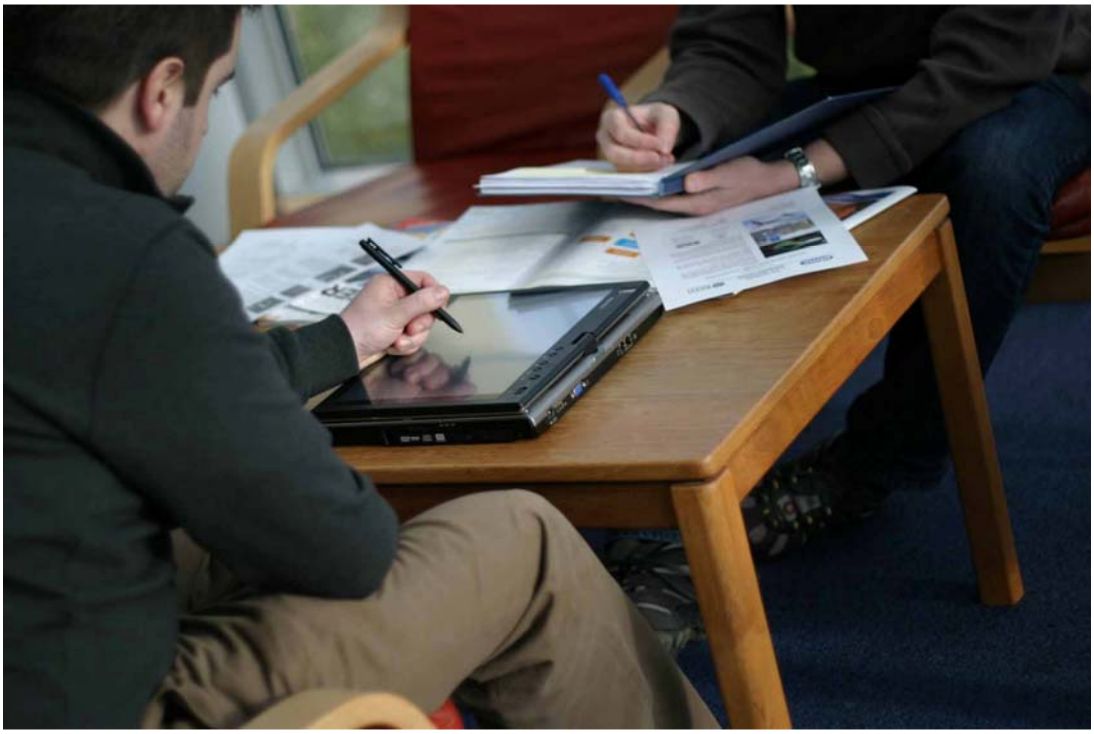


Figure 8-3 – A Tablet PC

Finally, one of the few e-logbooks aimed specifically aimed at engineers is the Electronic Engineering Notebook, or EEN (Gwizdka, 1998), which is a PDA based e-logbook designed to replace existing paper logbooks. This research aimed to "*improve access to design information by engineers*" in a non-obtrusive manner. The EEN application was developed and deployed on a PDA. EEN allows the input of unstructured text via a pen, with semantic classification and searching based on formal engineering ontologies describing parts, parameters, rationale, issues, requirements, actions and meetings. The set of ontologies used are reproduced in Table 8-1:

Main concept	Attributes	Relations
Requirement	Name, description, expression, status	Requirement_of, has_rationale, raises_issue
Rationale	Name, description	Rationale_for
Part	Name, description, type	Has_requirement, has_subpart, subpart_of, has_parameter, has_rationale, raises_issue
Parameter	Name, description, unit, value, physical dimension	Parameter_of, has_rationale, raises_issue
Issue	Name, description, status	Issue_of, has_action, solved_by
Action	Name, description, status, due date	From_issue, raises_issue
Meeting	Name, description, date	Raises_issue

Table 8-1 – Set of ontologies used to structure notes (*reproduced from* Gwizdka, 1998)

A number of experiments were undertaken with 20 undergraduate and graduate design students doing a simple design task, with three different conditions:

1. A free-form (unconstrained) interface with pre-defined terminology for semantic structuring
2. A free-form interface with user-defined terminology for semantic structuring
3. A fixed-form interface (i.e. a form template with pre-defined fields) with a pre-defined terminology driving the template deign.

The results of the experiments were analysed in both a quantitative and qualitative manner main conclusions from the evaluation were that:

- The 'free-form' interface was easier to use than a fixed-form (template driven) interface
- Classifying notes after they had been taken was easier (compared to fixed-forms),
- Users had difficulty applying the semantic categorisations correctly, although project management items such as 'action' and 'meeting' were universally understood.
- Users preferred concrete (not abstract) terminology
- The categorisation terminology used should be appropriate to the task, but purely user-defined terminology leads to a large number of terms, reducing the usefulness of any subsequent search activity.

- The high variability in note-taking styles needs to be taken into account in the design of e-logbooks. For example, some users wanted to group related notes, whilst others preferred a purely chronological arrangement.

8.1.3 Keyboard and Web-based Notebooks

There are many general note-taking applications, such as Evernote (2009). These allow note-taking via a keyboard and mouse interface, the insertion of other files and pictures and various forms of classification, including simple folders, tags, or a combination of the two. They also allow searching of the content by keyword or tag and are primarily for personal information management. A more recent development has been the move of such systems being hosted online. This allows access to the notes from any location and (importantly) any device, as personal users now frequently access the internet from multiple devices such as home and work computers, as well as mobile devices (see, for example, SyncNotes, 2009).

Although there appears to be less published research into keyboard and web-based e-logbooks, there has been a significant number of e-logbooks in the natural science and pharmaceutical industries, with Taylor (2006) identifying 29 different vendors. These e-logbooks (commonly referred to as electronic laboratory notebooks – or ELN's) have been created with a very different motivation and contain very different feature sets when compared to many other e-logbooks that have been aimed mainly at personal information management. Most fall into the category of paper replacements, with communal (shared) creation and ownership of the information.

Research Notebook (Knowligent, 2004) and Electronic Laboratory Notebook (ELN) of Myers (2003) are both server-based logbooks, accessed through a web-browser. The primary input mode is via a keyboard, although images can be inserted and dynamic links created between files. Both attempt to bridge the gap between personal and enterprise-level records management by providing data security and authentication features such as digital signatures and limited structuring of information through the use of templates to enable integration with a workflow such as standard experimental protocols.

Similar systems such as CambridgeSoft's (2009) E-Notebook function as a 'module' in a broader range of packages such as data visualisations tools and databases of chemical information etc. This typifies an important driving force behind the adoption of ELN's in natural sciences and pharmaceutical research - namely their ability to integrate with other systems, (particularly bioinformatics databases and chemical information), the ability to download experimental protocols as 'templates', automatic recording of large volumes of data and enhanced compliance with regulations. However, there is a lack of empirical evidence of the benefits of these approaches. Indeed, Schraefel et al., (2004) noted that whilst the chemists interviewed did not doubt the ability of keyboard and web-based e-logbooks to capture the data required, it was suggested that paper logbooks held particular and necessary affordances that these systems did not sufficiently replicate.

In the engineering domain, an early implementation of a system that had some logbook functionality was the SHARE system of Toye et al., (1993), which was a template and tag-driven system for gathering and sharing informal engineering design information. One of the first 'dedicated' e-logbooks was PENS – the Personal Electronic Notebook with Sharing – of Hong et al., (1996). This attempted to replicate what was identified as the *reflective* nature of existing paper-based logbook use (aimed primarily at oneself and recorded but not shared). PENS supported the quick recording of notes via a keyboard, but only had very limited graphics support. These notes could then be transferred to central server for sharing. PENS has been used in several pieces of research, notably by Liang et al., (1998) and Yang et al., (2005), although its current status is unclear. More recently, there has been interest in weblogs and wikis as types of logbook, with Currano & Leifer (2009) noting that "*as information resources have become increasingly digitised, and drafting has been replaced by CAD software, there is an accompanying trend toward replacing paper logbooks with electronic tools, such as wikis and blogs".* There have also been evaluations of wiki's as a collaborative logbook (see, for example, Walthall et al., 2009; Parker & Chao, 2007; Werasinghe & Salustri, 2007). In the largest of these studies, Walthall et al., (2009) deployed a wiki to over 500 engineering design students working in teams of five. The goal was to better understand the role of wikis in early stage collaboration. The software deployed was DokuWiki and it was used over one semester. Whilst the response of the students was largely positive, Walthall et al. (2009) note that there was large variation in how the wiki was used. Some teams used it largely as a project planning tool for meeting minutes, whilst other teams did record design ideas. Finding information on other teams' wikis was also noted as problematic, as the structures differed so widely, suggesting a slightly more structured approach may have be useful. However, the teams that did access other groups' wikis successfully did report that the information was useful. It was also noted that the ability to attach documents to pages would have been useful, as would the ability to sketch. In this system, the students had to sketch on paper, before scanning and uploading the image – clearly a limitation given the prevalence of sketching observed in chapters 6 and 7.

8.2 Discussion – Supporting e-logbooks

Figure 8-4 places the e-logbooks discussed above into the classification of Schraefel et al., (2004):

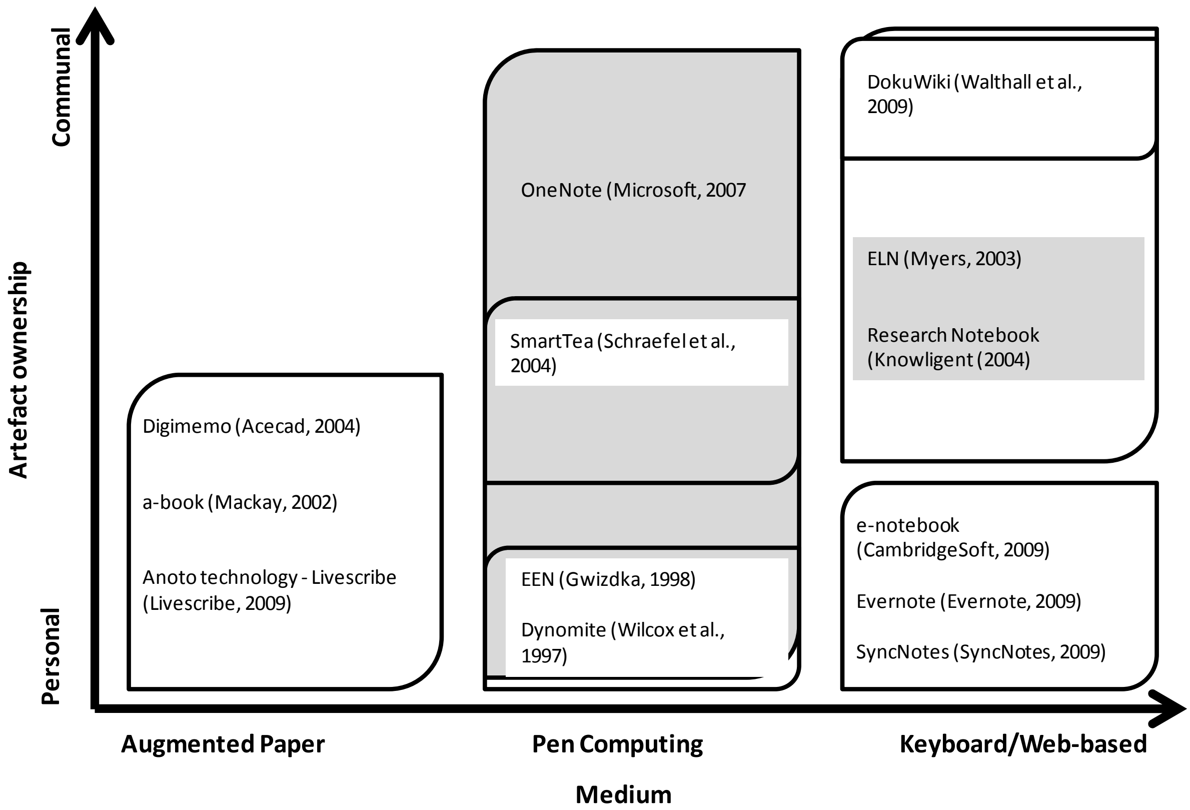


Figure 8-4 – Classification of reviewed e-logbooks (*adapted from* Schraefel et al., 2004)

It can be seen that the augmented paper approaches have generally focussed on emulating the affordances of paper, with the augmentation mainly aimed at helping the individual. Although having some type of electronic augmentation could aid sharing (through, for example, easily being able to email a logbook page to a colleague), this is not the focus of these logbooks. The pen computing solutions are spread between those intended for individual use and Microsoft (2007) OneNote™ which can be used either as a personal notebook, or completely communally in a shared space. A similar range is evident in the keyboard and web-based logbooks, although as expected from web-based tools such as wikis, they are not designed for individual use.

In order to appraise the capability of these existing products and technologies to support the requirements of engineers, the key functionality of the logbooks discussed above needs to be understood. Five main classes of activity (representing a typical logbook information lifecycle) are used to structure the following discussion and are defined as follows:

- **Creating/recording** – How information is recorded, and what form it takes.
- **Classifying** - Marking or structuring information to aid understanding and re-use

- **Browsing/navigating** – Reading or reviewing logbooks contents (flicking through pages etc.)
- **Searching** – Structured ways of locating a particular piece of information.
- **Sharing/collaborating** - Sharing means a person sending information, or making it available if requested whilst collaborating is the synchronous or asynchronous creation or editing of content by two or more individuals/groups.

The functionality of the logbooks summarised in 8.1 are now discussed with respect to the information lifecycle activities defined above. Other observations on issues such as portability and other practical considerations are then made in 8.2.6, before a summary of the findings is presented in 8.2.7.

8.2.1 Creating/Recording

Firstly and importantly, none of the technologies reviewed can support all thirteen classes of information identified in Chapter 6 without additional effort to convert some of the types of information, such as pictures, into a suitable format. In the case of augmented paper logbooks such as the a-book (Mackay et al., 2002), whilst digital and paper formats can both be handled, the effort required to synchronise and subsequently retrieve the mixed-format information is higher.

In the case of replacement electronic logbooks such as EEN (Gwizdka, 1998) or SmartTea (Schraefel et al., 2004), the effort would be centred on digitising relatively small amounts of paper such as Post-it™ notes. Arguably though, the benefits that electronic replacements provide in terms of being able to embed or link to actual models, instead of representations of a single viewpoint could outweigh the inconvenience of having to digitise small amounts of paper-based information. For example, a 3D model could still be manipulated in an electronic logbook, as opposed to a single, un-editable 2D representation in a paper logbook. However, support for single viewpoints is still necessary as they often illustrate particular points being made which would not be apparent from the model alone, and annotation of a particular feature, as evidenced in Chapter 6.

Comparing augmented paper logbooks to pen computing solutions, it is evident that the retention of paper as the primary recording medium holds several key advantages over pen computing as it retains the well documented affordances of paper such as reminding by physical presence (Sellen and Harper, 2002) whilst allowing electronic backup, distribution and searching. However, such augmented-paper systems do have potential drawbacks, such as their inability to include dynamic content such as hyperlinks or video and difficulties keeping the paper and electronic copies synchronised. The ‘interaction lens’ of the a-book (Mackay et al., 2002) offers an interesting solution, although requires adaptation of existing systems and considerable change to existing methods of work to support it. Further, Schraefel et al., (2004) note that the assumption that electronic technologies cannot replicate the affordances of paper sufficiently well is unproven. Improving screen technology (in terms of size, resolution, pressure sensitivity and cost) means it is less likely to be so in the future. Further, Schraefel et al., (2004) note that "*…the acknowledged cumbersomeness of [augmented paper devices]"* is what motivated them to re-visit electronic alternatives.

The second important aspect of creating and recording was manifested in chapters 5-7 with large numbers of sketches and other free-form types of input. Wilcox et al., (1997) point out that "*freeform input, spatial layout and even doodles (for their visual cues) are an integral part of the note-taking process*". This (together with the prevalence of sketching observed in chapters 6 and 7) is why logbooks that do not allow free-form input seem to be less appropriate for engineering logbooks. This view is also supported by Gwizdka (1998) who observed that free-form input was easier than 'fixed-form' templates and Schraefel et al., (2004) who noted the highly negative reaction of Chemists to this type of e-logbook. Walthall et al., (2009) also found that support for sketching was necessary, but lacking in current wikis used as collaborative logbooks. This implies that keyboard and web-based e-logbooks are unlikely to be successful in the engineering domain without modification to support these types of input.

Another key area that has received little attention is the finding by Sellen & Harper (2002) is that in knowledge work, reading and writing occurs simultaneously over 50% of the time (e.g. reading a book whilst taking notes in a logbook). Given that many of the products and technologies reviewed are designed to overcome the difficulties of switching between paper and electronic formats, this activity is generally poorly supported by existing attempts. For example, the analysis of the scenarios in Chapter 5 revealed that logbooks are commonly used to 'mediate' between the individual and formal outputs such as research, but no specific regard is paid to how this may be facilitated with the ways of recording information suggested by most of the e-logbooks reviewed. The exceptions to this are found in the pharmaceutical and scientific domains, where explicit attempts to integrate the captured logbook content into a wider workflow are made through, for example, the ability to download experimental protocols. However, most of the technologies are not engineering specific, meaning integration with common engineering data types (e.g. CAD, analysis software) is lacking.

However, one area where all the technologies reviewed provide a clear benefit over existing paper-based books is in the automatic recording of time, data and other routine metadata. Automatic recording of this information appears to lower the classification burden on the author and also provides useful metadata for subsequent searching and re-use. This is now discussed in more detail in 8.2.2 & 8.2.3 respectively.

8.2.2 Classifying

Classification of some sort is usually necessary to support searching and re-use. As well as some basic automatic recording of time or date, some of the technologies described here allow classification by 'tagging' elements such as lines of text or sketches. Others such as the Research Notebook™ (Knowligent, 2004) and SmartTea (Schraefel et al., 2004) rely on a more structured approach to note-taking via templates. The wiki technology evaluated in Walthall et al. (2009) relied on browsing pages, supplemented with keyword searching – both of these aspects are discussed later.

In the case of EEN (Gwizdka, 1998), the terminology used for the classification is based on engineering ontologies as described in Table 8-1 and provide a way of providing detailed and structured information for storage and retrieval, without constraining the user at the time of input. Research into different levels and modes of classification (Gwizdka, 1998) supports the view that a free-form interface, with structuring occurring after note-taking is preferable, whilst analysis of previous logbooks (Chapter 6) has revealed that authors use symbols such as stars or bold words to 'tag' entries, suggesting engineers would find classification by tagging fairly easy and natural.

Significantly, abstract terms (such as 'parameter' or 'requirement') were not well understood and led to confusion (Gwizdka, 1998). Concrete terms were much more well understood– for example, users in the evaluation of EEN were more receptive to classifying information with terms such as "depth" rather than "parameter" or "requirement", remarking that they "*do not think in terms of rationale, parts, and parameters"*. Another significant finding was that 'project management' terms such as 'action' and 'meeting' were universally understood.

Allowing users to define their own terminology for classifying was also tested by Gwizdka (1998). Whilst it was noted that the resulting terminology was universally understood by the author, the proliferation of similar terms or domain-specific language has the potential to affect re-use by both the original author (through having to remember the terminology used) and particularly organisational re-use where the original author is not present. Domain-specific terms and abbreviations also have the potential to limit re-use in the longer-term. Other technologies, such as Microsoft OneNote (Microsoft corp., 2005), allows users to define custom sets of tags for classifying information, although it is not possible to define attributes in the OneNote™ application.

The main contradiction that emerges from these existing products and technologies is that there is a need to provide a system that balances the ease of creation for the author with the ease and extent of potential re-use in the engineering domain. The benefit of getting this trade-off right in demonstrated in Gwizdka (1998) through higher and more accurate use of terms the engineers could understand. Similarly, a key success factor for the SmartTea systems of Schraefel et al., (2004) was that it should become 'transparent' to the user within 10 minutes (that is, very little effort is required to adapt to it). Finally, Walthall et al., (2009) notes that students who reported that the wiki was easy to use were more likely to use it, and that they felt the outstanding issues were easy to resolve.

8.2.3 Browsing/Navigating

Being able to access recent information quickly and 'browsing to remind' are key activities for engineers. In this research, 'browsing' is defined as the act of working through pages in a linear fashion. Navigating is defined as the act of systematically finding particular information in a visual fashion (as opposed to using a keyword search or based on memory alone). The importance of both of these finding strategies has been highlighted in Chapter 4, with a majority of engineers accessing their current logbooks on a daily basis and 'browsing to remind' themselves of, for example, actions from past meetings or experimental set-ups. Chapter 5 also confirmed the importance of the logbook in mediating between various information sources and that being able to quickly browse the logbook was beneficial to this activity. This relates to the role of logbooks in self-explanation and problem solving (Trafton & Trickett, 2001) and as a tool to develop and refine ideas (Currano & Leifer, 2009), which frequently requires the last iteration of a design to be revisited.

