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INVESTIGATING THE STRUCTURE AND ORGANISATION OF ENGINEERING LOGBOOKS FOR MORE EFFECTIVE RE-USE

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1. Introduction

Many practicing engineers maintain a record of their work, usually in the form of a logbook or a detailed diary of their day-to-day activities. These records provide potentially valuable reference material for the engineer, the design team and the wider organisation. Despite this, a large proportion of the content may remain unreported and inaccessible by any formal means, hence potentially valuable information may be lost. Further, it has been reported from the pharmaceutical industry that the "*pitfalls of paper*" (i.e. the difficulty in searching and sharing paper-based results) cost US $1bn last year in lost opportunities and duplicated work [Butler, 2005].

Whilst Butler's observation focuses on the pharmaceutical industry, it is arguable that similar magnitudes of cost are likely to be incurred across the various engineering industries and in-particular those involving the design of large, complex products such as aircraft or machine systems. For these reasons it is highly desirable to provide improved tools and methods for supporting the engineer in the recording, re-use and sharing of their working notes (logbooks). To begin addressing this, a study of the information content [McAlpine et al, 2006a] and existing logbook technologies [McAlpine et al, 2006b] has been undertaken. These studies revealed that even the state-of-the-art electronic logbook technologies [*see, for example* Microsoft corp., 2007] do not support the wide range of information types found in engineering logbooks and that existing technologies cannot effectively replicate the affordances of existing paper-based logbooks such as quick, free-form input .

Whilst an understanding of these first two dimensions (the information content of logbooks and existing logbook technologies) is essential for the development of improved methods, it is also necessary to investigate a third dimension: how engineers currently structure and organise the content, how this affects information re-use and how these limitations could be overcome. It is this third dimension that is the subject of this paper. In particular, a methodology for characterising the structure of logbook entries is discussed and the results of its application to a set of logbooks is presented. These findings are used to inform the development of a strategy for improving the recording and subsequent re-use of logbook information content. The strategy is discussed in detail and examples are given of how the strategy facilitates more effective management of logbook information for both the individual and the wider organisation.

2. Characterising structure and organisation

The methodology used in this study is described in section 2.1. This is followed by the results in sections 2.2 and 2.3. The key barriers that current logbook structure and organisation have on re-use is then discussed in section 2.4.

2.1 Methodology

A detailed assessment of 16 engineering logbooks – representing over 2000 pages of engineering-design related information – has been undertaken by the authors. The first part of this study explored the information content and resulted in a characterisation of the various information classes contained within engineering logbooks and is fully reported in McAlpine et al [2006a]. The thirteen classes of information previously identified in this work were: *written notes*, *meeting notes, contact details, calculations, tables of figures, completed forms, sketches, graphs charts, CAD drawings, external documents, annotated external documents, annotated CAD drawings and memorandums*.

This classification of information classes is used in this paper as a framework in which to characterise the structure. In the previous study an entry was considered to comprise "*one or more classes of information separated by two dates or a terminator*" (a terminator could be a ruled line or an empty portion of a page). In practice it was found that entries were easily discerned with little room for misinterpretation and the same definition for an entry is adopted for the study described in this paper.

The characterisation of structure involved identifying the information elements which either define or can be associated with each information class. These items of metadata include, 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 1, below:

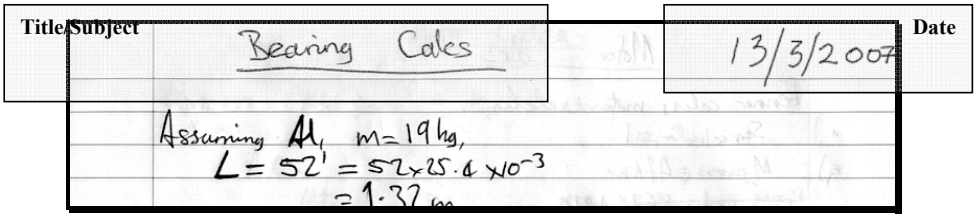

Figure 1. Example of Identifiers

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 indexing and 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 identifying limitations of current paper-based logbooks.

