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THE DIGITIAL DIVIDE: INVESTIGATING THE PERSONAL INFORMATION MANAGEMENT PRACTICES OF ENGINEERS

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ABSTRACT
Whilst there exists a significant amount of work exploring the Personal Information Management (PIM) practices of various general groups of people (such as ‘knowledge workers’), or specific PIM tools (such as email, or task management tools) there has been considerably less research focussed on the PIM practice of engineers. Furthermore, the revolution in working practices witnessed over the last decade means that previous studies may fail to give an accurate picture of today’s practice.
To address this, a detailed investigation into the PIM practice of 27 engineers working across various stages of the product lifecycle is presented. Through semi-structured interviews and a detailed mapping exercise of the engineers’ PIM tools and sources, their ‘information world’ is characterised. The research also sheds light on the relationships between informal PIM tools and more formal document types that are the output of the design process. Users’ satisfaction with their current PIM practice is also revealed, together with the seven most commonly cited issues. Lack of PIM tool *integration* is identified as a critical problem, and suggestions are made for both further research and practice.

Keywords: Personal Information Management, Knowledge Management

1 INTRODUCTION AND BACKGROUND
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*” [1]. Items like logbooks, diaries and email systems form ‘personal information collections’ (PIC’s) which according to [1], 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.
Personal Information Management (PIM) refers to the methods by which individuals handle, categorise and retrieve such information [2]. It is “*the practice of managing the information that helps us in our daily lives*” [3] and may be “*viewed as an effort to establish, use and maintain a mapping between needs and information*” [1]. However, whilst there exists a significant amount of work exploring the PIM practices of various general groups (such as knowledge workers [4]) and specific PIM tools such as email [5], or paper-based logbooks [6][7], there has been considerably less research focussed on the wider PIM practice of engineers. Furthermore, the revolution in working practices witnessed over the last decade means that many previous studies are unlikely to give an accurate picture of today’s practice.
Given that the process of engineering and engineering design itself may be viewed an information transformation process [8][9], effective information management clearly has a role in creating and sustaining the competitive advantage of an organisation. Arguably, then, effective PIM practice is a corner-stone of an effective organisation, allowing individual engineers to work productively, translating concepts and ideas into revenue-generating products.
This paper therefore aims to provide a more fundamental and up-to-date knowledge on the PIM practices of engineers. To this end, a detailed investigation into the PIM practice of 27 engineers working in a range of organisations and across various stages of the product lifecycle is presented. Through semi-structured interviews and a detailed mapping exercise to construct a visual representation of the engineers’ ‘information world’, the results reveal what personal tools and

document types are used, and with what frequency. The research also sheds light on the relationships between the informal PIM tools and the resulting formal document types generated during the design process, such as the output of analyses, reports and works instructions. Finally, the exploration of satisfaction levels and commonly cited issues also suggest possible future directions for engineering information management research and practice.

2 METHODOLOGY

This section provides an overview of the methodology in terms of the research questions posed and their associated objectives. How the interviews attempted to answer these objectives is then addressed, before the analysis and presentation of the data is discussed.

2.1 Research Questions and Objectives

The aim of this research is to address the lack of recent PIM research in the engineering field by obtaining a broad picture of current PIM practice, in terms of *what* types of information and tools are used, and *how* they are used as part of the engineers' wider workflow. With this in mind, two research questions were posed: i) what personal information sources do engineers use and ii) how are these sources used as part of the engineers' wider workflow? In order to answer these questions, four specific objectives were formulated:

1. Identification of the informal PIM tools and formal documents engineers use, the number of engineers using them, and their frequency of use;
2. Investigation of the relationships within and between PIM tools and formal documents;
3. Determination of the current satisfaction levels of engineers with regards to their PIM practice,
4. Exploration of key issues engineers have in terms of their current PIM practice, with the aim of providing future direction for both research and practice.