Paper is well suited to browsing activities by providing subtle visual and tactile cues gained from turning pages (Sellen & Harper, 2002). Clearly, then, augmented paper-based approaches such as the a-book (Mackay et al., 2002) have an advantage in this area. A drawback is that the user is then required to switch between two views (paper and electronic) to see all the information (e.g. links or attached files) which has been noted as cumbersome. Another drawback of paper-based systems is that browsing in this fashion does not scale well. Whilst evidence from previous chapters suggests it works well for the current logbook, as the amount of information grows, so does the difficulty of browsing it. In terms of navigating, paper-based and augmented paper systems both require additional effort to either maintain an index or contents page of some sort, or to again switch between the paper-based and electronic versions, both of which require additional effort. The fact that only 7% of engineers surveyed on Chapter 4 used an index or contents page suggests the effort of maintaining one is too great for most users and situations.

Pen-computing or keyboard/web-based logbooks certainly have the potential to support the activity of navigating large volumes of information more efficiently than paper by virtue of having the ability to display dynamic content. One way in which several of the reviewed logbooks such as EEN (Gwizdka, 1998) and DokuWiki (Walthall et al., 2009) provide options for this is by allowing hierarchical browsing and dynamic re-arrangement of pages based on their properties, such as how they are tagged, or by title or date. Therefore, instead of browsing to find, for example, notes from a previous meeting that may be at any point in the logbook, one could display all the meeting notes in a single aggregated view:

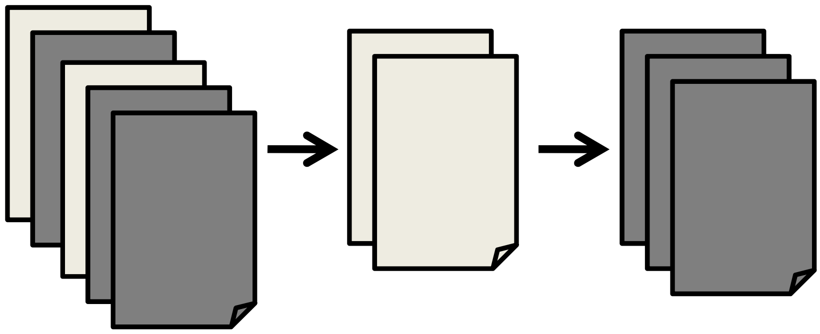


Figure 8-5 – Dynamic rearrangement of logbook content

However, of the two types, pen-based interfaces offer arguably more natural options for browsing pages with more natural and tactile interfaces, and could potentially provide the 'best of both worlds' in this regard. Despite this, it is important to note that none of the e-logbooks reviewed here has published an evaluation detailing the effect of different types of interface on the user's ability to browse and navigate, although it is noted in Gwizdka (1998) that it does have an effect.

8.2.4 Searching

Related strongly to navigating, all the technologies reviewed provide some search capability (defined here as structured, query driven, automatic navigation to a particular piece of information), either by searching tagged content or - in the case of keyboard/web-based logbooks - a keyword search. It is argued that the ability to search logbooks is one of the greatest advantages that electronic logbooks could provide over their purely paper-based equivalents. Although the search methods could clearly be improved upon by using more sophisticated handwriting recognition and contextual or semantic search techniques, search facilities should provide a major and immediate benefit for individual engineers. For example, it has been noted in Chapter 4 that whilst engineers typically access their current logbooks on a daily basis, nearly 20% did not retain past logbooks, with a further 42% referring to them for specific events only. Whilst it could be argued that this is because they contain little of value, this is not borne out by either the comments of engineers in the previous research, or findings that the respondents were "*generally dissatisfied*" by the note-taking process (Wilcox et al., 1997) and that most engineers indicated that more search options such as keyword searches would be "*highly beneficial*" (Chapter 4).

Despite the capabilities of electronic searching, sketches or other visual objects which make up a significant amount of the typical engineering logbook are still not easily searchable. Further, despite advances in handwriting recognition, accuracy is still variable depending on writing styles and the amount of domain-specific vocabulary and abbreviations used (both of which are prevalent in logbooks). It is argued that using a well developed terminology for tagging information elements may overcome this to some extent and allow more effective searching, as well as navigating (8.2.3). Being able to search for non-textual elements is especially important given the number and significance of sketches and other graphical representations in engineering.

It was noted in Section 8.1 that Gwizdka (1998) explored several different types of terminology to classify elements in the Electronic Engineering Notebook (EEN). Whilst it was noted that users found concrete terminology easier to understand and apply compared to abstract terminology such as 'parameter' or 'requirement', the abstract terminology was re-used more often to tag notes. This is important because in the user defined terminology condition, large numbers of concrete terms were created by the users, which was noted to adversely affect the ability to subsequently search notes. These findings are also strongly supported by Lowe (2002) who investigated the attributes used by engineers when searching for information. The most frequently citied attributes used in searching for information were simple terms like project names, authors, titles, unique document identifiers such as report numbers, and dates.

8.2.5 Sharing/Collaborating

Given that a significant proportion of design is now undertaken in distributed teams, support for sharing and collaboration is particularly important. Indeed, the engineers surveyed in Chapter 4 indicated that easier sharing and collaborating would be very beneficial or 'of some benefit' to their work. In addition, a clear need for some kind of sharing is indicated from the survey, with 70% of respondents citing 'answering colleagues' questions' as a reason for re-using logbook information.

Web-based notebooks such as ELN (Myers, 2003) have been designed from this perspective and hold an obvious advantage for sharing, as notes are held centrally on a network. The relatively structured form of ELN may also make re-use by stakeholders other than the original author easier, compared to free-form, unstructured text such as that found in paper and augmented-paper logbooks. In addition, although not specifically addressed in the published research, e-logbooks based on pen-computing technologies such as SmartTea (Schraefel et al., 2004), EEN (Gwizdka, 1998) and OneNote (Microsoft, 2005) also have the ability to be shared in this manner, and there is no reason why the files from these e-logbooks could not be held centrally to facilitate sharing. Indeed, this is already the case with the central backups performed by the SmartTea e-logbook (Schraefel et al., 2004), although the objective in this case was data security, not sharing.

However, simply providing a technical means of more than one person accessing the information has been shown to be insufficient for effective sharing: For example, Walthall et al. (2009) found that sharing logbooks between project teams was problematic, due to the problem of *user-defined structures*. This is a similar problem to that of *user-defined terminology* discussed in 8.2.4, which could also negatively impact the potential to make logbook material shared. Even within a single design team, one particular structure may not be suited to all types of user, particularly in a multidisciplinary team.

There is also the issue of the personal nature of such records, with 80% of respondents of the survey in Chapter 4 unhappy to let customers and suppliers access data (although most would be happy sharing with a colleague). ELN (Myers, 2003), OneNote (Microsoft, 2005) and DokuWiki (Walthall et al., 2009) allow permissions to be set for different types of user.

A wider issue with sharing logbook information concerns whether the sharing is instigated by the author in response to a question, or whether logbook content can routinely be made available without intervention by the original author to, for example, explain the context in which the entry was made. Chapter 6 showed how the inconsistent application of metadata (such as a lack of source for external documents) could mean that it could be difficult to form a judgement of trust or quality for information accessed independently of the original author. None of the logbooks reviewed appear to tackle this question.

At the extreme end of this scale, DokuWiki of Walthall et al., (2009) and to some extent Myers (2003) ELN go beyond the traditional idea of facilitating sharing of an individuals' notebook to co-creation (and co-editing) of content in a shared space, blurring the boundary between a traditional logbook and a space for collaboration. Whilst it has obvious utility for some tasks (such as relevant people adding and commenting on information, or updating actions, it is not clear what effect such a permanently shared space would have on the ideation (Currano & Leifer, 2009) and other reflective activities that appear such an important part of logbook use. It is not reported in Walthall et al., (2009) whether the students also kept an additional 'personal' logbook. If so, using wikis as a logbook could, arguably, increase 'information fragmentation' and potential loss by introducing another 'step' between an individuals' ideas and the formal project record.

There are, however, positive aspects to logbooks that facilitate collaborative work. For example, the analysis of logbooks in Chapter 6 reveals lots of free-form annotation of multiple document types - such as images, CAD drawings, and the use of Post-It™ notes to add comments, as well as emails commenting on particular issues. The act of collaborating is therefore clearly of importance to engineers. As such annotations often made little sense to anyone but the authors, the voice recording facilities of Dynomite (Wilcox et al., 1997) and OneNote™ (Microsoft corp., 2005) could provide an interesting additional benefit, although the evidence appears largely anecdotal at present. Another area of particular importance in collaborating and annotating is identifying multiple authors. Web-based logbooks such as ELN (Myers, 2003) are good at identifying and authenticating authors, as is the Anoto system (Anoto, 2009), as each pen has a unique ID, although the issue of combining data from multiple pens has not yet been tackled.

To summarise this section, whilst enhanced sharing and collaborating is another area where improvements over paper could provide real and immediate benefits to both the individual engineer and wider organisation, a key trade-off emerges: How can the ability of logbooks to support individual work (ideation, reflection, storing personal data such as passwords etc.) be retained, whilst allowing easier sharing and collaborating to support modern engineering design work? It is argued that of particular importance in resolving this issue and issues that emerged from will be how the classification method allows for both an individuals' preference without hindering re-use in various potential scenarios.

8.2.6 Other Practical Considerations

Literature (see for example, Wilcox et al., 1997; Gwizdka, 1998) and previous chapters have highlighted the wide range of situations in which engineers use logbooks. For example, they may be carried to various locations, both in and outdoors. Their role in affording quick recording of notes and ideas is also important. Therefore, as well as the observations considered above, a number of practical requirements were also evaluated against the well documented affordances of paper identified in the literature review (Chapter 2) and the logbook analysis in chapters 4-7. The criteria included a number of practical considerations: portability, degree of autonomy, start-up time, readability and input rate.

In terms of portability and autonomy (i.e. the ability to be used independently of, for example, networks or power supplies), keyboard and web-based devices are obviously at a disadvantage and in this regard are unlikely to be suitable in many engineering note-taking scenarios. For example, of the interviews reported on in Chapter 5, all used their logbooks away from their desks for at least some tasks (most commonly taking minutes in meetings or documenting manufacturing issues/experimental rig layouts). It is therefore also argued that purely collaborative logbooks such as DokuWiki of Walthall et al., (2009) that rely on a network connection for use are unlikely to be suitable for the majority of engineers without adaptations which could detract from their usability. For example, notes taken may have to uploaded to the wiki once back in an office, creating an additional task from which engineers are unlikely to benefit.

The pen computing solutions are generally better in this regard, with the more recent Tablet PC offerings having around 8 hour autonomy and much lighter when compared to earlier offers such as the platforms on which Dynomite (Wilcox et al., 1997) and SmartTea (Schraefel et al., 2004) were implemented. Augmented paper solutions have the highest portability and autonomy of the systems tested, but at the expense of features such as the ability to easily embed some types of information.

Ergonomic and usability considerations such as *start-up time* and *readability* of the screen/interface in a variety of conditions also need to be considered if the logbooks are to be successful, as does *input rate*. Research Notebook (Knowligent, 2004) suggests typing input rates are 40-100% greater than writing for most people. However, these figures fail to takes into account start-up time (up to two minutes for a typical Tablet or desktop PC) which becomes significant when recording short notes, time taken recreating spatial layouts, formatting and tables, and time taken to digitise sketches and diagrams, which are commonly observed in existing logbooks. Whilst pen computing solutions do have a start-up time, sketches etc. do not need to be digitised separately. Again, augmented paper solutions such as Livescribe (2009) appear to offer the most benefits in this area, although as the level of augmentation increases (such as in the case of Mackay et al's., 2002), the start-up time, readability and complexity of keeping the electronic and paper records synchronised increases.

8.2.7 Summary of Findings

Firstly, Table 8-2 summarises the capabilities of the logbooks with regards to the previously defined information lifecycle activities. Table 8-3 then summarises the suitability of each type of logbook with respect to the requirements for an engineering e-logbook derived in previous chapters:

	Augmented paper			Pen computing				Keyboard/web-based				
Name	**Digimemo**	**a-book**	**Livescribe Anoto pen**	**SmartTea**	**Electronic Engineering Notebook (EEN)**	**Dynomite**	**Microsoft OneNote™ (Tablet PC)**	**Electronic Laboratory Notebook (ELN)**	**Research Notebook™**	**e-notebook™**	**Evernote™**	**DokuWiki**
Reference	Acecad (2004)	Mackay et al., (2002)	Livescribe (2009)	Schraefel et al., (2004)	Gwizdka, (1998)	Wilcox et al., (1997)	Microsoft (2005)	Myers (2003)	Knowligent (2004)	Cambridge soft (2009)	Evernote (2009)	Walthall et al., (2009)
Creating & Recording	Free-form Pen	Free-form pen, and linking to other information and physical objects via PDA	Free-form pen, audio	Free-form stylus		Free-form Stylus, Audio	Free-form Stylus, Audio, video, Importing other data types	Keyboard, Importing of other data types (files, pictures hyperlinks etc.)				
Classifying	No in-built facilities, Grouping downloaded files on computer only	Linking to other pages and physical objects via tagging, Indexing via PDA	Allocation of notes to folders when downloaded (e.g. project A, B etc)	Template-driven process, tailored to each experiment	Tagging and linking of elements based on engineering ontology	Tagging elements with properties, Tagging pages with keywords	Custom tagging of elements (e.g. sketch, 'To-Do' etc)	Templates to guide note-taking, tags (description, author etc.) Can be fixed or user defined	Templates to guide note-taking, User defined keyword tags for pages	Templates for each experimental step, multiple 'virtual notebooks' for different experiments	User defined tags at page level multiple 'virtual notebooks' for different projects	Different groups of pages through multiple 'namespaces' – analogous to different sections in a notebook, Descriptive page titles

Navigating	Browsing book, Scrolling files on computer, grouped by title, date etc.	Browsing book, Scrolling through contents page on 'Interaction Lens' PDA	Browsing book, scrolling files on computer, grouped by title, date etc.	Scrollable list of experiments	Scrolling through pages, Semantic index. Dynamically created views, hyperlinks	Scrolling pages, Browsing contents page, Dynamically created views	Scrolling through pages, Dynamically created views, hyperlinks	Scrolling through pages or contents page, hyperlinks			Scrolling through pages or contents page that lists all notebooks, hyperlinks	Scrolling through auto-generated hierarchical table of contents, browse pages, hyperlinks
Searching	Browsing book, Browsing files on computer, grouped by title, date etc.	Page name or by date, Tag search by name (user assigned)	Page name and properties, Keyword (via handwriting recognition)	Unknown – focus on note-taking practice and not retrieval	Keyword search of Semantic index	By tags, keywords attached to pages and page properties	Tags, Page title, Keyword via handwriting recognition	Keyword search of tags or typed text.	Keyword, Attachment names, Keyword search of user entered tags	Keyword or chemical structure	Keyword search of tags or typed text. Keyword via handwriting recognition	Keyword search of typed text or namespaces
Sharing & Collab.	Can send electronic files, No support for multiple authors	Can send electronic files, Unknown support for collaboration	Can send electronic files, Some support for multiple authors	Can send electronic files, held on central server, but no explicit support for sharing	Can send electronic files, No support for shared logbooks		Can send electronic files, Shared workspace with some access control.	Can send electronic files, Shared workspace with access control.	Web-based sharing of notebooks, with access control		Web-based sharing of notebooks with some access (but not version) control	Tools to publish pages to other sources such as social networking sites. Web-based, collaborative, support for multiple authors and version/editing control

Table 8-2 – Summary of e-logbook features

Table 8-3 now synthesises the main observations of each type of technology and summarises their suitability for use as a general engineering e-logbook, concluding that the Tablet PC platform is the most suited at present:

Activity	**Main Observations**		
	Augmented paper	**Pen computing**	**Keyboard/web-based**
Creating & Recording	Free-form pen input, but constrained on information types	Free-form pen input, can insert any other electronic file types	Input via keyboard, can insert any other electronic file types
Classifying	Page names and some user-defined tags	Templates and tags of various types used, tagging by page of individual pieces of information	Generally use either template driven approach with pre-defined steps (e.g. Research Notebook of Knowligent, 2004). Can also add metadata/tags at page level
Browsing & Navigating	Ability to browse paper logbooks as normal, or on computer by scrolling pages or automatic tables of contents	Scrolling through pages, or via automatically produced tables of contents. Dynamic rearrangement of pages also possible.	
Searching	Requires downloading of logbook to computer – generally limited to simple searching	By tag or keyword, also keyword search of handwriting in OneNote™ (Microsoft, 2007) Keyword searching of audio and video files via automatic transcription in OneNote™	Keyword search of text or page titles. Handwriting recognition for scanned-in handwritten notes in Evernote™ (Evernote, 2009) Search by chemical formulae for specialist e-logbooks possible
Sharing & Collaborating	Easier to share electronically as records stored on computer, but real-time collaboration not possible.	Easy to share electronic files. Can also create shared logbooks and work on them together, with author and version control. Some examples are purely web-based, requiring network connect to use	
Practical Considerations	Generally small, quick start-up, good autonomy and no screen readability problems	Start-up time longer than most augmented paper devices. Autonomy (battery life), screen readability, size and weight can be an issue, but technology is improving	Not portable (although can usually access from any computer). Do not easily support sketching. Start-up time generally same as pen computing e-logbooks
Overall Potential to meet req's for general engineering e-logbook	**Medium** Main drawbacks are issues with synchronising paper and electronic versions, lack of support for information types and lack of functionality for collaboration	**High** Retain pen input, generally provide reasonable trade-off between useful functionality such as support for many information types, and practical considerations. Screen technology improving rapidly.	**Low** Whilst they retain most of the functionality of portable pen computing devices, lack of portability and pen input a major drawback. Requiring constant network connection in some cases could be problematic

Table 8-3 – Synthesis of main points from review

8.3 General Observations

As well as the specific issues relating directly to e-logbook technologies discussed above, four more general issues related to the development of the e-logbooks have emerged over the course of the review:

1. What was the ***rationale*** and how the ***requirements*** have been derived for the e-logbooks reviewed.
2. The ***specificity*** of the solutions to particular tasks or domains.
3. The ***integration*** of solutions into the wider information management space.
4. How the ***Evaluation*** of the solutions was performed.

Firstly, for the most part it appears that the ***rationale and resulting requirements*** for the most of the e-logbooks reviewed has been largely anecdotal or assumed[7]. Where research has been carried out into the needs or requirements of the users, this has often been from a particular perspective, to support a particular type of task (such as enhancing collaboration or shared understanding in the case of Walthall et al., 2009) or to explore a particular type of technology (such as wikis or Tablet PC's). Whilst this has produced interesting research and allowed in some cases detailed evaluations of the resulting e-logbook, because the solutions have not always been created to address a well-defined user need, the resulting shortcomings in the e-logbooks have only been identified after considerable effort has been expended in development and evaluation.

Exceptions to this are, for example, the SmartTea system of Schraefel et al., (2004) and Wilcox's (1997) Dynomite system, both of which used a variety of techniques such as interviews, document analysis and ethnographic techniques to elicit user requirements before embarking on design. Interestingly in both of these cases, the majority of the resulting requirements – such as the need for pen input, sketching support, and flexible structuring and classification options are broadly supported by the findings of previous chapters.

This may be illustrated by considering the evolution of the technology platforms many of the pen-based e-logbooks were designed to exploit, illustrated on the timeline in Figure 8-6, overleaf:

[7] In the case of commercial e-logbooks such as Microsoft's OneNote™ and CambridgeSoft's (2009) e-notebook, a detailed account of these aspects is not publicly available, so these examples should be considered not to be included in this point.