2.2 Results - characterising structure

Thirteen identifiers were present in the 16 logbooks characterised. These are listed and defined where necessary below:

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
Source	The source for the information in the entry or a reference, e.g. reference to a textbook
Author	Who made the entry or annotation on an entry
Name of contact	"
Telephone number	"
Email address	"
Organisation	To what company the contact belonged

Table 1, below, shows which of these identifiers were associated with each information class:

Table 1. Identifiers associated with each information class

Identifiers \ Information Classes	Written notes	Meeting notes	Sketches	Contact details	Calcs	Tables of figures	CAD Drawings	Annotated CAD	External docs	Annotated External	Memo's	Graphs and charts	Completed forms
Date	×	×	×		×	×	×	×	×	×		×	×
Title/Subject	×	×	×		×	×	×	×	×	×		×	×
Description									×	×			
People		×											
Location		×											×
Page number	×				×				×	×			
Revision							×	×					
Source	×				×		×	×	×				
Author	×		×				×	×	×				×
Name of contact				×									
'Phone number				×									
Email address				×									
Organisation		×		×			×	×					×

2.3 Results - characterising organisation

All the logbook entries were arranged in chronological order, although some start at both the front and back 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. For example, a new entry would begin with the date or subject. Entries were sometimes terminated with a ruled line, or denoted by empty space, with new entries starting on a new page.

Only two of the 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, along with other visual cues such as folded page corners. 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.

2.4 Limitations of current practice

It is clear that the wide variation in structure and organisation of individual logbooks will significantly affect the extent of their 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, sources of information were rarely identified, and the author of annotations was never indicated. Six core information-based logbook activities, identified in McAlpine et al, [2006b] have been used to structure these and the other key limitations. Table 2 summarises the key limitations affecting re-use for each of these activities:

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 because they are viewed as a personal resource, 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. To improve re-use, an information-based classification strategy, based on the above characterisation, is proposed and discussed in the next section.

Table 2. Key limitations affecting re-use

Logbook Activity	Key limitations
Creating	• Inconsistent structure and organisation of entries • External documents such as CAD only represent single viewpoint
Classifying	• Lack of identifiers (metadata), inconsistently applied in personal style
Browsing/Navigating	• Lack of cross referencing • Visual cues personal to author and do not reflect interest of other 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

3. Improving structure and organisation

It is proposed to improve the structure and organisation of logbook information with a strategy based on three components:

1. **Templates** to structure high-level logbook activities. They are analogous to logbooks pages and act as 'containers' for other information.
2. Three types of **Tag (tags, holders and mark-up)** to classify the information contained within the templates.
3. A set of **Identifiers** associated with each template and tag, adding further metadata

The relationships between these three components are represented in Figure 2 and discussed in detail below:

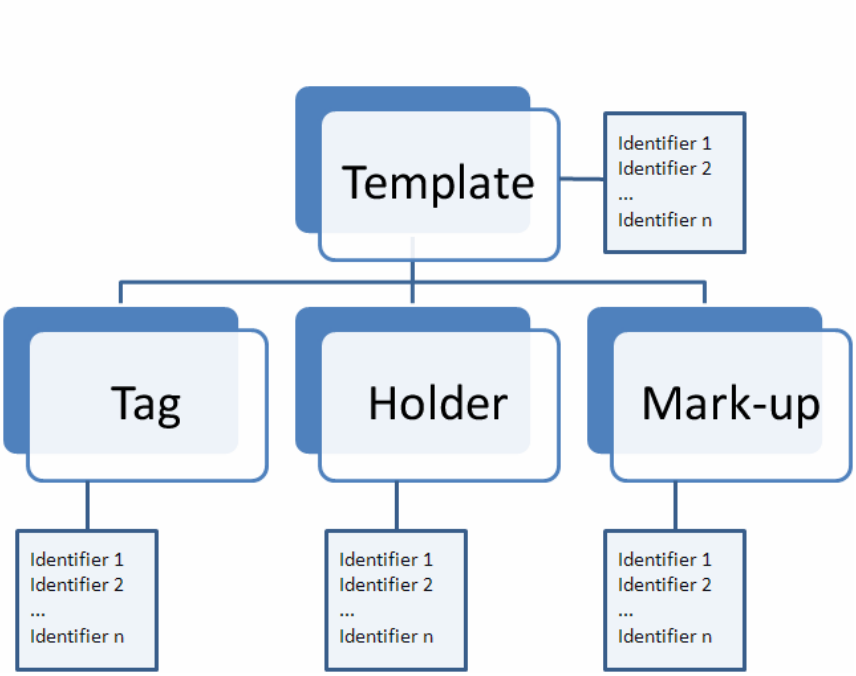

Figure 2. Relationship between components of strategy

3.1 Templates

In this study, it was observed that some logbook entries represented 'containers' in which other information existed, and that these would be best represented by page templates. 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, thus retaining the flexibility of existing logbooks in this regard. Three classes of information are represented as templates in this strategy:

1. Written notes
2. Meeting notes
3. Completed forms

For example, a new entry is always created for meeting notes, which is then used to contain 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 'Written notes' will be the template for generic design instances. Finally, completed forms already use a template to gather the necessary information.