2.2 Dataset and Method

Twenty seven practicing engineers were interviewed. They were chosen to represent a broad cross-section of levels of experience, job role, lifecycle stages and types of industry in the UK. There was an almost equal split between engineers from large companies and Small to Medium-Sized Enterprises (SME's), and of engineers working at the design stage and manufacturing/in-service, with around 30% (mainly from SME's) indicating they worked across the entire product lifecycle. All the engineers were interviewed in their organisation, mostly at their desks or in an adjacent meeting room. Table 1 summarises the nature of the participating organisations:

Table 1. Summary of Nature of Participants

	Nature of Organisation	Type of Organisation	Number of interviewees
A	Aerospace design & manufacture	Large multinational	4
B	Packaging machinery	SME	4
C	Aerospace design & manufacture	Large multinational	6
D	Precision components	SME	5
E	Aerospace design	Large multinational	1
F	Pharmaceutical manufacture	Large multinational	1
G	Automotive components	Large multinational	1
H	Academic (University)	Large UK-based	3
I	Medical devices design & manufacture	SME	2

In order to gather all the information required to meet the objectives, a three-part semi-structured interview was developed. The first part gathered basic data such as the years of experience of the participant, their job role, level of qualification and lifecycle stage(s) over which they mainly work.

The main part of the survey consisted of an A3 sheet of paper that had been pre-populated with types of personal and 'formal' information types or containers. Participants were asked to create a 'map' of their information world – identifying what information types they used (both personal and formal), and how they used them in terms of their links with other types – i.e. where the information in one tool/source was re-used or contributed to another. Following a pilot study, it was observed that

participants often under-reported the number of sources of information used when un-prompted. Therefore, it was decided to pre-populate the map with various types of personal and formal information, derived from previous work [4][6][10][11][12].
The participants were also asked to talk the interviewer through how and why each link was created. The audio recordings of these conversations were then used to aid the interpretation and analysis of the created maps. To illustrate the method and demonstrate the complexity of the captured data, a typical map is shown in Figure 1.