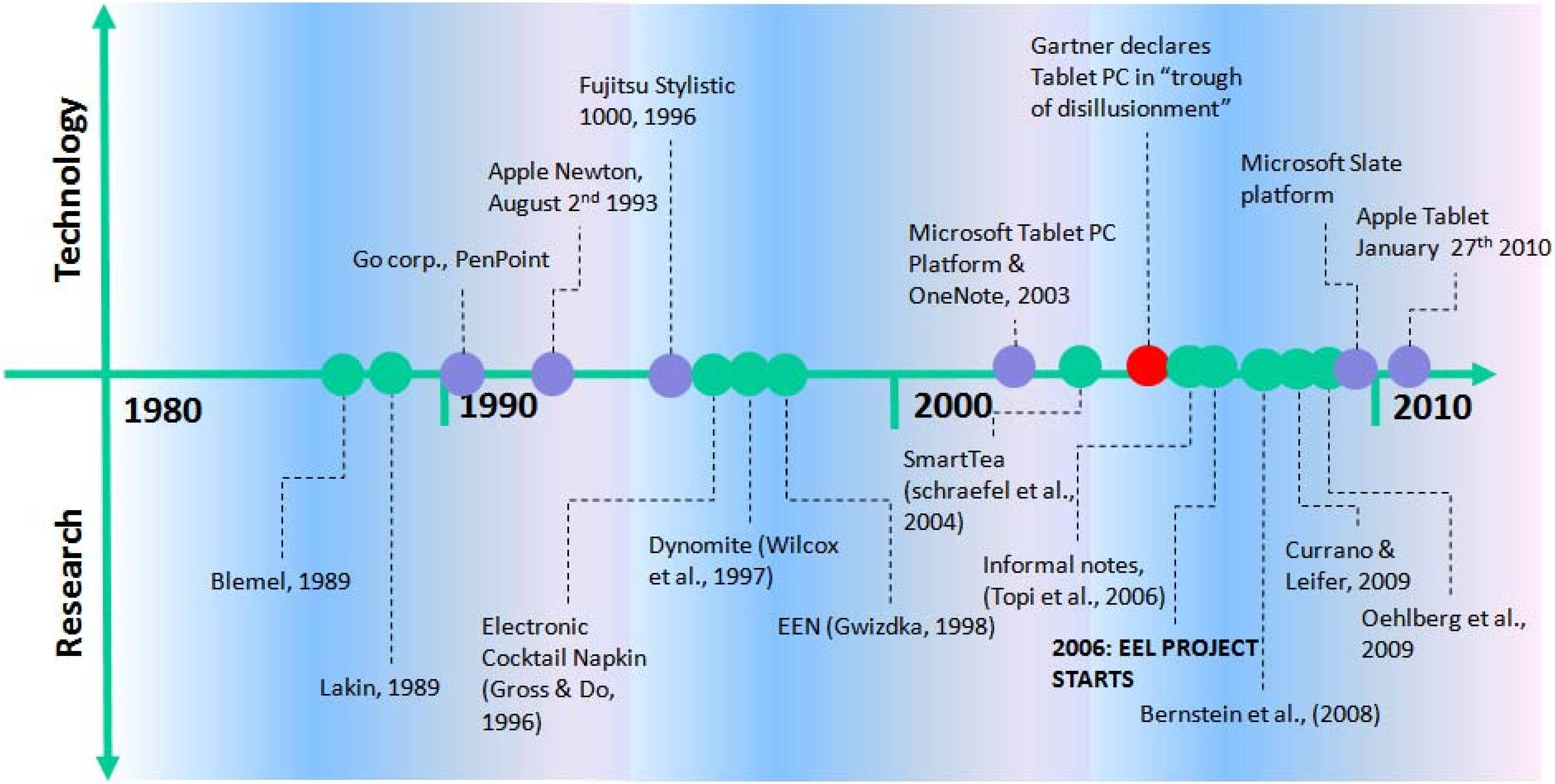


Figure 8-6 – A brief history of pen computing and logbook research

From Blemel (1989) making the statement that the "*the automation of engineering notebooks should be simple and easy"*, it can be seen that following the introduction of pen-computing platforms such as the Apple Newton and Fujitsu Stylistic in the mid-1990's, there were a number of attempts at e-logbooks for knowledge work (although only one aimed specifically at engineers). However, a number of limitations of the early pen computing platforms (such as limited wireless connectivity, screen size and resolution and a lack of applications) meant that interest soon dissipated.

Interest remained subdued until 2003, when pen computing once again took off with the introduction of Microsoft's Tablet PC platform. Research was soon directed at seeing how the technology could be exploited, both in academia and by software vendors. Probably the most successful of these attempts was the SmartTea project of Schraefel et al. (2004). Surprisingly, there have been no attempts at engineering e-logbooks using Tablets, despite Microsoft OneNote making a successful attempt at a general e-logbook. However, yet again the platform failed to live up to early expectations and in 2006, Gartner (an IT consulting firm) declared the Tablet PC in the "*trough of disillusionment*" and predicted it would take another five years to be widely adopted.

Whilst the figure above is not intended to be comprehensive, what it does illustrate is that in the last two decades, there has been very little in the way of fundamental research into how existing logbooks are actually used, with most research instead being motivated at least in part by the introduction of new technologies, both in the 1990's, and again from 2003. However, since the failure of the Tablet PC to be widely adopted, there has been an increasing interest in gaining more fundamental understanding of how and why paper has remained such a persistent features of knowledge work, despite the advent of numerous technologies designed to replace it. This understanding is now well placed to take advantage of the next generation pen computing solutions, such as new offerings in the form of Apple's iPad (Apple, 2010).

Another issue is the ***specificity*** of many of the previous solutions to particular tasks of domains meant that an apparently successful e-logbook developed for one domain may not be universally well received. Therefore some caution must be used in adopting particular design features or even the underlying concepts. For example, many of the e-logbooks reviewed have been designed to explore a particular function (such as linking audio to written notes), or to support a particular type of work or domain (e.g. chemistry in the case of the SmartTea logbook from Schraefel et al., 2004). Whilst the structure and functionality of SmartTea was well received in evaluation, the very wide variation of tasks for which logbooks are used (see Chapter 5) means that such an approach would be unlikely to work in its current form in the engineering domain. The only e-logbook aimed specifically at engineers was EEN (Gwizdka, 1998), which should arguably be seen more as an attempt to explore various classification schemes rather than a e-logbook for evaluation in a 'real world' setting.

In terms of **integration**, it was noted in the literature in Chapter 2 that a criticism of some personal information management systems is that a lack of integration with a users other sources of information or way of working can actually exacerbate the problem of *"information fragmentation"* – with Jones (2004) noting that "*instead of, OneNote actually introduces a whole new file format…"* This is certainly evident in methods of information representation, with standards used varying considerably. For example, some are effectively stored as plain text or as an html document (Walthall et al., 2009), whilst others use various standards for the hardware or software around which they were built (e.g. Gwizdka, 1998). There is little evidence that any regard has been paid to the long term storage and retrieval of the notes.

Secondly and perhaps more importantly, few considered the logbook as part of a wider workflow. Previous chapters (in particular Chapter 5) have revealed that logbooks 'mediate' between many types of work, with the content often being re-used in some form, such as whilst writing reports It could be argued that the general nature of some of the logbooks reviewed means that considering logbooks in this way could be difficult. In addition, all the logbooks do, by their nature, make finding and re-using the information an easier activity than it is with existing paper-based logbooks. Where the logbook has been aimed at a more defined type of work (for example, chemistry in the case of Schraefel et al., 2004 and other natural sciences in the case of Myers, 2003) more effort has been directed at integrating the logbook into wider working practices and tools in a more considered way, which was well received during evaluation. It must be recognised, however, that whilst such tightly integrated systems can work well in specific circumstances, the wide variation of types of activity in engineering design mean that it not be appropriate in many cases. Indeed, Gwizdka (1998) argued that even structured approaches to tagging information were difficult because of the wide variety of not just activities, but individuals' note-taking styles. Again, there is clearly a trade-off between ease (and flexibility) of use and ease of re-use.

Finally, turning to ***evaluation,*** it is noted that the types of evaluation varied widely, with few of the e-logbooks reviewed evaluated in 'real world' settings. Notwithstanding that the exploratory nature of some concepts and designs means this would not have been appropriate, there appears to be a general lack of even suggestions as to how such an evaluation mighthave been carried out. How to separate possible issues in evaluation is also not comprehensively covered. For example, whilst it is inevitable that these are intertwined to some degree, the question of how to separate evaluation of the usability of the interface and utility of the actual functionality is not well addressed.

More generally, a wide range of metrics were used, with little overlap between those used in the e-logbooks reviewed. For example, one key indicator for Schraefel et al., (2004) was whether the logbook became 'transparent' to users within 10 minutes, whereas the EEN of Gwizdka (1998) was evaluated with a range of detailed metrics characterising how notes were classified. Again, whilst the wide range of e-logbooks and stages of research reviewed means this was to be expected to some degree, there appears to be little in the way of 'best practice' or other framework or set of metrics for evaluating this type of technology. Whilst the commercial offerings such as Microsoft's (2007) OneNote™, Knowligent's (2004) Research Notebook™ and CambridgeSoft's e-notebook did have evidence of use in organisations, the results were presented largely as anecdotal accounts from users.

8.4 Concluding Remarks

This chapter has presented a review of 13 current e-logbooks of various forms, ranging from those that seek to closely emulate paper, to systems designed to completely replace paper and arguably challenge the concept of logbooks as a personal work record (for example, wikis such as DokuWiki of Walthall et al., 2009).

The resulting learning from this review may be grouped into three main areas: i) the overall approach likely to be most appropriate for engineering environment, ii) the need to consider other practical and physical requirements and iii) the more general observations arising from the review discussed in 8.3.

In terms of the overall approach, regardless of the medium adopted, how the logbook works must be rooted in users' existing practice. Where this has been taken into account (see, for example Schraefel et al., 2004; Wilcox et al., 1997) before designing the e-logbook, it has generally been well received in evaluation, with users more likely to adopt it. Similarly, after trying a number of approaches to classification, Gwizdka's (1998) main recommendations were that classification schemes should be appropriate to the task and that account needs to be taken of individuals' varying note-taking styles. This point is further illustrated by the observation that none of the e-logbooks reviewed explicitly supported all the types of information in existing paper-based logbooks, established in Chapter 6, or in many cases consider the users' wider information space, in terms of where information comes from, and how it is subsequently re-found and transformed (into, for example, formal reports or CAD drawings).

In terms of the types of technology reviewed, whilst all have the ability to meet many of the requirements arising from previous chapters, the prevalence of sketches and annotations strongly suggest pen-computing devices are most suited to e-logbooks in the engineering domain. Whilst the hardware platforms do not replicate so well the affordances of paper like the augmented paper e-logbooks, it was argued that they do provide the best trade-off between functionality , ease of use and practical considerations, such as portability and autonomy. In addition, there have been significant advances in screen technology for these type of devices in the decade since, for example, Wilcox et al., (1997) and Gwizdka, (1998)[8].

Four other more general issues emerged that were largely independent of the type of technology employed. Firstly, it was observed that often the rationale or requirements for many of the review e-logbooks were influenced by available technology, assumed needs or tackled from a particular perspective. Secondly, it was noted that the specificity of the solutions to particular tasks or domains meant caution had to be exercised in applying ideas or concepts from these e-logbooks to other domains. Approaches to the integration of solutions into the wider information space were also varied, from stand-alone devices not designed to support this type of activity, to e-logbooks aimed mainly at the natural science and pharmaceutical research domains that featured heavy integration, although it was argued that the wide variation in the types of work recorded in engineering logbooks meant that this approach was unlikely to be suitable in the majority of cases.

Finally, how the evaluation of the e-logbooks was performed again revealed the use of a range of techniques and metrics. It was noted that there did not appear to be any particular framework or 'best practice' for such evaluations. Beyond anecdotal success stories from the vendors of the commercial systems, there was also little guidance on how the e-logbooks could be deployed in practice, or what the cost-benefit of such a deployment might be. These findings will be used together with the requirements derived in previous chapters to produce a requirement specification for an engineering e-logbook in Chapter 9, before a technology demonstrator (aimed at showing how the Tablet PC platform could be used) and strategy for its evaluation and deployment is presented in Chapter 10.

[8] More recently, 'Electronic paper' or 'Electronic ink' devices have become available (see, for example, PlasticLogic, 2009). The screens have a high resolution and paper-like feel and require no power to maintain an image. Although at present their main purpose is for reading and not for keeping records, such devices also have no start-up time, are comparable in size to an A5 notebook and incorporate tactile navigation interfaces and wireless communication technologies. They are not included in this review as no e-logbooks exist that utilise them – this issue is discussed more fully as part of a wider evaluation strategy in Section 10.2.

9 Requirements and Specification for an Engineering E-logbook

This section brings together the findings and resulting requirements for an Engineering E-logbook (EEL) in order to develop a fundamental requirement specification for the next generation of engineer's logbook. The resulting specification, developed in Section 9.2, covers the key principles of the design philosophy, information management, architecture and integration and other technological and practical requirements. In specifying the solution, particular attention will be paid to the critical trade-offs or contradictions that have been identified at various points in this thesis. Section 9.3 then discusses how the proposed specification meets the requirements of engineers, before conclusions are drawn in 9.4.

9.1 Requirements Arising from User and Document Studies

This section synthesises the requirements identified in earlier chapters and discusses the key trade-offs or contradictions inherent in several of them. Firstly, the requirements from each chapter are consolidated in Table 9-1, overleaf, along with the rationale or source of evidence that supports or justifies their inclusion. In the case of Chapter 8, this includes evidence from the various existing e-logbooks and associated technologies reviewed with respect to engineering activities:

Chapter	Study	Observation/Evidence	Corresponding Requirement
4	Logbook Use Survey	Logbooks are not purely source of documentation, but serve as a tool that allow 'ideation' and reflection in design work, by reminding of work in progress (72% of respondents), supporting further work (82%), which are referred to on a daily basis (62%).	Improve apparent shortcomings of the logbook as a source of documentation whilst maintaining the unique affordances of paper that support the logbooks' role as a tool for ideation and reflection
		34% Respondents maintain separate logbooks for each project	Allow flexible organisation of logbooks
		80% of respondents not happy sharing information with customers or suppliers	Allow retention of privacy through access control mechanisms
5	Logbook Use in Context	Sketching and other free-form input "*essential*"	Support for pen input and sketching
		Ability to collate many types of external document	Support for all types of external documents
		Browsing entries an effective mode of retrieval due to short-term nature of much logbook material, with highlighting and other symbols commonly used, although being able to re-arrange content would help	Allow browsing by page, in chronological order, with visual symbols to aid re-finding
		Need for a more effective way of searching older entries for more specific information, in various ways, such as by project or information type	Support searching by various criteria as appropriate
		Difficulty transforming and sharing information with distributed team – currently have to scan sketches and attach to emails.	Support critical 'mediation' role by allowing more effective searching and transforming of information into more formal sources and for sharing electronically

5 cont..		Common role of logbooks as task manager	More effective management of tasks such as automatic collation of tasks spread throughout the logbook, or their identification for transfer into another task manager
		Portability and flexibility valued	Must be comparable size (generally A4) and weight and able to be used autonomously all day. A degree of ruggedness may be required in certain roles (e.g. manufacturing).
		Links between logbook material and corresponding formal record implicit/held largely in memory	Mechanism for more explicit links between logbook material to support organisational re-use
		Strong trend towards electronic, searchable records, with manual effort required to include logbooks	Electronic format preferred for easy inclusion in electronic, searchable archives
		Individuals needed to retain control of creation of logbook material	Balance individual need for privacy and control with organisation requirement for record-keeping
6	Logbook Content, Structure and Organisation	13 Information classes derived from 26 different information types.	Logbook should support the full range of information classes identified, including sketches and other pen annotations
		Wide variation of personal styles of note-taking	Flexibility in logbook structure and organisation to support different recording and re-finding styles. Consider trade-off between personal nature of logbook and organisational re-use
		Simple terms like titles, times, dates and project names used to identify entries for subsequent re-finding, but applied in a very inconsistent manner, severely limiting re-use by anyone but the original author	Support the application of consistent, simple metadata to aid search and retrieval and reduce the dependence on the authors' memory/browsing for older entries, whilst not over-burdening the author.
		Author and purpose of logbook often not evident, hampering organisational re-use	Include ability to identify author and purpose of logbook

7	Relationship to Formal Information	High number of sketches in logbooks High proportion of 'exploratory' entries compared to formal reports, with lots of problem solving and other 'ideation' activities Much logbook material transformed into formal entries (e.g. Figures 7-9 and 7-10), although sometimes with errors or in necessarily different forms	Support for sketching essential Retain features that support ideation - pen input, sketching, un-constrained layout and interweaving of information types Consider trade-off between ease of use and ease of re-use in terms of how structuring or classification is performed to ensure characteristics of paper logbooks that support ideation role are maintained. Easier transformation of logbook material into formal electronic documents and other information systems by identifying logbook content in appropriate ways, e.g. actions, types of information or stages in the design process.
8	Technology review	Pen computing solutions appear to have most potential to meet requirements derived in Chapters presented above (sketching, search capability etc), although ongoing concerns with screen technology. Post-classification of information less distracting than having to specify structure before creating information (Gwizdka, 1998) Abstract classifications terms (part, parameter etc) hard to use to classify information for Engineers. Concrete, non-domain specific classification terms easier to apply and more widely used (Gwizdka, 1998)	Pen computing solution preferable Post classification of information to ensure quick recording of notes and ideas etc ('ideation' mode of use) is supported Use concrete (not abstract) non-domain specific terms to make classification easier

		Rationale for e-logbooks and resulting requirements often assumed or anecdotal, resulting in poor uptake. Most successful e-logbooks in various domains have considered user requirements in detail before embarking on design	Need to understand and support requirements of users (such as pen input) before designing/deploying to encourage uptake
		Specificity of solutions limited applicability to different situations	Needs to support the specific needs of engineers whilst being flexible enough to enable its use across large organisations/supply chains to maximise benefits
		General lack of integration with other information sources in many attempts. Where this has been considered (e.g. SmartTea project of Schraefel et al., 2004 and other commercial offerings), it has been a successful driving factor	Consider integration with wider workflow to maximise benefits and encourage uptake

Table 9-1 – Requirements derived from various user and document studies

9.2. Specification for an Engineering E-Logbook (EEL)

This section presents the development of a specification for an engineering e-logbook (EEL). Firstly, the overall principles that should guide the design of EEL are defined and discussed. How these requirements should be fulfilled in terms of information creation, classification and re-use is then presented in 9.2.2-4, followed by the architecture (9.2.5) and other technological and practical considerations (9.2.6).

9.2.1 Key Principles

Taking into account the findings from the previous studies synthesised in Table 9-1 and the literature, the over-riding design principles for the next generation of e-logbook are that it should be:

1. **Lightweight** - have the minimum possible features to be effective and be intuitive and simple to use.

2. **Highly flexible** - in terms of its structure and organisation and how the information is recorded, classified and re-used.

3. **Customisable** – to suit the particular needs of different types of engineer (e.g. design vs. service engineers).

These principles reflect the underlying observations from all of the specific studies undertaken and necessarily demand a trade-off between ease of use and ease of re-use. For example, high flexibility in software is often associated with more complex user interfaces that present more options to the user. However, it was felt that the satisfying the aforementioned three principles is essential for user acceptance and wide spread adoption. With these principles in mind, specific requirements derived from the studies in chapters 4-8 have been used to create a specification for an Engineering E-Logbook (EEL). How logbook information is managed – in terms of its creation, classification or management and subsequent retrieval – forms the backbone of the specification and each of these areas is now discussed in turn.

9.2.2 Creating Information

Supporting the creation of all the types of information identified in the previous studies is an essential requirement and is highlighted here as one of the main reasons that previous e-logbook attempts have not been successful. For example, the well documented importance of sketching in determining design outcomes necessitates the ability to support pen input.

For similar reasons, it is also essential that the integration of external documents and free-form annotations of any information type are supported. In the case of external content, the option to embed (or attach) and link back to the original file must be provided. External content such as images or screenshots of, for example, CAD models representing a single viewpoint must also be easily integrated and annotated. Information must also have the ability to be interwoven – that is, that any information type can be recorded in any order.

9.2.3 Classification/Management of Information – The O-A Schema

Strategies for the classification of information has received considerable research attention (see, for example, Baeza-Yates & Ribeiro-Neto, 1999; Hicks et al., 2008; and Giess et al., 2008). However, the previous chapter argued that it has often appeared to be a weak point in previous e-logbook approaches, with some of them created to test the classification scheme. One contradiction posed is that previous research (Gwizdka, 1998) has identified post-classification (classifying after the information has been created) as preferable, as it does not disrupt the thought process or flow of the engineer. However, this can lead to very inconsistent structuring and use of contextual information, as evidenced in Chapter 7. To fulfil the requirement that there should be consistent application of metadata to aid retrieval whilst at the same time post-classification of the information, it is proposed that the optimal solution is limited pre-structuring of the overall activity to improve consistency, with post-classification of the information itself.

It has been shown that logbooks are almost always structured with metadata at the beginning of entries such as dates, titles, project names or general descriptions, albeit in an inconsistent fashion. It was apparent when analysing the user scenarios in Chapter 5 that engineers tended to think about activities (e.g. meetings) or objects (e.g. sketches, outlines of reports, to-do items etc) when describing how logbook information was created and transformed. For example, a common scenario was for 'to-do' items to be scattered throughout the logbook, then consolidated to form a list. It was also common for notes taken at a previous meeting to be reviewed before the next meeting, or for sketches and calculations to be retrieved when creating reports and presentations. These observations are also supported in the literature by Lowe (2002) who found that engineers ranked terms such as the project name, author, title and date of various types of documents as the most important attributes when searching for information. This is further supported by Gwizdka (1998) who found that using abstract terms to classify logbook content was problematic, as were user-defined terminology, because remembering the terms used became difficult as their number increased.