3.2 Tags

With three of the 13 information classes represented by templates, the remaining ten information classes are classified by a tag and associated with the template for that entry. A tag is a visible symbol identifying the information class (e.g. sketches and calculations), with associated identifiers to add additional metadata, such as date, subject etc. In many cases these identifiers will be inherited from the template in which the tag is embedded, although some tags will have different requirements (especially those for external documents and annotations). In these cases, there will be two special types of tag for classes of information with different requirements for its capture: 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 **mark-up** tag with different identifiers for author and time/date, as these may differ from those recorded in the template for that entry.

3.3 Identifiers

The identifiers associated with each template and tag are properties of that template or tag and are designed to add context and additional ways of structuring, organising and retrieving the information. The actual identifiers associated with each template and tag are derived from the results of the analysis of existing logbooks presented in section 2.2, with the following modifications:

- Identifiers for 'title/subject' or 'project' were recorded together in the analysis. This is because they were often written together. For example, a written note might be identified by "Ideas for project A cost estimation". However, it was felt that separating these terms would bring worthwhile gains for identification and re-use of the information.
- The identifier 'page number' has been omitted as it would not be needed in a logbook with the time and date recorded, that will be dynamically re-arranged.
- All classes of information have been given a minimum set of identifiers for consistency, even though that identifier might not have been present in the logbooks in all cases. The added identifiers are 'project' (for all classes), 'description' (for several information classes) and 'author' (for annotated documents).

3.4 Example

An example of the of how the three components of this strategy could be applied a logbook entry (reproduced from an actual engineering logbook entry) is given in Figure 3, below. It illustrates a

written note template with a sketch tag, a holder for an external document and some calculations, with their associated identifiers:

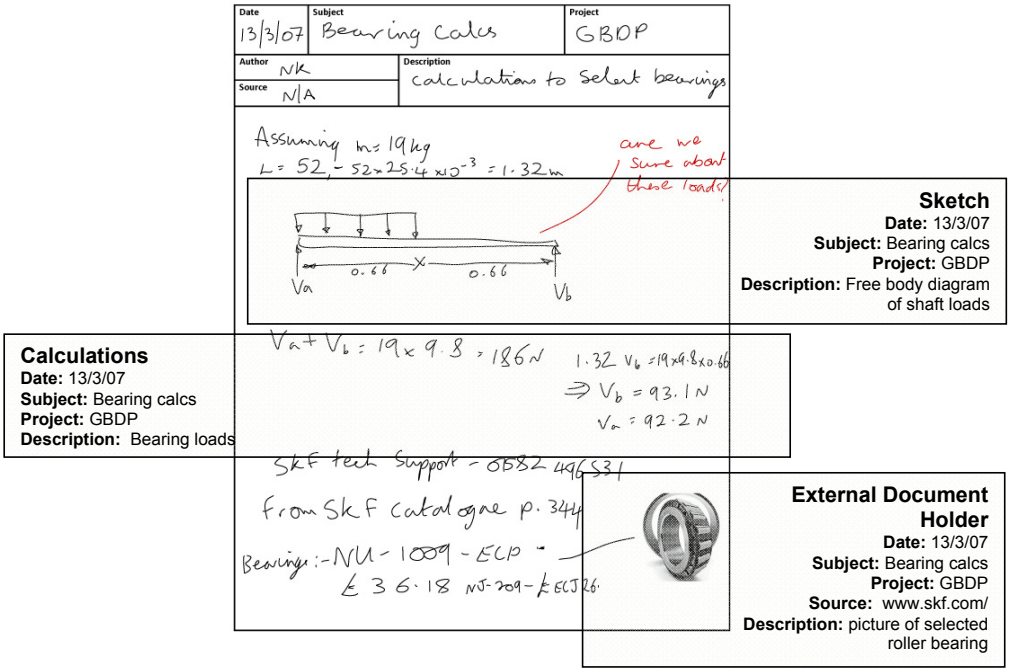

Figure 3. Example of marked-up logbook entry

4. Discussion

The proposed approach offers benefits for both the user during the recording of logbooks entries and the re-use of entries at a later date, both by the individual engineer and others. First, the rationale for this strategy is outlined and benefits and limitations identified. Examples of how it could facilitate more effective re-use are then detailed.