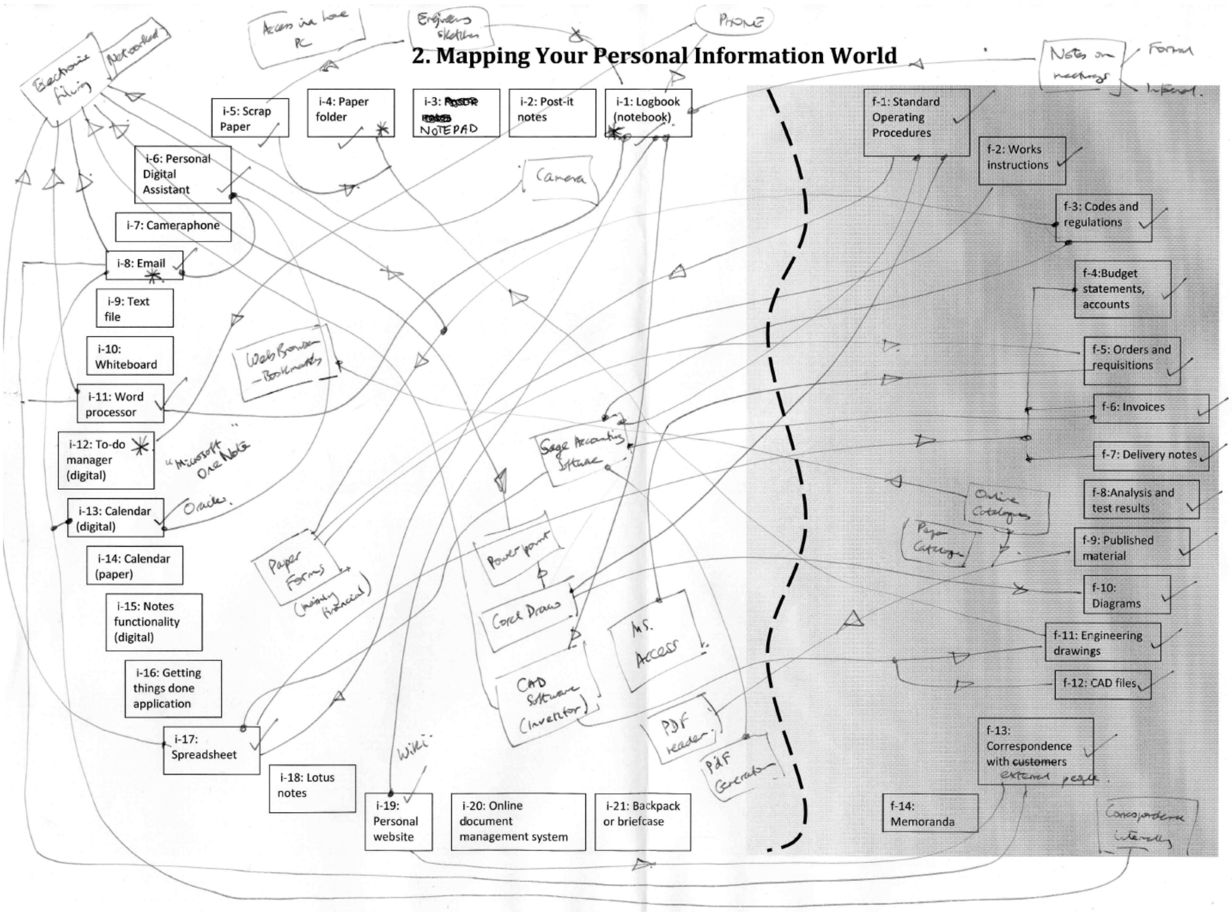

Figure 1. Example of Completed 'Information World' Map

The third part of the survey explored participants overall satisfaction levels (i.e., whether their current PIM strategy met their needs). They were asked to record their response on a Likert scale, which was used to derive a percentage figure for their satisfaction level. Participants were also asked to give the top three positive and negative points about their current PIM practice, as well as suggestions on what features or other measures could be taken to improve it. These responses were synthesised to identify common themes through clustering by the authors.

3 RESULTS

The analysis of the results is grouped into three main parts:

1. General key trends, such as the number and type of personal and formal sources used;
2. Analysis of the flow of information and nature of the relationships between information types/sources, in terms of the number of links between tools & documents (i.e. if the information created in one tool/document is transferred or used to create information in the other document);
3. Current satisfaction levels with PIM tools and practice, and common issues experienced.

3.1 General Trends and Correlations

The first somewhat striking finding was the sheer number of personal information management tools that were used – 61 in total. However, as illustrated in Figure 2 (and in common with [4]), there was a very 'long tail' of 38 tools with fewer than three users:

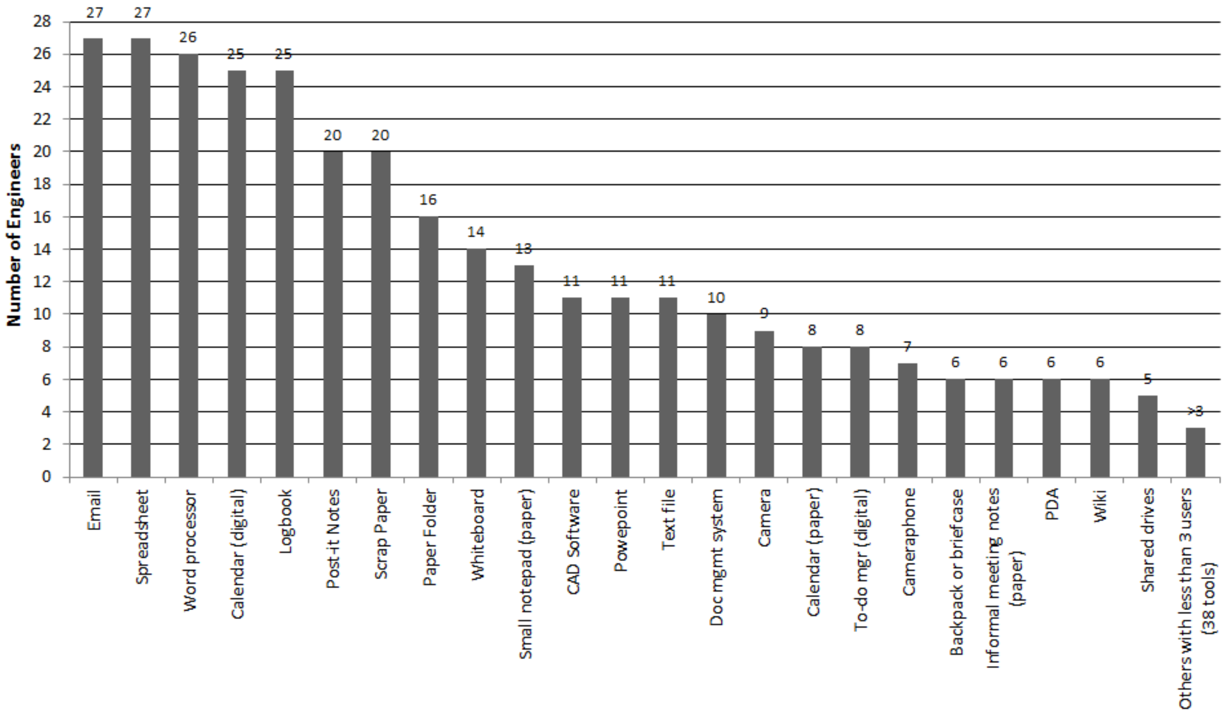

Figure 2. Most Commonly Used Personal Tools

Perhaps unsurprisingly, email and spreadsheets are amongst the most commonly used tools, with word processors, digital calendars and paper-based logbooks also widely used. Of the 23 tools with more than three users illustrated in Figure 2, eight (35%) are 'non-digital', with most being paper-based. The average number of PIM tools used was 13 (SD=3.9), with the minimum being eight and the maximum 24.

Turning to correlations, it was found that the *number* of PIM tools used did not vary significantly with product lifecycle stage or type of position (managerial or non-managerial). There was more variation between organisations and by highest qualification level, with engineers with PhD's and Chartered status (CEng) using more sources on average, although this could not be shown to be statistically significant due to the sample size.

Additionally, there appeared to be no significant differences in the *types* of PIM tools used across the different organisations, lifecycle stages, and across educational qualifications and years of experience in their role. Whilst the *nature* of the PIM tool use may have varied with these factors, this was not investigated.

Interestingly, three of the most popular tools (email, word processors & spreadsheet programs) were also used in a more formal context, illustrating an increasingly blurred boundary between personal and 'enterprise' information. However, in this case, they have also been categorised as personal tools because of the informal nature of their use – i.e. often the word processor documents and spreadsheets were created purely for the individual and were not shared with others. Examples include text-based task lists and spreadsheets created to work through a problem, before formalising the solution in a report, or using the results as the basis of more complex analyses, such as making an initial estimate at boundary conditions for numerical models. The same is true of CAD software and document management systems, which can be used in a formal or informal context.

As part of the mapping exercise, the participants were asked to list all the 'formal documents' they produced or contributed to as part of their job role. A similar pattern emerges for the formal documents, with 31 types identified in total, although the 'tail' of formal documents produced by fewer than three users is shorter, at 12. The most commonly produced documents were analysis and test results, customer correspondence, diagrams, standard operating procedures and works instructions. In contrast to the 35% of paper-based personal tools noted above, all the formal documents were created electronically.