Focusing on the critical use/re-use trade-off in order to provide useful search criteria with the very minimum overhead required from the user has led to the adoption of an Object and Activity-based (O-A) classification schema for logbook information, consisting of three aspects, all derived directly from how existing paper-based logbooks are used and the information types they contain (Chapter 6):

1. **Templates** to structure high-level logbook activities. These are analogous to a logbook page and act as containers for an entire entry and its information content.
2. Several types of **Tag** to classify the information contained within the templates to aid retrieval and subsequent re-use.
3. A set of metadata (termed **Identifiers**) associated with each template and tag type to add further options for search, integration and re-use.

The relationship between these aspects is shown in Figure 9-1, before being discussed in detail:

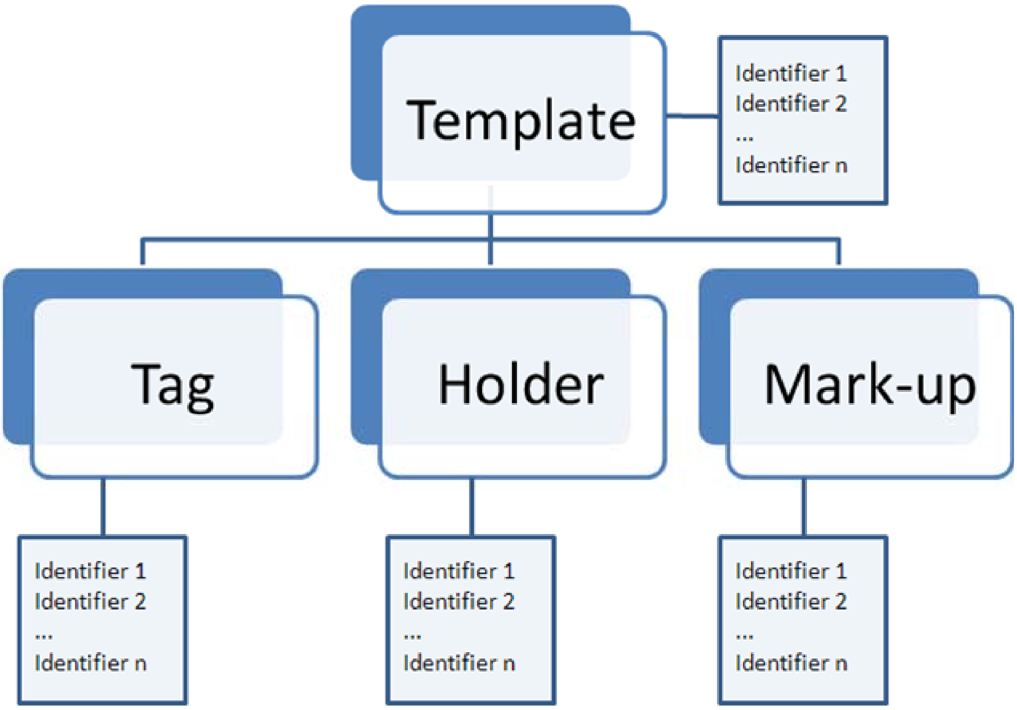


Figure 9-1 – Relationship between aspects of information management schema

Templates

In this study, it was observed that some logbook entries represented 'containers' in which other information existed. It is proposed that these would be best represented by page templates. For example, a new entry is always created for meeting notes, which generally contains a single class of information – handwritten notes taken during the meeting. Other logbook entries almost always consisted of several classes of information together. For example, it was common for a logbook entry to be created for a particular purpose (e.g. design ideas, analysing results of a test etc.), but this commonly consisted of written notes, followed by a sketch, or calculations, and external documents. Therefore 'Design notes' will be the template for generic design instances. Finally, forms such as those used by a service engineer to complete a report already use a template to gather the necessary information. Because of the structured nature of this task and the fact that the service engineer knows in advance the information to be gathered, this type of use represents an instance where pre-structuring of the entry content is appropriate. Therefore three classes of information are represented as templates in this strategy:

1. **Meeting notes** – Any notes taken as part of a meeting or collaborative design session.
2. **Design notes** – Any type of individual design activity.
3. **Forms** – Covering any instance where information is routinely collected in a structured manner.

Whilst it could be argued that many other classifications of activities could be distinguished (such as problem solving types, stages in a design process, individual or collaborative work etc.), it is argued that requiring engineers to chose in advance on what type of activity they are about to embark has been shown in Gwizdka (1998) to be problematic. Further, there has been no evidence from the studies presented in previous chapters of how and why logbooks are used that engineers actually think in these terms when *retrieving* logbook information.

However, it was noted in the review in Chapter 8 that a major factor in the adoption of e-logbooks in the pharmaceutical and science domains has been the integration of e-logbooks in the wider work-flow, which for lab-based experiments often consists of a pre-determined, highly structured set of activities in the form of an experimental protocol. Should an organisation adopt a more structured workflow, or wish to enforce a particular workflow through e-logbooks for legal or regulatory compliance reasons, then the principle of the template-based approach still affords support through customisation of the forms template.

The associated identifiers for each template were derived from the findings in Chapter 6 and the literature in chapters 2 and 8. The templates and associated metadata are summarised in Table 9-2:

Template	Associated Identifiers
Design notes	*Date, subject, project, description*
Meeting note	*Date, subject, project, description, people present, location*
Forms	*Various depending on exact requirements*

Table 9-2 –Template and associated metadata

Pre-structuring some information at the logbook-entry level ensures more complete capture of important information such as the date, the project being worked on and the purpose of the entry, but still allows almost completely free-form entry once the identifiers are completed and thus fulfils the requirement of retaining the flexibility of existing logbooks.

Tags

The tags to mark-up individual information elements have been derived from two main sources. The information types identified in Chapter 6 have been used to derive several types of *Object* tag, whilst the descriptions of use in Chapters 4 and 5 have been used to define a number of *Activity* tags.

With three of the 13 information classes represented by templates, the remaining ten information classes are classified by an 'Object' tag and associated with the template for that entry. An Object tag is a visible symbol identifying the information class (e.g. sketches and calculations), with associated identifiers to add additional information for search, retrieval and integration. In a similar fashion to the template identifiers (metadata), the identifiers associated with the various types of tag have been derived from the analysis of structure and organisation (Chapter 6) and further informed by observations from the literature in Chapters 2 (literature review) and 8 (technology review).

In many cases these identifiers should be inherited from the template in which the tag is embedded, although some tags will have different requirements. Therefore, two special types of tag for classes of information with different requirements for its capture will be used: External information classes (External documents, CAD drawings and annotated versions) will be contained in a special class of tag, (termed a holder) with an identifier to record the source of the document. For similar reasons, annotation or mark-up, which is distinct from other elements as it comments on existing information (e.g. an annotation on an external document or a comment on a written note or meeting note) – will also have a special 'mark-up' tag with different identifiers for author and time/date, as these may differ from those recorded in the template for that entry. However, the method of application of the tags will be the same in all cases.

As well as various types of Object tags, several chapters (notably 5 and 7) highlighted the role of logbooks in keeping track of *activity*-oriented information such as tasks or other important or notable pieces of information that require further action, such as meeting dates or information from suppliers. Further, it was noted that the simple chronological nature of logbooks was frequently incompatible with the non-chronological nature of activities (for example, a task or other activity-oriented information element could be required at any point in the future, could gain importance over time, or need to be accessed multiple times). Therefore two 'Activity' tags are proposed, one covering tasks and another covering other miscellaneous information elements of importance to the author. Finally, it is proposed that a 'private' tag be used to hide instances of non-work related or particularly sensitive information, allowing it to be filtered out of searches. The full schema, hereafter termed the Object-Activity (O-A) schema is presented in Table 9-3:

Tag Class	Tag name	Associated Identifiers
Object / General	Contact detail	*Date, company, email, telephone, address, description*
	Calculation	*Date, subject, project, description*
	Graph/chart	
	Sketch	
	Table	
Object/ Holder	External document	*Date, subject, project, description, source*
	CAD	
Object / Mark-up	Annotated external document	*Date, subject, project, description, source, annotation author*
	Annotated CAD	*Date, Annotation author*
	Memorandums/other annotations	*Date, Annotation author*
Activity	'To-do' item	*Due date, project, description*
	'Important' item	*Due date, description*
Misc.	Private	n/a
	Custom	*Custom1, custom2…*

Table 9-3 – Tags and associated metadata – the O-A Schema

Figure 9-2 shows a typical logbook page and represents how the template and each of these tags (in this case a sketch and calculation tag, and an external document holder for a picture) would be used:

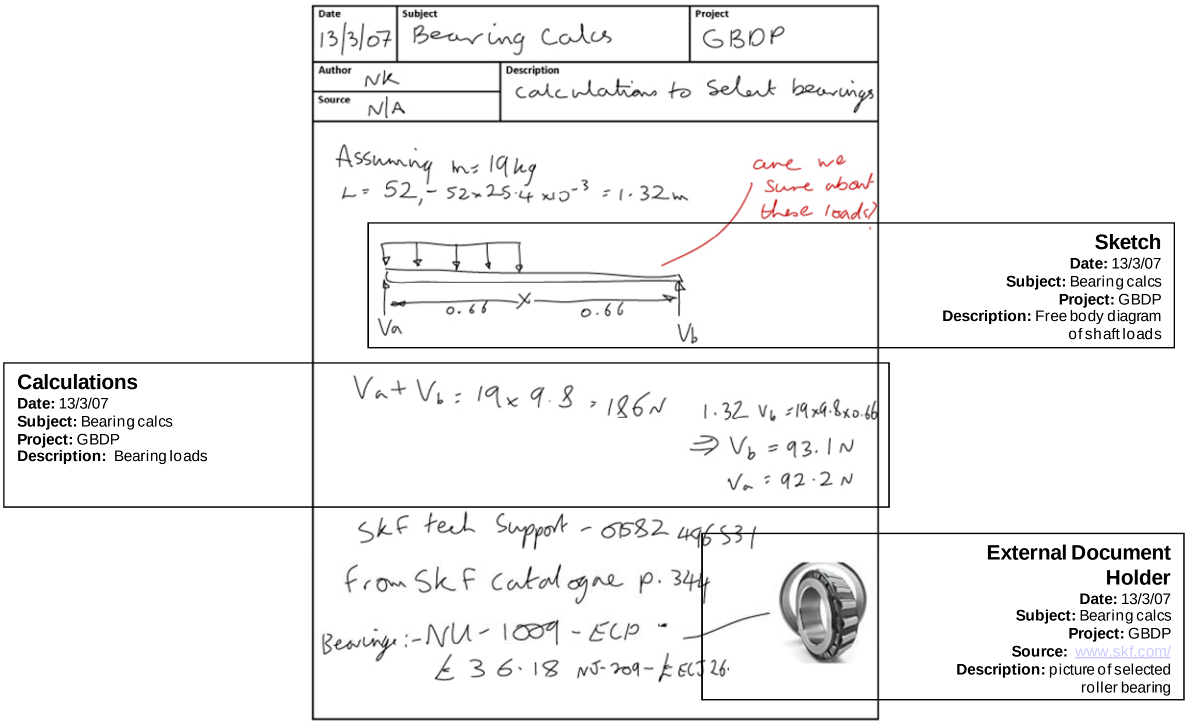


Figure 9-2 – Example of tagged page

Note that it is not the intention that every information element on every page should be tagged, but rather that information considered important to the individual, such as sketches, or details of suppliers that the author know they commonly have a need to re-find. The *description* identifier is also intended to be optional by default. In addition, whilst tags can be used to classify logbook content at any point after its creation, it is suggested that entries should be tagged at the earliest convenient opportunity (e.g. after a meeting) or at the end of each working day. This both ensures the context can be recalled and also has the potential to encourage reflection on the content of the entry.

Note also that whilst this schema is designed to be applied manually, the collection of many elements of metadata can and should be automated as far as possible. Whilst it is possible at present to apply times/dates etc. automatically, this could be extended to include, for example, location via Global Positioning System (GPS) information, or people present in meetings via integration with scheduling applications.

9.2.4 Architecture and Integration/Sharing

This section outlines the architecture for an e-logbook system to support the requirements in terms of how and where information is stored and the potential for exchange with other systems. Figure 9-3 depicts the overall architecture of EEL and in particular its relationship to other information systems within the personal and group/organisational contexts.

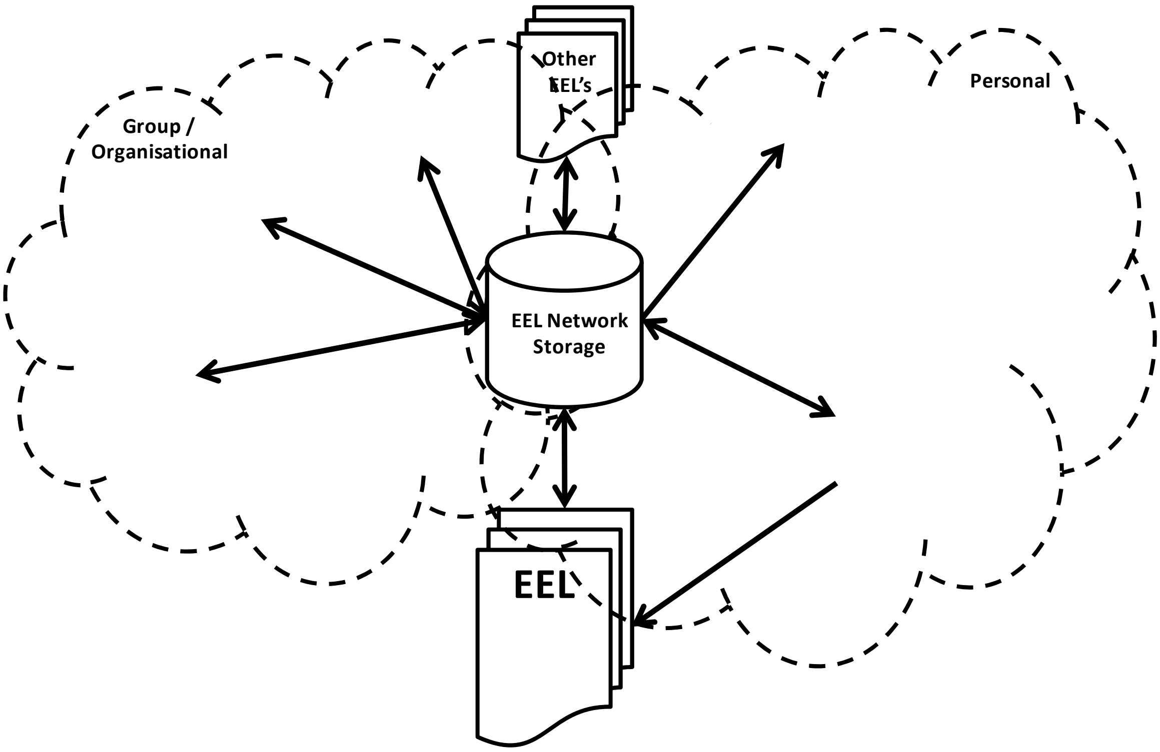


Figure 9-3 – Proposed architecture

It is intended that EEL is positioned between a user's personal information space and that of the group and wider organisation. How the O-A schema described in Section 9.2.3 permits links to be made between systems in both the personal and organisational spaces is now discussed.

Information Storage and Synchronisation

In terms of information storage, it is required that whilst the information is created and held locally on the e-logbook device, it is synchronised or backed-up on a central e-logbook server, fulfilling the need for a system which does not require a permanent network connection, but ensuring complete and automatic logbook records are retained for legal compliance, overcoming the problem of missing archival information. In this way, persistent links between the logbook information and various other systems such as Product Lifecycle Management (PLM), Knowledge Management (KM) and Document Management Systems (DMS) may be facilitated. These are now discussed in turn.

Linking to Group/Organisational Information Spaces

This aspect of the EEL specification meets the requirements to consider logbook use as part of a wider workflow and to provide more explicit links between formal records and the associated information logbook content, which at present is often only held in the memory of the individual (Chapter 5).

For example, it has been suggested that the linking of sketches to extend PLM could be achieved by linking sketches to the Electronic Bill of Materials (eBOM), which records details of product parts and their relationships in the form of assemblies and sub-assemblies (Huet et al., 2009, Figure 9-4):

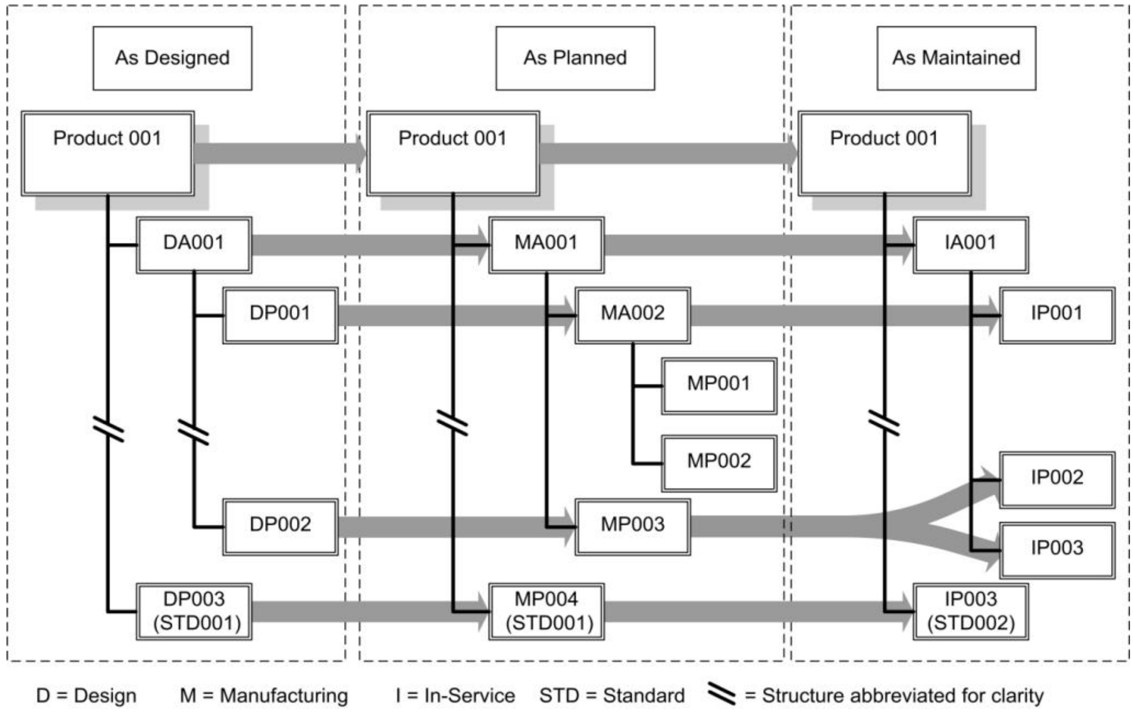


Figure 9-4 –PLM system structure (*reproduced from* Huet et al., 2009)

Sketches could be integrated into the eBOM through either the *Sketch* tag and associated identifiers, such as *Description,* or a new custom identifier for the sketch category to indicate a part number or assembly/sub-assembly to which the sketch relates, in the case of more detailed sketches created in later design stages. In this way, the eBOM could be extended to include the product 'as conceptualised' as a stage before 'as designed' as in Figure 9-4. Additionally, because the information management schema is customisable and extensible, other company-specific schema elements (such as ATA numbers used in the aerospace industry to provide unique identifiers for particular aircraft parts) could provide even further scope for links to PLM and other product data management systems.

KM systems such as expertise locators or lessons learned databases could also benefit from the automatic linking of people to projects with which they are involved, or even topics they are currently working on by making available the *Author, Project* and *Description* identifiers. Further, the design record could be enriched by the linking of the informal record to its more formal counterpart, as evidenced in Chapter 7.

Finally, links between logbook material and document management systems (DMS) to enrich the design record may also be achieved in multiple ways, either with the tags as defined or with further custom tags or templates. For example, these records could be used to supplement the formal record by linking logbook pages created for the same project to the corresponding formal reports using the *Project* identifier. A further level of granularity could be achieved by either the manual linking of relevant logbook pages by the authoring engineers at the time of synchronisation, or automatically using the *Description* identifiers to return logbook pages alongside formal documents using keyword searching.