4.1 Rationale for strategy

Perhaps most importantly, this strategy is based on the current working practices of engineers and explicitly supports the types of information engineers record, which was shown not the be the case in most existing e-logbook implementations [McAlpine et al, 2006b]. As such, it is hypothesised that it will be intuitive and useful to engineers and facilitate effective re-use. It must be noted however, that whilst this underlying hypothesis has not yet been formally evaluated - and that the adoption of new methods and technologies is also strongly dependent on other social and organisational factors - the authors believe that the strategy has four significant features that merit its further development:

1. It avoids the **significant difficulties evident in other classification approaches**. For example, much criticism has been levelled at hierarchical folder structures [Boardman, 2004] and Gwizdka et al [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 is, by comparison, relatively lightweight.
2. It recognises that logbook entries can be made at any stage of the design process and that they are often quick and informal in nature. It uses a **novel combination of limited pre-structuring and post-classification** to support this. Pre-structuring through templates ensures

more complete information is gathered, increasing the quality of context-adding identifiers (metadata), but still allows completely free-form input for the entry itself as post-classification of information is considered less burdensome by users [Gwizdka et al, 1998] than classifying at the time of creation.

3. Whilst it must be noted that the nature of the entries (e.g. whether they represent rationale etc.) are not recorded, the strategy could still **facilitate organisational re-use and identification of design rationale** through integration with other information sources. This is discussed in more detail in 4.2 below.
4. It is **extensible and customisable**. As well as adding elements for specific types of entry, the set of identifiers used could also be expanded to include other properties specific to an organisation or needs of the design (e.g. ATA numbers commonly employed to identify components in the aerospace industry).

4.2 Facilitating re-use for individuals and organisations

Perhaps the most fundamental limitation affecting personal and organisational re-use of logbook information is the difficulty in locating information. As well as providing a more consistent structure and more metadata via identifiers, an e-logbook implementation of this strategy would allow the logbook to be searched in a faceted manner, both within an individuals' logbook and across collections to facilitate organisational re-use:

From an individual perspective, the author could re-arrange their logbook entries to read, for example, "*all notes on project A*", or "*contact details I recorded at the design conference meeting*", or more complicated queries such as "*a sketch made by Jo during a meeting two weeks ago*". These queries could also be supplemented by keyword searching the 'subject' or 'description' identifiers. Further, from a usability perspective, tags and holders could provide visual cues for navigating (i.e. quick, visual scanning of logbook pages), which has been identified as a key activity, quite separate from searching [McAlpine et al, 2006a]. Sharing logbook information or even shared team logbooks would also be made possible.

Although originally envisaged as strategy to enable the individual engineer better access to their logbook entries, the strategy could also enable a number of organisational benefits: Firstly, the strategy would allow better compliance with intellectual property and audit requirements. For example, more complete metadata would facilitate the retrieval of all records relating to a particular project or person, long after the individuals involved have left the organisation. Although the detail of the entries may then have to be assessed manually, this is still a significant improvement over the current situation and has been a strong driver for adoption of e-logbooks in the pharmaceutical industry.

Secondly, from a knowledge sharing perspective, a consistent structure and metadata are important as they can allow a better assessment of quality and trust to be made. Information quality and trust have been identified as key elements when making decisions about re-use and increasing the level of participation or knowledge sharing in virtual communities [*see, for example,* Chiu et al, 2006].

Finally, it has already been noted that the strategy does not identify the nature of logbook entries in terms of what they contain (such as design rationale). However, better access to the rationale contained within logbooks can still be achieved by integration of the informal logbook information with more formal information contained within product lifecycle management (PLM) systems and other document management systems. For example, meeting notes created by the participants could be linked to the formal record of the meeting, or the notes exploring design alternatives could be linked to the formal document containing the chosen solution, providing access to 'primary data' and additional rationale for little additional effort.

5. Conclusions

Logbooks contain a significant amount of potentially valuable design information that is not recorded elsewhere. However, this information cannot be easily accessed and re-used by either an organisation or in many cases even the original author.

In order to understand the limitations to the more effective re-use of logbook information in an engineering context, an in-depth study of engineering logbooks, comprising over 2000 pages of information, has been undertaken. The first part of the study explored the information content of the logbooks and current attempts at e-logbooks and is reported elsewhere. The second part of the study, reported in this paper, deals with the structure and organisation of the logbook and how this affects re-use. In particular, logbook structure and organisation is characterised and a number of key limitations are identified. However, it is clear from the informal nature of logbooks and variation in personal styles, that a key trade-off in improving re-use is retaining the ability to record a range of types of information quickly, whilst improving consistency and providing more metadata to aid re-use.

To this end, a strategy for improving the structure and organisation - based on a combination of templates and information-based tags - is proposed. Reflecting the information types found in existing paper-based logbooks and how they are used, significant benefits are envisaged for the individual and wider organisation, such as easier searching and retrieval and integration to formal information to facilitate more complete documentation.

Informal testing during the development of the strategy has been undertaken and provided positive feedback. The strategy is currently being implemented through an e-logbook demonstrator in order to evaluate the approach more extensively through a number of real-world engineering scenarios created with the industrial collaborators.

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