Linking to Personal Information Spaces

In a similar way to linking to group or organisational information systems, the information management schema also has provision for links to be created to other information systems that comprise the individuals' personal information space. For example, the most common aspect of the logbooks' role in personal information management encountered in Chapter 5 were the creation of task lists from logbooks. This is directly supported by the O-A schema in two ways: Once actions have been identified with the appropriate tag, they can either be searched, collated into a single view, or transferred to another task manager programmatically. The associated identifiers could also be used to group tasks by project, due date etc. and also have the potential to be customised with, for example, other people involved, or a priority ranking.

In addition, it is a requirement that the ability of existing paper-based logbooks to 'mediate' between personal spaces and more formal output should be retained, as the collating and transformation of information both into and out of the logbook was shown to be a common mode of use (Chapter 5). This is supported in terms of the inputs from the wider personal information space by, for example, the identifier recording the source of external information to allow links back to the authors personal file store.

Sharing

The other advantage of central storage of tagged logbook information is to facilitate sharing of the information with other EEL's, which is currently achieved by scanning and emailing individual pages (Chapter 5). Because of the electronic format and central storage, sharing of either whole logbooks, pages or even individually tagged elements such as sketches is (with appropriate access controls) easily achievable. However, it is an important requirement that any O-A schema customisation is deployed on at least a department/group or organisation-wide basis – not on an individual level. This is because allowing individuals to define the terminology used for classification schemes has been shown to make searching and sharing more difficult as people other than the original author can be unfamiliar with the terms used (Gwizdka, 1998). If required, the terminology can be further restricted by the use of drop-down lists for current projects,

9.2.5 Browsing and Searching

The retention of the ability to browse logbook content, as well as various ways to search it in a more structured manner were both requirements arising from the findings in Chapters 5-7.

In terms of browsing, the retention of chronological input is supported, and the tags are designed to be visible on the page, with some replicating current paper-based practice, such as tagging important items and tasks. It is proposed that browsing can also be enhanced by allowing dynamic re-arrangement of logbook content based on either templates or tags. For example, the amount of information over which browsing is effective could be extended from its current period of weeks by allowing grouping of meeting note or design note templates, which could then be browsed, or through grouping of, for example sketches or tasks, discussed earlier.

To meet the requirements for more effective ways of structured searching, the O-A schema is designed to facilitate search by not only the information object or activity, but also by the associated identifiers, in a multi-faceted manner, with queries such as "*meeting about Project X*" or "*all sketches from last year*". It is argued that the brief nature of the 'free text' identifiers means that even with a pen-computing solution, they can be entered as plain text via a soft-keyboard, to afford easier searching without the need for handwriting recognition.

9.2.6 Other Technological and Practical Aspects

There are two separate but interrelated issues that must be addressed in terms of the physical/technological requirements: the characteristics of the device itself (i.e. hardware) and issues of how the information is stored and managed (effectively software). These are now discussed in turn.

Previous chapters have revealed the significant affordance of existing paper logbooks in terms of their compact size and portability. This is of importance as engineering logbooks are commonly used in a variety of locations, both within offices (at meetings, for example) and off-site at customers or suppliers. It is therefore identified as a requirement that EEL maintains these characteristics. The three most significant physical challenges therefore relate to i) the autonomy (primarily battery life) of electronic products, ii) display technologies (LCD displays generally having poor readability in most outdoor conditions) and iii) survivability. Although specific 'ruggedised' devices are available for a variety of specialist applications, they invariably trade-off size, weight and cost in the process. Chapter 8 argued that the Tablet PC platform (Microsoft, 2005) offers the best current option for EEL. Whilst current Tablet PC's may struggle to meet the requirements in all regards, a number of technologies are currently the focus of significant development efforts to produce devices with a thinner and lighter form-factor and more appropriate screen technology (see, for example, iRex, 2009; PlasticLogic, 2009) which, it is argued, will result in hardware platforms capable of meeting all aspects of the EEL specification with three to five years. The relatively platform-independent nature of the EEL requirements and the O-A schema mean there should be little problem migrating to new hardware in the future.

The second issue (of how the information is stored) will also have a significant bearing on the success or otherwise of the logbook. Physical paper logbooks affords near-permanent archiving of information, although the trade-off is that they are not machine tractable. Proprietary formats such as the one in which this thesis is written are capable of being accessed and searched from anywhere in the world, although further work is required to ensure they can still be read in the future. This is necessary because logbooks often form a historical record of the design of a product or product/service system that may be in use for 50+ years, with a legal requirement to retain records for 99 years after this date of last manufacture (Chapter 5). Therefore, platform independence and a flexible, open format were also essential requirements, met through the lightweight, flexible nature of the O-A schema. Although the exact specification of the file format will depend to some extent on the technology platform adopted, it is argued that the hierarchical nature of the O-A schema lends itself to representation in XML or a similar open mark-up language able to be interpreted and displayed on multiple devices, and in multiple ways.

9.2.7 Summary of EEL Specification

The elements of the EEL specification discussed above are now summarised in Table 9-4:

Area	Key Aspects
Creation	• All information types to be supported • Free-form pen input • Support for annotations and identification of authors
Classification and Information Management	• Overall design principles are for a lightweight, flexible and customisable solution • Pre-structure activities for consistency with three templates for meeting notes, design notes and forms • Post-classify information objects and activities with pre-defined schema, consisting of non-domain specific language • associated identifiers consisting of an a type and description (e.g.: Project: *project name*) • All elements customisable to particular organisational requirements (e.g. custom forms of identifiers) • As many identifiers as possible to be applied automatically (dates etc.) to lower burden for author
Architecture and Integration	• Locally stored, centrally managed and shared, with access control • Scope for integration with personal information space of electronic files and task manager • Scope for various types of integration with formal systems including DMS, PLM and knowledge management platforms
Browsing and Searching	• Support for book-like browsing with visual tags to aid navigation • Dynamic re-arrangement and grouping of pages, objects and activities • Multi-faceted searching via Template type, Object or Activity tag, Identifier and free-text identifier description
Other Technological and Practical Aspects	• Light weight, portable • Approximately A4 size • Minimum autonomy of one working day • Ruggedised for certain environments where necessary (e.g. manufacturing) • Largely hardware platform independent • Flexible, open data format such as XML for long-term access

Table 9-4 – Summary of EEL Specification

9.3 Discussion – How EEL Supports Engineers and Organisations

This section first discusses in general terms how the elements of the specification support the improved management of logbook information (9.3.1) whilst also meeting other, more human-centred and practical requirements (9.3.2). Two of the logbook-use scenarios presented in Chapter 5 are then used as 'case study' examples in Section 9.3.3-4, to demonstrate in concrete terms how EEL could deliver various individual productivity and organisational benefits.

9.3.1 Improving Information Management

The main goal of this thesis is to improve the management of informal information and in particular logbooks and their content. The O-A classification schema is a central element in achieving this, fulfilling the requirements presented in Table 9-1. As well as supporting or affording the modes of use identified in Chapters 5 and 6 the schema fulfils (or at least does not preclude) many other requirements to enhance information management, including easy customisation and non-domain specific terms. Because of the personal and multi-faceted nature of logbooks, this ability to customise the classification to some degree is essential, as are flexible retrieval options for information in individual logbooks or across collections of logbooks, with multiple ways of searching to reflect various requirements for retrieval, both personal and organisational. For example, the authoring engineers commonly require relatively specific information (e.g. "*a sketch showing the experiment I did two weeks ago*"). In contrast, organisational re-use when the author is not present may be much more general in nature, spread across logbook collections and therefore require non-specialist terms and a limited and easy to understand search vocabulary, which the O-A schema also provides. For example, a collection of logbooks could be searched for "*all meetings where X was present in the last two years"*, or "*All sketches relating to Project Y*".

It was also observed that one particularly important aspect of logbook information management that emerged from the literature and the user survey in Chapter 4 is that authors need to have control over the circumstances of disclosure of logbook information. Storing the logbook information in electronic form obviously facilitates easier sharing, but the author retaining control is a key requirement, which is provided for in the schema through a specific tag for personal information, and also the possibility to create access control rules based on, for example, the author, the membership of a project team, or meeting attendees.

Finally, EEL supports multiple types of integration with other information systems. Such integration has the potential to improve the completeness of the design record for more effective re-use and also to improve legal compliance and intellectual property management for the organisation.

9.3.2 Other User Benefits

As well as improving the management of logbook information for both individual and organisational re-use, the specification detailed previously addresses other aspects of logbook use identified in chapters 4-8. Firstly and perhaps most importantly, this information-based strategy is designed to support the wide range of information types found in logbooks, which was shown not to be the case in many existing e-logbook implementations (Chapter 8). It is also based on current logbook practice and because of this, the strategy is relatively simple, and should be intuitive to users. It thus avoids the difficulties of more complex classification approaches. For example, Gwizdka (1998) found that users often had difficulties applying semantic categorisations based on engineering ontologies, with users reporting difficulty differentiating terms and that it felt "*unnatural*". This strategy recognises that logbook entries can be made at any stage of the design process and that they are often quick and informal in nature. EEL is designed to be as **lightweight** as possible, using a novel combination of limited pre-structuring and post-classification to minimise as far as possible the classification burden: Pre-structuring through templates ensures complete information is gathered, increasing the quality of context-adding identifiers (metadata), but still allowing completely free-form input for the entry, providing **flexibility** for different note-taking styles. Post-classification of information is considered less burdensome by users (Gwizdka, 1998) than classifying at the time of creation.

It was also identified that **flexibility** in terms of re-finding and re-use was also required. To this end, EEL supports browsing in a book-like fashion, as this appeared to be an effective mode of use for reminding of work in progress. The role of logbooks to support self explanation (Trafton & Trickett, 2001) and ideation (Currano & Leifer, 2009) also meant that it was essential that classified information be presented in a format that affords browsing whilst being more computer tractable than at present. The other dimension of flexibility inherent in EEL is that whilst the specification was created with the vision of an e-logbook as the optimal solution, the specification does not pre-suppose a wholly technological solution. Indeed, important aspects of it could be used with existing paper-based logbooks, or some aspects omitted if resources do not permit them, or need does not require them.

Finally, the O-A schema has been designed to provide a core set of terms for general engineering use and allows complete freedom for organisations to **customise** and extend the schema to their specific requirements.

Drawing from the detailed scenarios of current logbook use presented in Chapter 5, two examples are now presented, illustrating how current logbook practice for both the individual and organisation could be improved by EEL. These two representative examples were chosen from the six original scenarios to illustrate how EEL can support the requirements of both the individual engineer and wider organisational requirements.

9.3.3 Example 1 – The Concessions Engineer

Section 5.3.2 described the current logbook use of an engineer responsible for providing support to manufacturing in cases where parts cannot be (or have not been) produced to the specification indicated. In summary, their current logbook use consists of recoding meetings and observations in the form of sketches and notes, before transferring the information into more formal records stored in a DMS. In addition to this, some files representing 'special cases' were transferred to a personal file store for quick reference. Finally, some concessions are also packaged for outsourcing. This is shown in Figure 9-5:

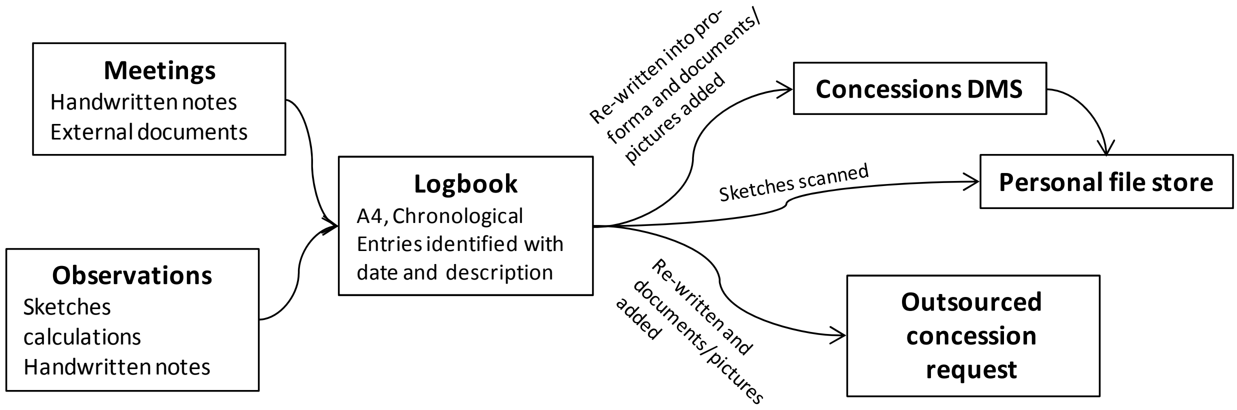


Figure 9-5 – Current logbook practice (repeat of Figure 5-3)

In terms of information management, the first requirement was for better integration between various types of paper/electronic sources – specifically between logbook entries, photographs and other documents. Integration of digital pictures could be achieved easily on Tablet PC platform by virtue of the electronic format, or even via an integrated camera. There was also a need for easier sharing of logbook and other paper-based information between distributed teams, particularly as some concessions were now outsourced. Again, the electronic format facilitates this, by allowing direct sharing of, for example, sketches and other material that currently has to be digitised or re-written.

Due to the short timescales over which each concession was active, searching by the author was generally not necessary. However, a personal file store of 'special' cases (consisting of the formal DMS entry and some informal information) was maintained for quick reference. Using a custom identifier for the unique reference numbers that identify each case, the logbook record can be associated with the DMS entry, allowing both logbook material to be transferred without being digitised, but also allowing access to past cases and rationale from other EEL's. Together with easily integrated photographs and documents, this would arguably increase the amount of rationale available, reducing the need for maintaining inaccessible personal records and consequently the dependence on "*knowing who to talk to*" This is illustrated in Figure 9-6:

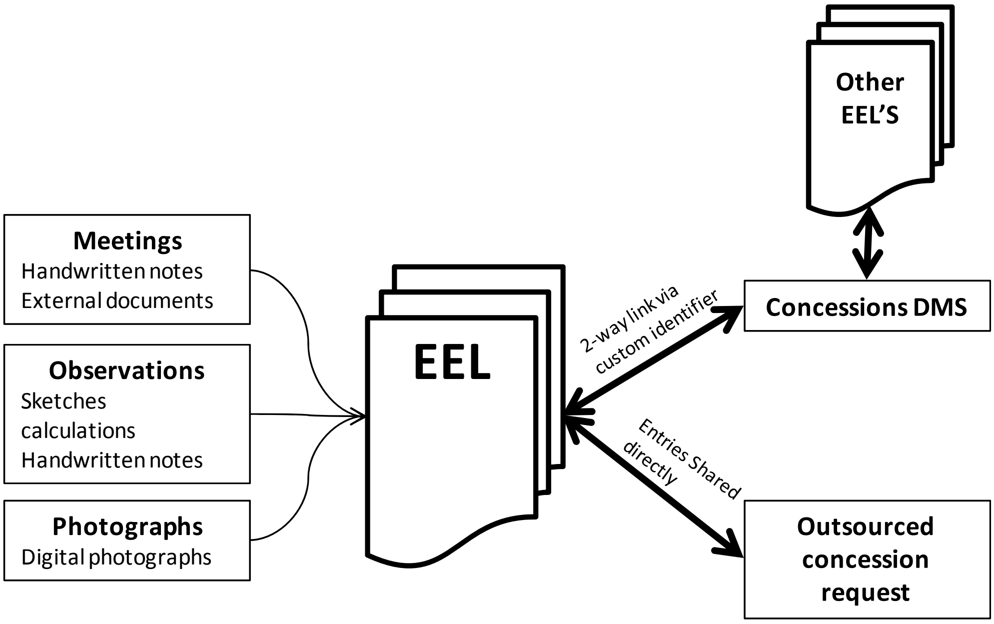


Figure 9-6 – Potential future logbook practice

9.3.4 Example 2 – The Archivist

The scenario created from the perspective of the archivist in Section 5.3.5 focussed largely on organisational aspects of record keeping: Currently, although there is a policy of keeping logbooks with technical content, very few are received compared to formal documents, and those that are kept are not accessed. In addition, those that are submitted have to be manually processed and catalogued. And whilst some logbooks are digitised, their hand-written content can't be easily searched. There is also a future requirement for digital records to be integrated and made available directly via the engineer's computer, to increase accessibility.

In terms of how EEL could improve the current situation, central storage of logbooks in an electronic form (as proposed in Chapter 9) means there is no need for manual submission of printed material, providing demonstrable legal and regulatory compliance. Another potential benefit is removing the need manually digitise and catalogue the content by using the O-A schema elements to automatically create searchable indexes of logbook material

It would also be possible to automatically associate logbook records with other sources of information, such as the corresponding reports, CAD and other archived data. This could be achieved in various ways, such as associating logbook records with their more formal counterparts via the *project*, *author* and *date* identifiers, or via linking certain types of information (such as sketches) with formal systems such as PLM, as described in Chapter 9. This would arguably provide more complete records and improve the scope for both traceability and re-use.

9.4 Concluding Remarks

This chapter first presented a synthesis of the requirements for the more effective management of logbook information gathered through a range of studies exploring the use and content of current paper-logbooks and a detailed review of existing attempts at electronic replacements.

A specification for a general engineering e-logbook was then developed to meet these requirements, covering areas of information creation, classification, integration with other systems, browsing and searching, and other technological and practical aspects. Although designed primarily to facilitate the more effective management of logbook information for both the individual and organisation, requirements based on other, more subtle purposes of personal information management such as the logbook's role in ideation and mediation were also considered, to ensure that the trade-off between ease of use and ease of re-use was handled effectively. The overall philosophy was therefore that it should be *lightweight*, *highly flexible* (in terms of options for classifying, searching and integration) and *customisable* to the needs of various engineering organisations.

The central feature of the EEL specification is the Object-Activity (O-A) schema, which is designed to improve logbook information management whilst retaining the affordances of paper logbooks (such as their support for the quick, lightweight recording of notes, self-reflection and ideation). The O-A schema uses a novel combination of templates to pre-structure entries, and tags with associated metadata to enable more efficient browsing of content, more structured ways of searching and integration with both personal and formal, enterprise sources. Two case studies based on current logbook use were used to illustrate how EEL delivers benefits through, for example:

- The ability to dynamically re-arrange content to support browsing to remind, as well as carrying out more effective searches on older logbook material to improve personal productivity.
- Integration of informal logbook information with an individual's wider personal information space such as task lists and personal electronic files, as well as allowing more types of information to be easily added to the logbook, with the electronic format allowing quicker and easier transformation of logbook information into more formal representations.
- Integration with more formal systems such as product lifecycle management (PLM) systems and other document management systems, supporting the mediation role of logbooks and enriching the design record to increase its potential for re-use.

- From an organisational perspective, centrally stored and managed logbook material affords better compliance with intellectual property and audit requirements – for example, all logbooks are automatically stored in a secure manner, and all records relating to a particular project or person could be retrieved quickly, long after the individuals involved have left.

In addition to the case studies above, it may have been beneficial to have conducted a 'focus group' style evaluation of the specification with a cross-section of the studied cohort, the results of which could have been used to gauge the general reaction to, for example, the overall template and tagging approach. Whilst not on the same level as a comprehensive evaluation of a 'finished product', this may have helped to inform a strategy for communicating the rationale for the EEL design and the importance of good practice in informal record-keeping. Such a focus-group was not undertaken for this research due to time constraints, but does form a recommendation for further research and is discussed further in Chapter 11.

It is also recognised that a comprehensive user-evaluation of the specification is a very important stage. To this end, the results of a pilot evaluation of a technology demonstrator and a pragmatic guide to evaluation and deployment are now presented.

10 Strategy for EEL Evaluation and Deployment

The previous chapter has detailed a specification for an engineering e-logbook (EEL) to meet the requirements derived from detailed studies of users and existing logbooks. Although outside scope of the main research programme, the industrial sponsor desired an understanding of how they might evaluate and deploy an e-logbook. This chapter therefore describes the creation of a technology demonstrator and presents a short, pragmatic guide for industry outlining a strategy for the evaluation and deployment of EEL in an industrial context. The creation of an EEL demonstrator system is outlined in Section 10.1, showing how EEL may be implemented in practice on a Tablet PC platform, before a strategy for EEL evaluation and deployment is presented in 10.2. Potential barriers to adoption are then discussed in Section 10.3, before conclusions are drawn.

10.1 Description of Demonstrator

For the demonstrator, Microsoft OneNote™ 2007 and its Application Programming Interface (API) was used, running on a Toshiba M400 Tablet PC. EEL consists of two elements, described below and discussed in detail in sections 10.1.1 and 10.1.2:

1. Custom OneNote templates for design notes, meetings and forms.
2. An add-on program creating using the OneNote API for tagging information elements with additional identifiers (metadata) according to the O-A schema defined in Chapter 9.

10.1.1 Design of Templates

The requirement for pre-structuring logbook entries to improve the consistency and quality of information is met by the use of templates. Three types of template are provided, representing the generic 'activities' identified in the logbooks: a generic 'Design note' template for general work, 'Meeting Note' for meetings and a 'Custom form' template which is customised to specific, often repeated tasks such as filling in timesheets, or completing checklists. An example of a meeting note template is shown in Figure 10-1:

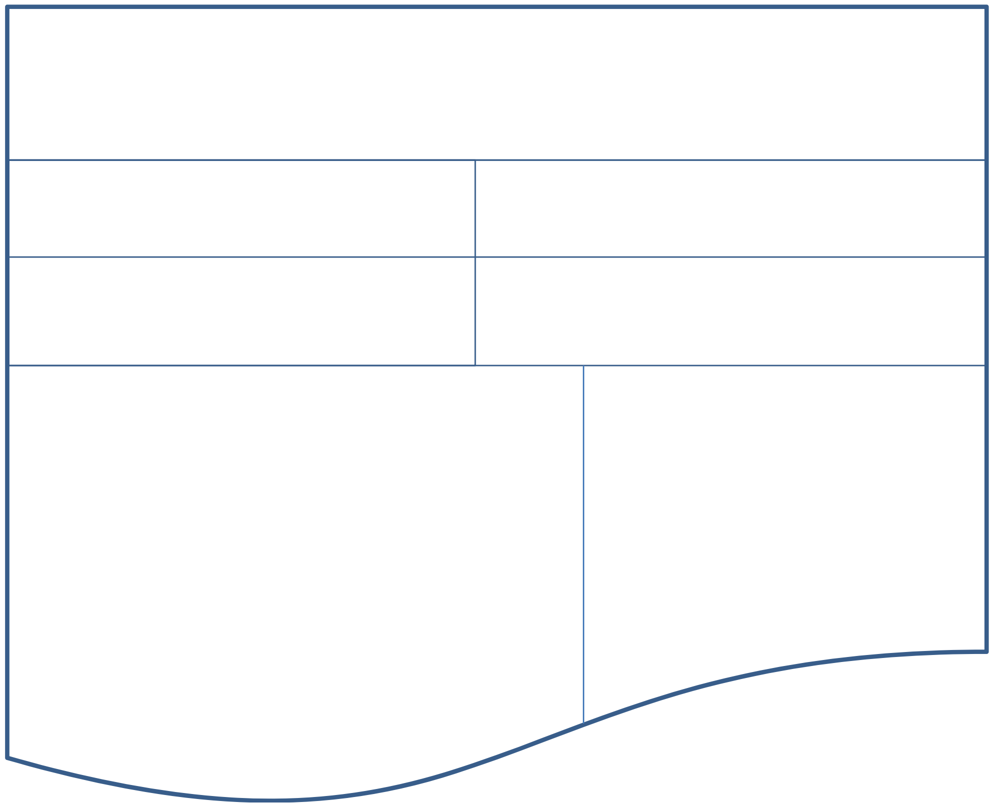


Figure 10-1 – Detail of Meeting note template

The templates are designed to structure only the collection of essential metadata, with the rest of the page allowing completely free-form entry. The only exception to this can be seen in the meeting note template, which demonstrates template customisation by incorporating a separate column for recording actions. This optional component was added to encourage good note-taking practice, as research has shown that actions often go un-recorded (Huet et al., 2006).

10.1.2 Tagging

The requirement for post-classification of the activities and various information objects was met through the use of the activity and object-based 'tags' containing additional metadata, described previously in Chapter 9.

Although OneNote did have the facility to tag information through 'note tags' which can be defined by the user, they do not allow additional metadata about that element to be recorded. To overcome this, OneNote's API was used to create a program to add additional metadata to any information element (writing, sketches, imported documents etc). Once the user has created the content, they select the element(s) they wish to classify using the selection tool. They then launch the EEL add-on, which exports the page, detects which elements are selected and prompts the user to enter the appropriate metadata via a simple drop-down menu. The page is then updated and re-imported into OneNote. This sequence of operations is shown for a sketch in Figures 10-2 to 10-4:

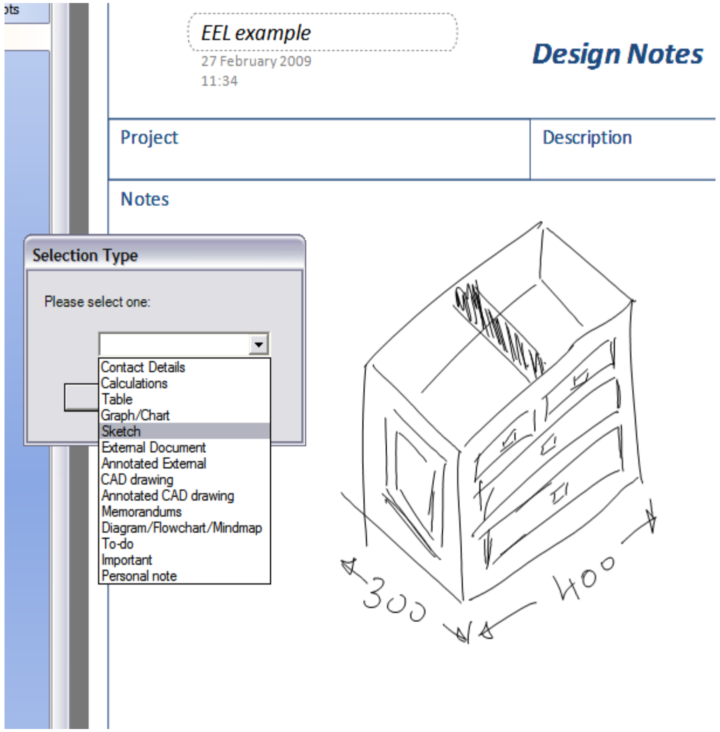


Figure 10-2 – Step 1 – Select information activity or object

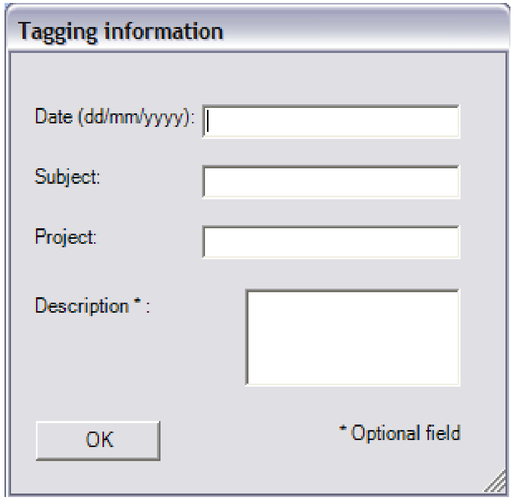


Figure 10-3 – Step 2 – Input required metadata

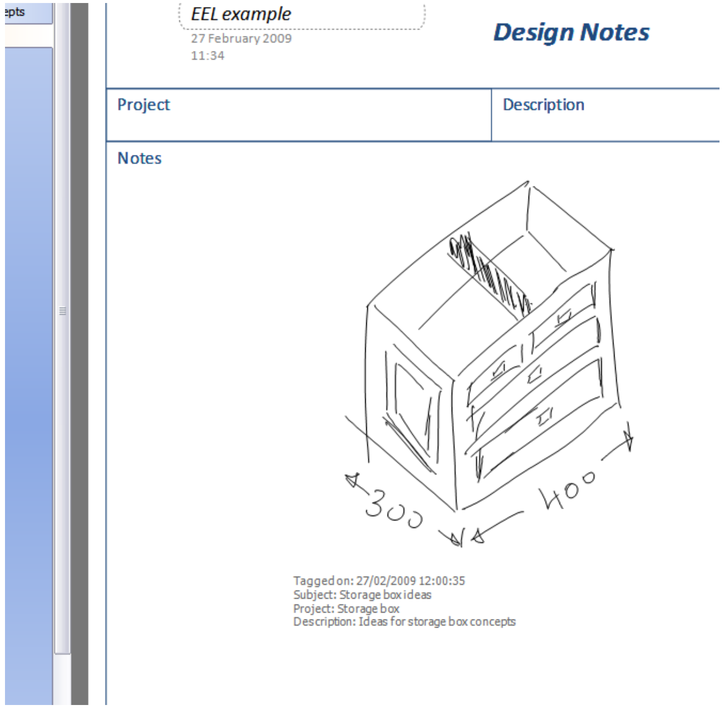


Figure 10-4 – Step 3 – Tags are added to the information element

Step 1: Information element (in this case a sketch) is selected and the EEL add-on launched

Step 2: Once the information object or activity is selected from a drop-down list, a dialogue box asking for the associated identifiers is opened:

Step 3: Once the information is confirmed, the tag is embedded on the page with the information element and also in the metadata fields of the page schema:

The tagged content can then be searched in multiple ways using either the tags, the identifiers associated with the tags or templates, or a combination of both using OneNote's built-in search functionality. For example, all 'to-do' items can be retrieved, or more specific queries such as "*Sketches relating to project X*" or "*all meetings held last week with Steve*".

Whilst it is recognised that the EEL demonstrator as described does not meet all the specification elements described in Chapter 9, many of the key features (flexible pen input, information management schema and search options) are included. The way the pages are tagged (both visually and via metadata fields in OneNote's schema) also means that the requirement for browsing in a book-like fashion is met, as well as enabling other ways of searching the logbook in the future, such as via faceted browsing (McMahon et al., 2004). Following initial testing, the EEL demonstrator was used in a pilot evaluation, the results of which are now described.

10.1.3 Pilot Evaluation

Although the resources required for a meaningful deployment and evaluation of the EEL demonstrator meant that it was outside the scope of this research, a small evaluation was undertaken, primarily to test the utility of the information management approach and inform the development of a strategy for a larger-scale evaluation and deployment. Two participants used the EEL demonstrator over a period of five weeks (the first for two weeks, the second for three). They were given an initial briefing and some training material for EEL and the OneNote application, but were allowed flexibility in how and when they used the e-logbook. The entries created during the pilot were evaluated by assessing the level of mark-up (to evaluate completeness of the schema) and levels of consistency in the contextual information. General reaction to the demonstrator and the EEL concept was also gathered.

During the pilot, 26 entries were created, and 25 tags applied in total. The template identifiers were completed in both cases without difficulty, although abbreviations were still used for the names of attendees in the case of meetings. The participants reported no difficulty understanding the tag or associated identifier terms, and they were applied accurately where used. Neither participant reported that any tags were missing.

The first participant used EEL for two weeks, mostly for meetings. They found browsing effective, but had little need for more structured search over short period. Consequently the tags were used mostly to identify actions. They found the templates usable and liked the ability to separate actions from the meeting notes. Tags were applied soon after the end of the meeting. The second participant also recorded meetings, but it was also used for information gathering. Entries were tagged if necessary at the end of the meeting or end of the working day. They commented that they used EEL to record information that would usually go unrecorded, and also transferred in information from their personal file store, as they had more confidence they would be able to find it again in EEL. The search functionality was rated as very useful.

In terms of usability, both commented that the screen technology was not as natural as paper. The weight, battery life and "*obtrusiveness*" in meetings was also noted, as was the start-up time of the applications.

The shortcomings of this deployment were that the logbook was used in isolation, meaning sharing and integration aspects were not implemented, although one participant did send logbook content to a colleague in the form of a PDF, where otherwise they "*wouldn't have bothered"*. The two participants were also not involved in engineering design work during the evaluation, meaning some of the Object tags for elements such as sketches and calculations were not used. However, both participants were generally positive and were able to use the demonstrator in the way intended, demonstrating that despite its current shortcomings, Tablet PC's should be a viable platform for implementing EEL.

10.2 Strategy for Evaluation and Deployment

This section details a strategy for the evaluation and deployment of EEL, informed from three perspectives: i)The insights into logbook use gained throughout this research – particularly during the survey and interviews with engineers (Chapters 4 and 5), ii)the lessons learned from previous e-logbook attempts reviewed in Chapter 8 and iii)the creation of the technology demonstrator described above. This section is intended to form a short, pragmatic guide for industry for the evaluation and subsequent deployment of e-logbooks in an engineering environment and in doing so addresses the issue of a lack of guidance identified in the literature and technology reviews. The overall strategy is presented in Figure 10-5, before each aspect is discussed:

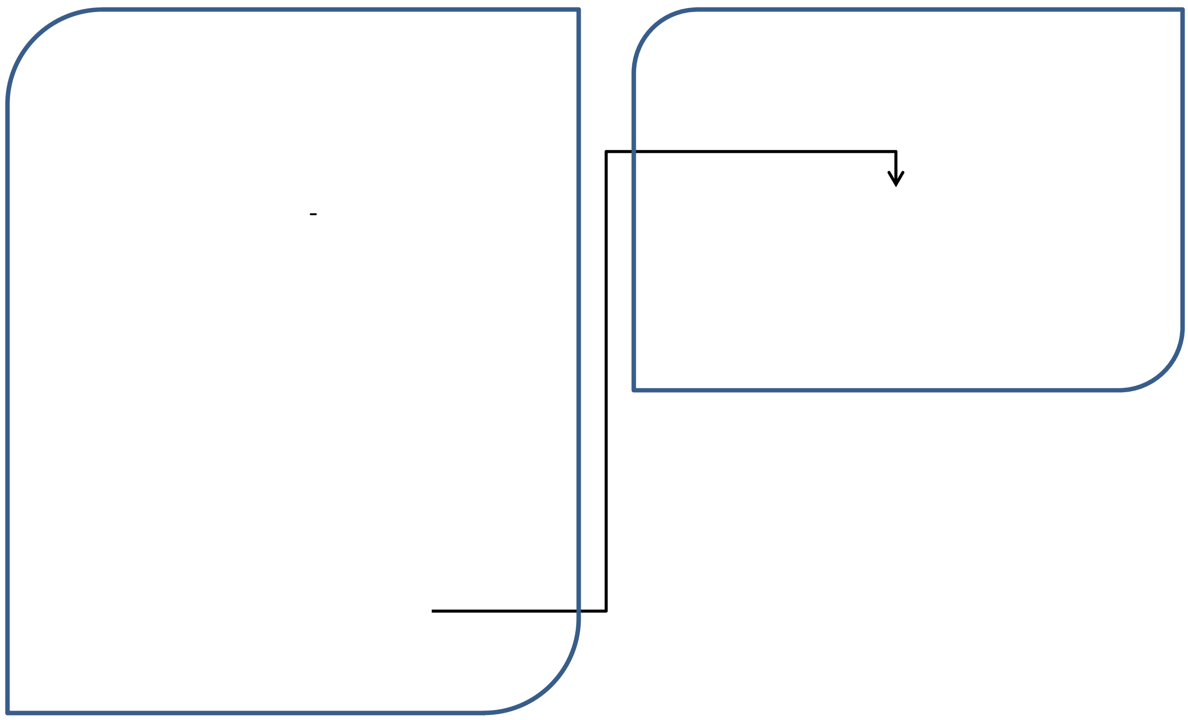


Figure 10-5 - Strategy for e-logbook Evaluation and Deployment

10.2.1 Audit Current Practice

A clear finding of the technology review presented in Chapter 8 was that many previous e-logbook attempts did not pay sufficient regard to current practice before embarking on design. Further, research in chapters 4-7 into what engineering logbooks contained and how they are used revealed that they are used in many different ways and for various reasons, and should not be thought of as simply containers for information. Therefore, the first and possibly most fundamental step is to understand logbook use and user needs in the context of the organisation. It is suggested that the audit takes a similar form to the interviews undertaken in Chapter 5, recoding the types and nature of information flow through existing logbooks. Information types and any forms used for routine data and information collection should be identified, such as pro-forma's used by service engineers. For the evaluation, it is suggested that this information is gathered from every person involved in the trial. With a clearer understanding of the current role of logbooks, clearer objectives may be formulated for the deployment, which will then inform how the schema is customised, what (if any) integration is necessary, and the most appropriate metrics by which to evaluate EEL.

10.2.2 Customise O-A Schema

The Object-Activity (O-A) schema described in Chapter 9 is explicitly designed to be used as a 'starting point' for general engineering use, but should be customised following the audit of current practice for maximum benefit. Two aspects are most likely to require customising: The template for forms, designed to be used to replace any existing forms used to record routine information, such as reports used by service engineers, timesheets etc., the design of which will obviously vary between organisations. Secondly, the list of activities, objects and associated identifiers may be changed to meet specific requirements identified in the audit. For example, the meeting template could be customised with an additional identifier indicating different types of meetings, critical decisions, or an identifier added to a 'task' tag assigning a priority ranking. Other engineering organisations may also have specific technical requirements, such as ATA numbers in the aerospace industry, used to identify unique parts of an aircraft. Such customisations may provide an useful additional criteria for searching and integration with, for example, PLM or other product management systems.

10.2.3 Select Technology Platform

Whilst a pen-computing solution was noted to be the most appropriate platform for EEL in Chapter 8, certain requirements relating to physical and technological capabilities cannot all be met by current pen-computing solutions such as Tablet PC's at the time of writing. However, the requirement specification is designed to be largely platform independent. Moreover, technologies such as electronic ink (e-ink) are becoming available (see, for example, PlasticLogic, 2009), along with thinner and lighter Tablet PC's. Such technologies will undoubtedly provide a more suitable platform in the future than the Toshiba M400 Tablet used for the demonstrator, which was found to be too heavy, and with insufficient battery life for a typical working day. Therefore a range of pen computing platforms available at the time should be evaluated against the audit results and objectives of the deployment, with particular attention paid to the portability, autonomy and ruggedness (if appropriate) of the device.

10.2.4 Consider Integration

The previous three steps should then be used to consider how the benefits of the deployment could be maximised through integration with other source of information, as integration has been shown to be an important factor in the success of e-logbooks in other domains. To some extent, the level of integration will depend on the objectives of the evaluation, with potential targets for integration with EEL chosen on the basis of how logbooks are used in conjunction with other information source at present. For example, Chapter 5 showed a common output from logbooks was an aggregated list of tasks. If this was the case, uptake of e-logbooks would likely be improved by ensuring an easy transformation between the logbook and this information source. Similarly, if one of the objectives is to improve the completeness of design records for legal or intellectual property reasons, attention should be paid to integration between EEL and any existing document management systems and other archives.

10.2.5 Pilot Evaluation

For the pilot evaluation, attention should be paid to three aspects: The metrics used to evaluate the pilot, the number of participants, and the length of the study.

The metrics chosen to measure the success or otherwise of the evaluation are likely to vary significantly according to the objectives of the deployment, the technology platform and level of integration, as well as the size and type of organisation. Arguably, however, previous e-logbook attempts have used metrics in one of three broad categories: personal productivity (generally assessed through case studies), amount of information re-use (e.g. number of times records are accessed, or amount of re-use of content) and other organisational aspects such as degree of legal compliance. It should be noted that metrics do not have to be selected to cover one perspective only. Indeed, it is recommended that at the evaluation stage, a balanced approach incorporating a range of metrics in the three areas should be used.

In terms of the number of participants and length of the evaluation, it is recommended that the pilot evaluation should involve a sufficient number of participants and be of sufficient length to ensure that the e-logbook can be assessed in a comprehensive and fair manner. For example, it has been shown that re-finding entries made within the last few weeks was almost always achieved by browsing quickly through pages and it was noted in the pilot evaluation in 10.1.3 that there was little need for the search facilities of EEL. Therefore if the structured search capability of EEL is to be assessed, it is suggested the length of the pilot study be at least two months. A similar logic applies to assessing the effect of EEL on sharing and collaborating, where the majority of people identified as sharing information should be included in the pilot. It is therefore suggested that the most suitable candidate groups in which to conduct pilots are likely to be small to medium-sized teams. Finally, at the end of the evaluation period, it is important to consider the root cause of any issues that have arisen – which, as indicated in Figure 10-5, may be a product of shortcomings of the audit not identifying critical factors, the O-A schema implementation (resulting in some activities not being supported), or issues with the technology platform or method (or lack of) integration.

10.2.6 Guidelines and Training

Whilst logbooks have been observed to be widely used in an engineering context, surprisingly few guidelines exist for their creation and use, both in educational settings, and most organisations. Training in logbook use and personal information management in general appears ad-hoc at best. Therefore, proper regard should be given to both training users in the use of the chosen technology, as well as producing more general guidelines and information on the importance of both potential individual benefits and the wider organisational objectives (e.g. legal compliance) to encourage better note-taking practice. Whilst the exact nature of the guidelines will again depend largely on the objectives of the deployment, it is suggested they cover the core areas of creation, classification (and the importance of metadata), and the re-use potential not just of their own logbooks, but also the enhanced re-use potential of information from other logbooks.

10.2.7 Deploy and Monitor

In larger organisations, the most practical approach is likely to be deployment on a department-by-department basis. In this manner, the learning from each previous deployment can be used to inform the next. However, the variability in note-taking practices between different types of engineer and job role means that it is recommended that the process of audit and customising the O-A schema should be undertaken for each department. There must also be a mechanism for ongoing monitoring and feedback to ensure items such as the O-A schema and form templates continue to meet the needs of the engineers. This could be achieved on a departmental level by assigning someone responsibility for records management, possibly as part of a wider knowledge management role.

10.2.8 Alternatives for Smaller-scale Deployments

Whilst has been argued that long-term use of integrated e-logbooks by a sufficient number of people is necessary to realise all the potential benefits of EEL, particularly for small organisations or limited budgets, it is recognised that this may not be possible. If a wide-scale deployment is not possible or appropriate, alternative strategies may be adopted by following the fundamental principles behind EEL.

For example, more consistent, re-usable information records could be obtained simply by introducing more training and guidelines for keeping such records, based on the O-A schema principles of recording consistent metadata to aid retrieval and manual linking to other more formal sources of information. Taking this a step further, it would also be possible to implement some features of EEL in a paper-based or hybrid system comprising of template-based paper logbooks combined with digitising into an electronic format and tagging with metadata. Finally, if e-logbooks are to be deployed to a small number of users, benefit could be maximised by focussing on identifying the most critical instances of personal logbook use. This could include the logbooks of, for example, a new project team. The O-A schema could also be applied retrospectively to, for example, the logbooks of a retiring senior engineer as a knowledge capture and transfer exercise.

10.3 Potential Barriers to Adoption

In addition to specific technological shortcomings of current technology platforms as e-logbooks, there are three other main barriers to the adoption of EEL in its current form that should be considered in parallel to the strategy presented above. Firstly, deciding on an open format for representation and long-term storage of the logbook data is of critical importance in the engineering domain. It has been suggested that XML has obvious utility for the hierarchical classification schema and for affording a more suitable interface for retrieval across multiple logbooks, although there are still issues such as how to handle embedded external documents and images.

Secondly, there are unresolved legal issues concerning the admissibility of e-logbook material in courts of law, with pharmaceutical companies reportedly printing out e-logbook pages, signing them by hand and archiving them in a safe (Butler, 2005). Clearly, then, data security and verification tools and techniques such as digital signatures and other cryptography techniques have a role to play in any commercial product. Whilst the regulatory and legal situation is very complex (especially with regards to international intellectual property law) it is becoming clearer in some cases. For example, in the pharmaceutical industry where e-logbook use is more common, the US regulatory body, the Food & Drug Administration have issued guidelines for compliance with regulatory requirements (US FDA, 2009). Many countries also now have legislation governing the use of aspects of electronic records, like digital signatures (see, for example, UK Electronic Communications act, 2000) and there is growing case law on which to formulate 'good practice' guidelines. Furthermore, despite these potentially complex issues, it is argued that in the vast majority of cases, having structured electronic records is preferable to fragmented, low quality paper records, or no records at all.

Finally, alternative approaches to informal information recording (such as integrating sketches directly with PLM systems) could arguably re-define the whole concept of a logbook in the longer term. However, it is argued despite all the tools and technologies that seemingly fulfil part of the logbook's role (such as diaries, electronic sketching tools, whiteboards, voice and video recording etc.), logbooks still exist, fulfilling many unique roles that are not easily replicated by dedicated systems. Indeed, Spinuzzi (2003) found that even with the introduction of new information systems designed to replace 'old fashioned' paper use, the imperfect nature of the systems meant there was still a need to record personal, informal information. It is therefore argued that logbooks are likely to remain a significant feature of engineering work for the foreseeable future.

10.4 Concluding Remarks

This chapter has presented the creation of a technology demonstrator aimed at showing how EEL could be deployed on the suggested Tablet PC platform. A strategy for the evaluation and deployment was then outlined. Informed from experience gained during the process of undertaking this research, it is intended to be a pragmatic guide for industry. The strategy emphasises the importance of understanding existing logbook use and content, customising the O-A schema to best support user needs, the importance of integration with other information systems, and ongoing training and support via local points of contact.

It has also been mentioned that smaller-scale deployments to tackle specific issues may also be made. Further, the importance good practice achieved through training should not be underestimated. A well delivered training package following the general principles embodied in EEL could arguably deliver substantial benefits. The benefits of good practice guidelines could potentially improve the management of informal sources, not only improving personal productivity, but also contributing to the reduction of (legal compliance) risk for the organisation, for relatively little investment compared to a full-scale e-logbook deployment.

11 Conclusions

First, the background and rationale for this research is summarised. The research questions are then revisited and the overall research strategy is restated. The main contributions to knowledge are then discussed, before the findings and contributions from each chapter are summarised. Recommendations for further research are then discussed, followed by recommendations to industry in the form of practical steps that may be taken towards the adoption of electronic logbooks in the engineering domain.

11.1 Background and Rationale

The rationale for studying engineering logbooks is based on the fact that the effective use of information and knowledge are prerequisites for successful engineering design activities and sustaining competitive advantage. This information and knowledge is generated and used in large volumes and consists of a large number of formal information sources such as component catalogues, reports and CAD models, as well as a large number of informal, personal sources such as logbooks, meeting notes, sketches, diaries and the output on whiteboards of collaborative activities.

It was contended that whilst the more formal sources have been relatively well researched, informal sources have received less attention (although there is a growing recognition of their importance). Of these informal sources, engineering logbooks were considered one of the most important due to their very widespread use and role in recording engineering-design specific related information, such as rationale and the outcome of meetings, sketches of concepts, information on customers and suppliers etc. However, it was proposed that the way logbook information was stored severely limited its ability to be re-found and re-used for various purposes, with potentially damaging productivity, financial and legal implications. It was argued that improved management of logbook information could lead to:

- More effective re-finding and using of various types of information by the individual author during the project, enhancing personal productivity.
- Increased re-use of past design information in the form of more complete records of rationale for decisions etc.
- Reduced risk to the organisation through more complete and re-findable records for legal, audit and traceability purposes.

It was also argued that there has been a low uptake of electronic replacements in the engineering domain, despite the considerable success of other personal information management tools and for electronic logbooks in the sciences and pharmaceutical industries. Following a review of current logbook research, it was concluded that this can be attributed to two main factors: a lack of understanding of curretn logbook use and content and a subsequent lack of guidance on how an electronic replacement could be implemented.

11.2 Research Questions

In order to improve the management of logbook information, two research questions were developed: The first research question sought to **investigate what logbooks contain and how and why they are used**. The three objectives associated with this question were:

1. Why do engineers maintain logbooks? What do they contain and how are they currently structured, organised and used/re-used?
2. Of the information in logbooks, what are the differences between it and its more formal counterparts? What makes it into the more formal sources and is there any loss?
3. What lessons may be learned from existing e-logbook attempts in both the engineering domain and more generally?

The second research question was developed to be more convergent and solution-focussed and concerned **how this understanding can be used together with new and emerging technology to improve the management of logbook information.** Again, three objectives were formulated to help direct the answer, but were designed to be more convergent and than those of the first question:

1. How can current and emerging technologies be used to best support improved management of logbook information?
2. What are the requirements for the next generation of engineering e-logbooks, to improve information management for the both the individual and wider organisation?
3. How can e-logbooks be demonstrated and evaluated in an engineering environment?

11.3 Research Strategy

Following findings from the literature review highlighting the relative lack of existing work in this area, a flexible research strategy was adopted. Flexible strategies are characterised by features such as:

- Not having a completely pre-defined structure but one that evolves with the research findings.
- Using mixed methods to collect data, both quantitative and qualitative.

- Including the researcher as an instrument for data collection.
- Focusing on the participants views (in a similar fashion to user-centred techniques).
- Seeking to understand problems, not a causal relationship, accurately reflecting 'real-life'.

To address the first research question (what logbooks contain and how they are used), a number of complementary studies were carried out. Firstly, a survey of engineers from a variety of backgrounds was conducted, exploring reasons for maintaining a logbook and questioning why they were used. This was used to inform a more in-depth study exploring logbook use in a wider information management context through interviews with a range of engineers and other stakeholders. To further triangulate these findings, a detailed analysis of logbook content, structure and organisation was undertaken. Consisting of over 3000 pages of information, the study assessed in detail what information they contain and how engineers commonly identify entries. Finally, a comparison of informal logbook information and its more formal counterpart in the form of reports and CAD was undertaken.

The second research question was addressed by creating a specification for an engineering e-logbook (EEL) based on requirements derived from the literature by way of a detailed review of existing e-logbooks and related technologies, and from requirements derived from the user studies in chapters 4-7. These were then embodied in a technology demonstrator, aimed at showing how EEL may be deployed on the suggested Tablet PC platform. A pragmatic guide for EEL's wider evaluation and deployment was then detailed, covering the steps an engineering organisation should follow for a wide-scale evaluation and deployment. How this strategy answered the research questions and associated objectives is now discussed.

11.4 Contributions to Knowledge and Main Findings

It was argued in chapters 2 and 3 that gaps in the current literature existed along two dimensions. Firstly, there was a lack of previous research into logbook practice. This lack of knowledge was both in terms of what they consist, and how and why they were used. The second gap related to the lack of understanding about how technology could best be used to support this widely used but little understood practice of keeping logbooks. As a consequence, there was very little in the way of guidance on how such informal, personal sources might be managed more effectively and very low uptake of new technologies. This was despite a number of e-logbook being developed over the past 20 years and despite almost every other aspect of engineering work being carried out in the digital domain. This thesis addresses both these gaps and provides two fundamental contributions:

1. An **in-depth understanding of the use, content, structure and organisation of engineering logbooks**, encompassing not only the logbook itself, but their relationship to formal information and use in the wider context of engineering work.
2. A detailed **specification for an engineering-specific e-logbook** to improve the management of informal engineering information, derived from both the use studies and a technology review of existing e-logbooks in engineering and other domains, with an associated strategy for the evaluation and deployment of e-logbook technology in an engineering context.

The main findings and contributions of each chapter is now shown with respect to the original research questions and objectives in Table 11-1:

Research Question	Objectives	Cp.	Study	Main Findings/Contributions
RQ1 - What do logbooks contain and how and why are they used?	**RQ1-1** Use, content, structure and organisation of logbooks	4	Logbook use survey	**Survey of 50 practicing engineers** • Understanding of logbook use in industry in terms of *why* they are used – revealing that they have many reasons, but are mainly a personal record to remind of work in progress. • Information on *how* often both current and past logbooks are re-used, and why they are re-used. This revealed that whilst current logbooks are typically accessed on a daily basis, past logbooks are either not retained, or accessed much less frequently. • Evidence of logbooks supporting three 'modes of use' - ideation, communication and documentation.
		5	Logbook Use in Context	**Interviews with six engineers** • Evidence of the wide range of personal information types and the often complex, fragmented relationships between them. • Recognition of the logbook's central role in the wider personal information space. **Interviews with six further engineers** • Identification of the critical role of logbooks in '**mediating**' between various types of work, and formal and informal information. • Detailed understanding of logbook use in the wider context of engineering work, in terms of the flow of information through the logbook. • An understanding of organisational issues in logbook use and how these are likely to change in the future.

RQ1 cont...		6	Content, structure and organisation	**Analysis of 26 Engineering logbooks** • Detailed understanding of the information types in engineering logbooks, how they are structured and what metadata is used to re-find entries. • For content, 13 classes of information were found, with some differences between levels of information types according to job role. • Analysis of revealing inconsistent levels of metadata used to identify entries, with dates, titles and projects being the most common.
	RQ1-2 Relationship of logbook information to more formal sources	7	Comparison of informal logbooks to formal project record	**Analysis of complete set of documentation comprising six logbooks, 11 reports and CAD** • Method and classification schema for characterisation of differences in content and nature between engineering information sources • Detailed understanding of the significant difference in nature and content of informal vs. formal records, with informal records tending to be more exploratory in nature, and containing many more examples of sketches and calculations. In contrast, the formal record provided a factual account of the final design, concentrating largely on performance of the chosen solution
	RQ1-3 Lessons from existing e-logbooks in both engineering and other domains	8	Review of existing e-logbooks and related technologies	**Review of 12 existing e-logbooks and e-logbook technologies from engineering and other domains** • Understanding of e-logbook use in other domains – notably pharmaceutical research, biology and chemistry, including the factors that have contributed to the relatively success of e-logbooks in these domains, primarily through providing integration with a wider workflow. • Analysis of areas where existing technologies can and cannot meet the requirements identified from users studies in previous chapters. • A recommendation that at the time of writing, the Tablet PC platform is most suited to meet the requirements for an engineering e-logbook (EEL).
RQ2 - How can this understanding be used together with technology to improve the management of logbook information?	**RQ2-1** How can technology be used to support e-logbooks?			
	RQ2-2 What are the requirements for next-generation e-logbooks?	9	Requirement Specification for an Engineering E-logbook	**Detailed engineering e-logbook (EEL) requirement specification, derived from user studies** • Detailed requirements in the areas of information creation, classification, re-finding, integration with other information sources and other practical considerations. • An information management strategy consisting of templates to support the capture of more structured and consistent metadata, combined with a novel, lightweight Object-Activity (O-A) schema to classify and manage logbook content, based on how and why engineers use

	RQ2-2 cont…			existing paper-based logbooks. • A solution aimed specifically at the needs and requirements of engineers, but flexible, customisable and extensible to many different types of engineering work and particular specialist requirements of different industries.
	RQ2-3 How can e-logbook technology be demonstrated and evaluated in practice?	10	Strategy for EEL Evaluation	**Strategy for the evaluation and deployment of engineering e-logbooks in industrial context** • A strategy for the evaluation and deployment of e-logbook technology in an engineering organisation, informed by the results of existing e-logbook implementations and the results of a pilot study. • The key feature of this strategy was a structured process to ensure the final e-logbook is customised to the needs of the particular organisation.

Table 11-1 - Relationship between research questions, objectives and contributions

11.4.1 Generality of the Research Approach

Another area in which this thesis makes a contribution is via the flexible, mixed-method approach described in Chapter 3. The aim of this approach was to incrementally build up knowledge and provide a high degree of triangulation between studies to give a rich picture of logbook use and content. Whilst the combinations of methods and studies undertaken will depend largely on the nature of the problem under investigation, the general approach could also be appropriate for other fields of investigation where understanding is required of a phenomena involving both social and technical aspects, where there exists little prior knowledge.

As well as learning from the overall methodology, this research has employed a number of new methods which could be used to further investigate logbooks and also other sources of information. For example, the coding scheme utilised in Chapter 7 has also been applied to emails. In a similar fashion, the mapping of information flow illustrated in Chapter 5 could be expanded to encompass the wider personal and formal information spaces to give a more complete picture of information use.

Finally, as well as methods useful to information management researchers to use, the investigation of logbook use in context (Chapter 5) and method for the analysis of logbook content and structure (Chapter 6) could also be useful to organisations looking to deploy e-logbook technology by following the strategy discussed in Chapter 10.

11.5 Recommendations for Further Research

This research has presented the results of studies which have provided a comprehensive understanding of current (largely paper-based) logbook use and how such information sources may be better managed through electronic alternatives. However, the following recommendations represent work that fell outside the scope of this thesis, either because they were not directly related to information management, or required significant software development and hardware resources not available over the course of this research.

11.5.1 The Role of Logbooks in Mediation

Chapters 5 and 7 both demonstrate the critical role of logbooks in mediating between various sources of formal and information. However, whilst both chapters draw on data representative of a common engineering design scenarios, there are two key factors that could influence the trends observed. Firstly the trends reported here could be different for other types of project concerning different stages in the design process, or in different organisations. For example, in the case of Chapter 7, a purely conceptual design exercise could well result in more emphasis on the rationale and design alternatives in the final report. Similarly, the detailed design of a component in a variant design may move to a CAD representation almost immediately, again meaning that the importance of the logbook as both a record and as a means of mediation could be reduced. Varying organisational practices (such as procedures or legal requirements relating to documentation in different industries) and also the nature of the team and their working practices may also have an influence. For example, if the team were distributed (i.e. not co-located as in the study in Chapter 7), the use of email or groupware may make it easier (or even necessary) to share informal representations in an electronic format, making their inclusion in the formal project record easier.

A similar argument could be applied to larger teams where project management tools such as workflow systems like Product Lifecycle Management (PLM) or shared calendars may reduce the amount of planning information in logbooks, or at least provide a source of such information that is easier to access. Extensive use of design rationale capture tools, together with PLM could even mean that the formal project record ceases to exist in the form of linear discourse (reports) in some cases.

Finally, it is argued that facilitating the linking or transformation of logbook records to more formal sources would increase the support for the mediation role and the potential for re-use through more complete records for audit and traceability. However, assessing the cost-benefit trade off for this additional effort could be difficult, as assessing information value has proved to be complex and often problematic (see Zhao et al., 2008 for an overview of existing techniques). It is therefore recommended that the mediation role of logbooks in the light of the factors mentioned above be investigated more fully.

11.5.2 Complete Evaluation of the Object-Activity Schema

As indicated in Chapter 10, although a pilot evaluation of the Object-Activity (O-A) schema has been undertaken with the technology demonstrator program, a comprehensive assessment would require significant software development, hardware resources and a representative number of users. This is because many of the most compelling benefits of e-logbook technology would arguably only be apparent through use by a sufficient number of users over a long enough period such that re-finding via structured searching (rather than browsing) becomes necessary for both individual engineers, and also from an organisational perspective where collections of logbooks can be searched and integrated with other information management systems.

11.5.3 EEL Integration

Central to the success of e-logbooks in the pharmaceutical industry and sciences has been their integration into a wider workflow, and the EEL requirement specification and the O-A schema have been designed to facilitate integration with various other information management systems and sources of information used in an engineering context, as described in Chapter 9. In addition, an important aspect of the evaluation and deployment strategy described in Chapter 10 was to maximise the potential cost-benefit through integration. However, the number and complexity of external systems meant that detailed technical work on how to realise such links was outside the scope of this research. Therefore, combined with a comprehensive evaluation of the O-A schema suggested previously, the technical means of achieving the integration should also be further explored and evaluated.

11.5.4 Collaborative Aspects

Thirdly, although the scope of this research was primarily to improving the management of logbook information, several of the scenarios presented in Chapter 5 included mention of collaborative work. This usually took the form of two people working together to solve a problem, the output of which was co-created in a logbook. Whilst such activities are enabled through the EEL specification in some ways (through, for example, identification of authors, shared or centrally managed logbooks), how this would work in practice given the prevailing view of logbooks as a personal resource requires further research. In addition, the technical means of identifying individual authors requires further work

11.5.5 International Aspects

Finally, much of the work reported in this thesis was carried out in organisations based in the UK. Whilst there is some evidence from the literature that logbook-keeping practice is similar in other western countries (see, for example, Currano & Leifer, 2009; Gwizdka, 1998, Oehlberg et al., 2009), there do not appear to be any detailed studies of how logbook use and content differs between cultures. Secondly, EEL is designed to facilitate sharing of logbook information, although the current O-A schema implementation is English language only. It is not clear how the management of logbook information in multiple countries and languages could work and this istherefore another area for further research.

11.6 Recommendations to Industry

Personal logbooks are a widely used personal information management tool, as well as a potentially valuable organisational resource. They contain many types of information such as meeting notes, sketches and calculations, much of which is directly related to engineering design (chapters 5-7). However, whilst paper logbooks have many affordances that make them a relatively effective information management tool (such as their ability to record many different types of information quickly and flexibly) their relative lack of structure, organisation and contextual information recorded alongside the information limits their potential as a tool for personal productivity.

As well as their role in personal information management, it has been show that logbooks have potential as an organisational resource, particularly as a provider of additional context and rationale when used in conjunction with formal reports (Chapter 7). They can also form a useful legal record for audit and intellectual property purposes, as they often contain the first documented instance of an idea or decision.

This research has proposed a specification for an electronic logbook designed to overcome the limitations of current paper-based logbooks, whilst retaining the affordances of paper that have seen logbook use continue despite almost every other part of engineering work moving at least partly to the digital domain. The specification for an engineering e-Logbook (EEL) has been derived from comprehensive studies of how and why existing paper-based engineering logbooks are used. It is intended to fulfil the requirements of many types of engineers and is thus designed to be flexible and customisable to any specific requirements that may exist in different types of engineering organisations. For example, small or medium-sized enterprises with a single product will clearly have different requirements to a multi-national company designing highly complex product platforms which may spend 50 years in service. Therefore, the most important recommendation is the need to follow a structured method for deployment as defined in Chapter 10 and summarised below.

11.6.1 Suggested Strategy

The suggested strategy for e-logbook deployment comprises a number of steps and is discussed in detail in Chapter 10, with the most important steps being:

1. **The audit of current note-taking practice**, aimed at understanding and customising the specification to the organisation's particular requirements before deploying, starting with an audit of current informal record keeping practice. This is possibly the most fundamental step, with most e-logbooks not paying sufficient regard to this (Chapter 8). It is suggested that the audit should comprise of interviews of a similar style to those presented in Chapter 5, focussing on exploring the information flow and user requirements, to enable the subsequent steps, discussed below.
2. **Customisation of the EEL O-A schema –** The O-A schema elements of templates and tags are designed to be customised to the needs of particular organisations according to the findings of the audit. For example, an organisation that carries out servicing or other routine activities may have pro-forma's that can be re-created in EEL. Similarly, organisations may use a specific type of information to identify certain projects or components (such as ATA numbers in the aerospace industry). The O-A schema is designed to be customisable to incorporate such elements.
3. **Integration –** The audit should also reveal how logbook information interacts with more formal sources. It was argued in Chapter 7 that making these links more explicit could enhance the overall design record by providing additional context and rationale for future

re-use, as well as increasing personal productivity through easier and quicker transformation of logbook material. The method of integration will vary widely depending on the complexity required. However, at the simplest level, even storing the formal reports together with the associated logbook record (either physically co-located or in the same folder on a computer) would make re-use considerably easier.

4. **Selection of an appropriate logbook platform** – Here it is important to consider how any solution could be integrated with existing infrastructure. Close monitoring of technology such as e-ink which could potentially meet aspects of the requirement specification that are currently not fulfilled with the Tablet PC platform is recommended. It must also be noted that, in contrast to previous e-logbook attempts, technology in this case should be viewed only as a means to an end. For example, although it was concluded in Chapter 9 that Tablet PC's offered the best platform to meet the full EEL specification at the time of writing this thesis, other technologies may be more appropriate to some organisations' needs.
5. **Appropriate training and on-going support –** The importance of guidelines and training for paper logbooks must not be underestimated. Chapter 5 revealed that none of the engineers interviewed had received any training or guidance in personal information management, or on how to keep records of their work. This led to a wide range of approaches to personal information management, resulting in information fragmentation and consequently limited ability for re-use, not just of the logbook material, but also the associated formal records, which could benefit from the additional context and rationale that logbooks provide (Chapter 7).

Other Options

EEL may also have utility for smaller-scale deployments, focussed on particular objectives such as knowledge transfer from retiring colleagues, the capture of more complete records from particular teams or stages of the design process, (such as conceptual design), or gathering information from service engineers.

The overall philosophy of the approach discussed in Chapter 10 and many aspects of the specification may also be embodied in the form of enhanced guidelines and training in informal and personal record-keeping. For example, the O-A schema described in Chapter 10 may be partially implemented with existing paper logbooks through the use of templates and a tagging convention based on colours, etc. Good practice guidelines should focus on the importance of *consistency* and *completeness* in note-taking, which EEL has been designed to encourage.

11.6.2 Potential Barriers to Adoption

Chapter 10 discusses the three most significant potential barriers to adoption, all of which require further work (or at least careful consideration) as part of an e-logbook deployment. Firstly, lessons from other types of archives indicate that the issue of the most appropriate format and data type in which to store logbook information is critical for both its long-term accessibility and its integration with other information types. Whilst the format and data type will be decided to some extent by the technology platform selected, the nature of any integration necessary and the design of existing archives should be considered from the outset of any deployment.

Secondly, legal issues surrounding e-logbook records - whilst becoming rapidly clearer - may still be a factor for some safety-critical engineering activities, or for activates where logbooks are likely to contain evidence for intellectual property claims (such as in new product development or fundamental research). Whilst legal advice is outside the scope of this research, it should be sought if considered appropriate to specific record-keeping situations.

Finally, it must be noted that despite the evidence of the critical role of logbooks in mediation, the nature of engineering work has changed dramatically over the last few decades and will undoubtedly continue to do so in the future. Whilst technologies that replace some logbook functions (particularly collaborative tools such as wikis) will continue to be developed, it is argued that e-logbooks of the type presented in this research represent a pragmatic and useful approach to improving informal information management in the engineering domain and - by virtue of their flexibility and ability to be customised to meet changing requirements - will continue to do so for the foreseeable future.

List of Relevant Publications

Journal Papers

McAlpine H, Hicks B, Huet G & Culley S (2006). *An investigation into the use and content of the engineer's logbook*. Design Studies 27 (4), pp.481-504.

Conference Papers (peer-reviewed)

McAlpine H, Hicks B & Culley S (2009) *Comparing the information content of formal and informal design documents: Lessons for more complete design records*. Proceedings of the International Conference on Engineering Design 2009 (ICED '09), August 24-27th 2007. Stanford, California, USA.

Huet G, McAlpine H, Camarero R, Culley SJ, Leblanc T & Fortin C. (2009*) The Management of Digital Sketches through PLM solutions*. Proceedings of the International Conference on Engineering Design 2009 (ICED '09), August 24-27th 2007. Stanford, California, USA.

McAlpine H, Hicks B & Culley S (2009) *Improving re-use of informal information through the creation of an engineering electronic logbook (EEL) – A demonstrator*. Proceedings of the ASME 2009 Design Engineering and Technical Conferences & Computers and Information in Engineering Conference (DETC/CIE 2009), August 30-September 2nd 2009. San Diego, California, USA. *(in press)*

McAlpine H, Hicks B & Culley S (2008) *Investigating the Structure and Organisation of Engineering Logbooks for More Effective Re-use.* Proceedings of Design 2008, 19-22nd May 2008, Dubrovnik, Croatia.

McAlpine H, Hicks B & Culley S (2007) *Characterising Personal Information in the engineering domain*. Proceedings of the International Conference on Engineering Design 2007 (ICED '07), August 28-31st 2007. Paris, France.

McAlpine H, Hicks B & Culley S (2006) *A Review of State-of-the-Art technologies for supporting a designer's electronic logbook.* Proceedings of Design 2006, 15-18th May 2006, Dubrovnik, Croatia.

Workshop Papers (peer reviewed)

McAlpine H, Hicks B and Culley S (2006b) *Attempting to Investigate the Design Information loss Between Logbooks and Formal Engineering Reports.* Design Rationale: Problems and progress workshop held during the 2nd Conference on Design Computing and Cognition (DCC '06), 9-13th July 2006, Eindhoven, The Netherlands.

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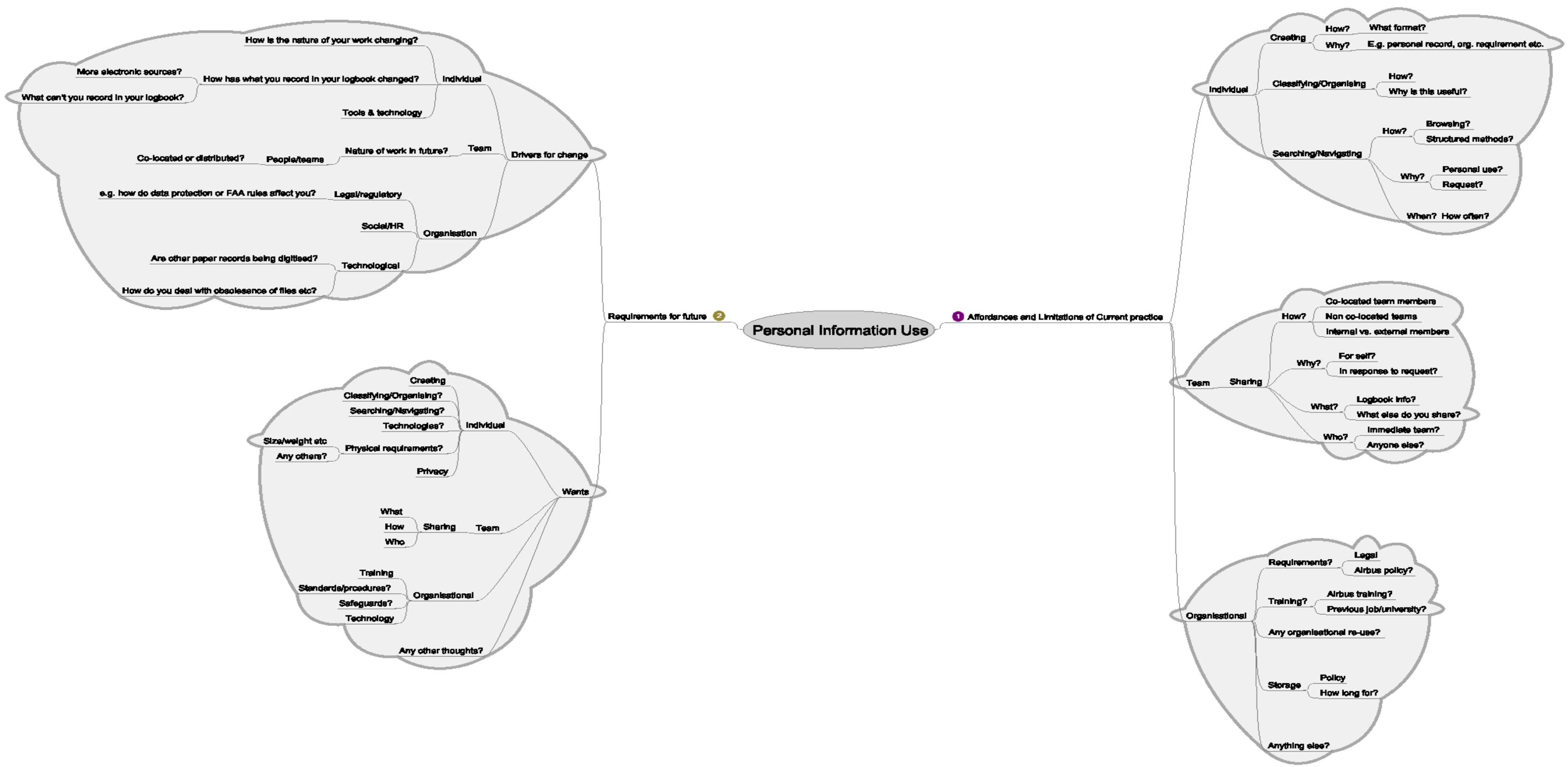
List of Appendices

Appendix A – Scenario Interview Framework



Appendix B – Data from Analysis of Logbook Content and Structure

Analysis - Occurrences

Type	ID	Classes	Entries	% of Total
Design	1	Sketch	41	25.47
		CAD Drawing	38	23.60
		External Document	30	18.63
		Calculation	26	16.15
		Written Note	16	9.94
		Annotated CAD	8	4.97
		Table of Figures	2	1.24
		TOTAL	**161**	**100.00**
Design	2	CAD Drawing	81	53.29
		External Document	47	30.92
		Annotated CAD	23	15.13
		Sketch	1	0.66
		TOTAL	**152**	**100.00**
Management	3	Meeting Note	85	51.20
		Written Note	47	28.31
		Sketch	16	9.64
		Memorandum	14	8.43
		Contact Information	4	2.41
		TOTAL	**166**	**100.00**
Management	4	Meeting Note	90	52.63
		Written Note		
		Sketch		
		Contact Information		
		Memorandum		
		Calculation		
		TOTAL		
Management	5	Written Note	79	56.83
		Sketch		
		External Document		
		Table of Figures		
		Meeting Note		
		CAD Drawing		
		Contact Information		
		Calculations		
		TOTAL		
Management	6	Meeting Note		
		Written Note	19	27.94
		Sketch	13	19.12
		Table of Figures	7	10.29

		Contact Information	1	1.47
		TOTAL	**68**	**100.00**
Service	**7**	Completed Forms	48	100.00
		TOTAL	**48**	**100.00**
Design	**8**	Written Note	169	55.96
		Table of Figures	88	29.14
		Calculation	24	7.95
		Sketch	15	4.97
		Annotated External	3	0.99
		Meeting Note	2	0.66
		Graph/Chart	1	0.33
		TOTAL	**302**	**100.00**
Design	**9**	Written Note	148	74.00
		Table of Figures	41	20.50
		Sketch	9	4.50
		Graph/Chart	2	1.00
		TOTAL	**200**	**100.00**
Management	**10**	Meeting Note	80	52.29
		Written Note	37	24.18
		Memorandum	20	13.07
		Sketch	10	6.54
		Table of Figures	4	2.61
		Contact Information	2	1.31
		TOTAL	**153**	**100.00**
Research	**11**	Written Note	95	45.02
		Contact Information	55	26.07
		Meeting Note	32	15.17
		Sketch	12	5.69
		Table of Figures	7	3.32
		External Document	6	2.84
		Calculation	3	1.42
		Memorandum	1	0.47
		TOTAL	**211**	**100.00**
Research	**12**	Calculation	50	29.24
		Written Note	49	28.65
		Graph/Chart	25	14.62
		Sketch	21	12.28
		External Document	18	10.53
		Annotated External	5	2.92
		Table of Figures	3	1.75
		TOTAL	**171**	**100.00**
Research	**13**	Calculation	83	47.43
		Written Note	30	17.14
		Graph/Chart	24	13.71
		External Document	17	9.71
		Table of Figures	9	5.14
		Sketch	9	5.14
		Annotated External	3	1.71
		TOTAL	**175**	**100.00**

Research	**14**	Written Note	58	49.57
		Sketch	44	37.61
		Table of Figures	7	5.98
		Calculation	3	2.56
		External Document	2	1.71
		Contact Information	3	2.56
		TOTAL	**117**	**100.00**
Research	**15**	Sketch	55	37.93
		Written Note	53	36.55
		Meeting Note	20	13.79
		Contact Information	9	6.21
		Memorandum	4	2.76
		External Document	3	2.07
		Calculation	1	0.69
		TOTAL	**145**	**100.00**
Research	**16**	Calculation	18	33.33
		Sketch	16	29.63
		Written Note	15	27.78
		Meeting Note	5	9.26
		TOTAL	**54**	**100.00**
Design	**17**	Written Note	16	39.02
		Meeting Note	7	17.07
		Sketch	14	34.15
		Table of Figures	2	4.88
		Graph/Chart		
		Calculation		
		External Document		
		TOTAL		
Design	**18**	Written Note	39	49.37
		Meeting Note		
		Sketch		
		Table of Figures		
		Graph/Chart		
		Calculation		
		External Document		
		TOTAL		
Management	**19**	Written Note	48	45.28
		Meeting Note		
		Sketch		
		Table of Figures		
		Graph/Chart		
		Calculation		
		External Document		
		TOTAL		
Design	**20**	Written Note		
		Meeting Note	21	16.03
		Sketch	38	29.01
		Table of Figures	1	0.76
		Graph/Chart	2	1.53

		Calculation	7	5.34
		External Document	1	0.76
		Contact Information	5	3.82
		TOTAL	**131**	**100.00**
Design	**21**	Written Note	62	41.89
		Meeting Note	15	10.14
		Sketch	34	22.97
		Table of Figures	2	1.35
		Graph/Chart	2	1.35
		Calculation	21	14.19
		External Document	5	3.38
		Contact Information	3	2.03
		Annotated External	4	2.70
		TOTAL	**148**	**100.00**
Design	**22**	Written Note	36	73.47
		Meeting Note	5	10.20
		Sketch	6	12.24
		Table of Figures	1	2.04
		Graph/Chart	0	0.00
		Calculation	0	0.00
		External	0	0.00
		Contact Information	1	2.04
		TOTAL	**49**	**100.00**
Design	**23**	Written Note	45	50.56
		Meeting Note	23	25.84
		Sketch	9	10.11
		Table of Figures	1	1.12
		Graph/Chart	1	1.12
		Calculation	7	7.87
		External Document	2	2.25
		Contact Information	0	0.00
		Annotated Ext	1	1.12
		TOTAL	**89**	**100.00**
Design	**24**	Written note	18	21.43
		Meeting note	19	22.62
		Sketch	23	27.38
		Table of Figures	4	4.76
		Graph	5	5.95
		Calculation	5	5.95
		External	3	3.57
		Contact Information	0	0.00
		CAD	7	8.33
		TOTAL	**84**	**100.00**
Design	**25**	Written note	13	17.33
		Meeting note	18	24.00
		Sketch	27	36.00
		Table of Figures	0	0.00
		Graph/Chart	2	2.67

		Calculation	12	16.00
		External Document	3	4.00
		TOTAL	**75**	**100.00**
Design	**26**	Calculation	43	35.25
		Written Note	22	18.03
		Graph	18	14.75
		Sketch	19	15.57
		External Document	6	4.92
		Annotated External	6	4.92
		Table of Figures	0	0.00
		Contact Information	8	6.56
		TOTAL	**122**	**100.00**

Averages by Job Role

Averages (Management)	Ave(%)
Written Note	34.62
Meeting Note	38.00
Sketch	13.75
Calculation	1.77
Table of Figures	3.78
CAD Drawing	0.24
Annotated CAD	0.00
Contact Information	1.67
External Document	1.44
Annotated External	0.00
Memorandum	2.09
Graph/Chart	0.47

Averages (Design)	Ave(%)
Written Note	37.98
Meeting Note	10.32
Sketch	18.91
Calculation	10.10
Table of Figures	5.06
CAD Drawing	6.56
Annotated CAD	1.55
Contact Information	1.11
External Document	5.36
Annotated External	0.75
Memorandum	0.00
Graph/Chart	2.31

Averages (Research)	Ave(%)
Written Note	34.12
Meeting Note	11.15
Sketch	21.38
Calculation	19.11
Table of Figures	2.70
CAD Drawing	0.00
Annotated CAD	0.00
Contact Information	5.81
External Document	4.48
Annotated External	0.77
Memorandum	0.54
Graph/Chart	4.72

Appendix C – Data from Comparison of Informal and Formal Documentation

By Category

	What			Why	
% of entries	Product	Project	Organisation	Problem solving	Communication
Logbook 1	51.7	62.1	40.2	89.7	67.8
Logbook 2	75.8	39.4	21.2	54.5	84.8
Logbook 3	66.0	66.0	43.4	60.4	94.3
Logbook 4	69.5	50.0	37.8	73.2	100.0
Logbook 5	74.0	53.4	38.4	76.7	98.6
Logbook 6	47.8	58.7	41.3	47.8	97.8

	What			Why	
% of entries	Product	Project	Organisation	Problem solving	Communication
Report 1	84.0	14.0	30.0	90.0	72.0
Report 2	87.5	20.8	12.5	45.8	87.5
Report 3	75.0	7.5	25.0	47.5	90.0
Report 5	82.9	17.1	37.1	68.6	100.0
Report 6	89.5	7.9	28.9	60.5	100.0
Report 8	86.3	11.8	13.7	56.9	98.0
Report 9	79.4	11.1	23.8	47.6	96.8
Report 10	87.5	10.0	25.0	60.0	100.0
Report 11	77.8	5.6	27.8	61.1	100.0
Report 12	82.4	26.5	32.4	82.4	97.1
Report 13	66.7	33.3	66.7	75.0	100.0

Category Averages

	What			Why	
% of entries	Product	Project	Organisation	Problem solving	Communication
Logbooks	64.1	54.9	37.1	67.0	90.6
Reports	81.7	15.1	29.4	63.2	94.7

By Term

Product

Product	Logbooks	Reports
Function	6.8	11.6
Performance	21.3	40.4
Feature	45.6	52.6
Op. Env.	5.9	11.6
Material	3.7	5.8
Manufacturing	1.4	1.7
Cost	11.0	12.5
Ergonomics	1.2	7.6

Project

Project	Logbooks	Reports
Risk	2.6	4.6
Planning	48.1	5.7
Team	11.2	3.9
Quality	3.6	2.7
Cost	2.4	0.3
Time	6.2	0.7

Organisation

Organisation	Logbooks	Reports
Stake Holders	3.0	3.2
Economic	9.8	8.2
HR	9.5	3.6
Physical	1.7	0.0
Financial	1.2	0.0
Knowledge	14.4	12.3
Tools/Methods	2.4	3.6
Practices	0.2	0.3

Problem Solving

Problem Solving	Logbooks	Reports
Goal setting	10.1	10.5
Constraining	4.9	8.0
Solving	53.8	35.0
Evaluating	9.1	25.8
Decision making	4.2	8.0

Communication

Communication	Logbooks	Reports
Clarifying	13.2	0.4
Debating	0.9	1.5
Informing	26.8	73.8
Exploring	63.8	24.0
Digressing	1.7	0.0
Managing	10.5	0.0

Information Types

	Logbooks	Reports
Written note	68.1	76.3
Meeting note	20.9	0.0
Sketch	33.1	8.6
Table of Figures	2.4	15.5
Graph/Chart	1.8	0.9
Calculation	13.2	4.3
External Documents	1.7	8.7
Contact Details	2.1	0.0
Annotated External	0.9	0.4
Diagram/Mindmap/Flowchart	0.2	2.6
External CAD	0.0	6.0