3.2 Information Flows and Relationships

The second part of the analysis explored the quantity and nature of links between the various PIM tools and formal documents. A link in this case means that the information created in the first tool/document is used to create information in the second. In total, nearly 1000 linking arrows were drawn between PIM tools and formal documents by the 27 engineers surveyed, including 565 instances of personal tools/sources linking to formal documents (Table 2):

Table 2. Number of Links Between Information Types/Sources

Nature of Link			
Personal → Formal	**Personal → Personal**	**Formal → Formal**	**TOTAL**
565	304	100	969

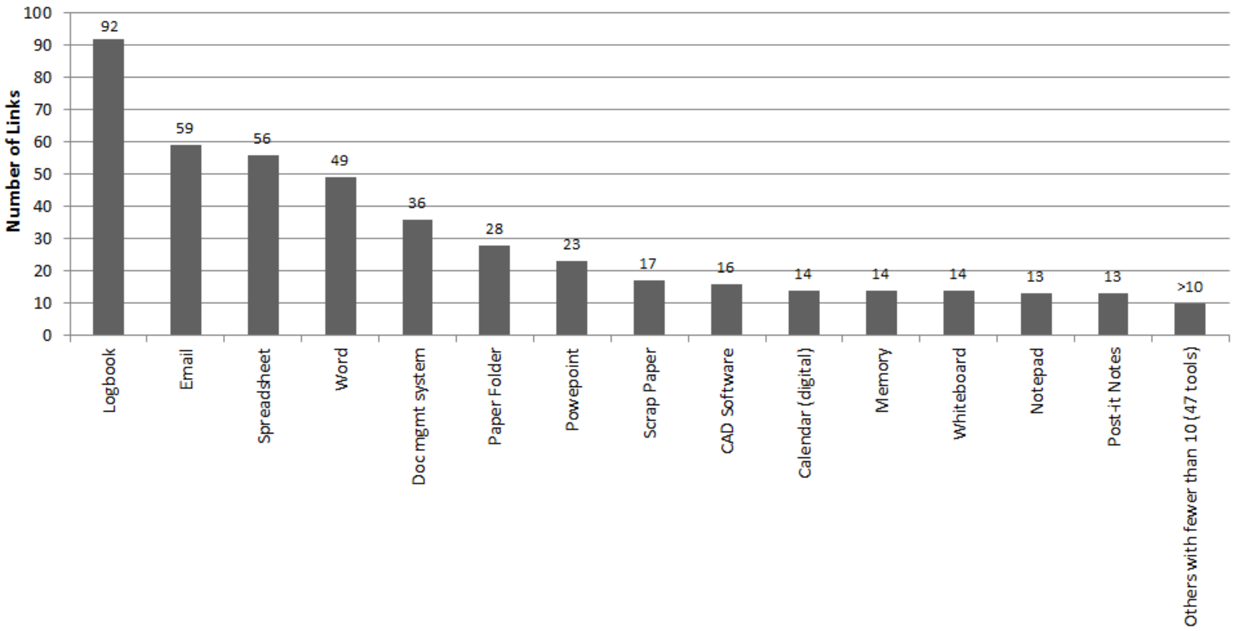

Figure 3. Most Common Personal to Formal Links

The PIM tools with the highest number of links to formal documents are shown in Figure 3. Four of the five most frequently used PIM tools also linked most heavily to formal documents, although participants indicated that paper-based logbooks had by far the greatest number of links to formal documents. This may be because of the variety of information they contain [6].

The formal documents most frequently linked to were also similar to the most frequently used: analysis and test results (77 links), correspondence with customers & suppliers (66), standard operating procedures (64), works instructions (55) and engineering drawings (50). Again the pattern is similar, with a very long tail of documents which do not link frequently to other tools or documents, such as invoices, delivery notes and online parts catalogues.

The number of links between personal tools/sources is lower, although the top four personal tools/sources most often linked to others are the same as those in Figure 3: logbooks (47 links), email (34), spreadsheets (24) and word processor documents (21), suggesting that these four tools form the core of many participants' PIM practice, both in terms of the number of users, and their integration with other types of formal documents and PIM tools.

3.3 Levels of Satisfaction

The mean satisfaction level with current PIM practice was measured by asking participants to mark their "*overall satisfaction with current PIM practice*" on a Likert scale. The mean satisfaction level for the population was 66%, although as Figure 4 illustrates, there were wide variations both within and between organisations (overall SD=18%), reflecting the wide range of PIM practices and personal nature of the activity.

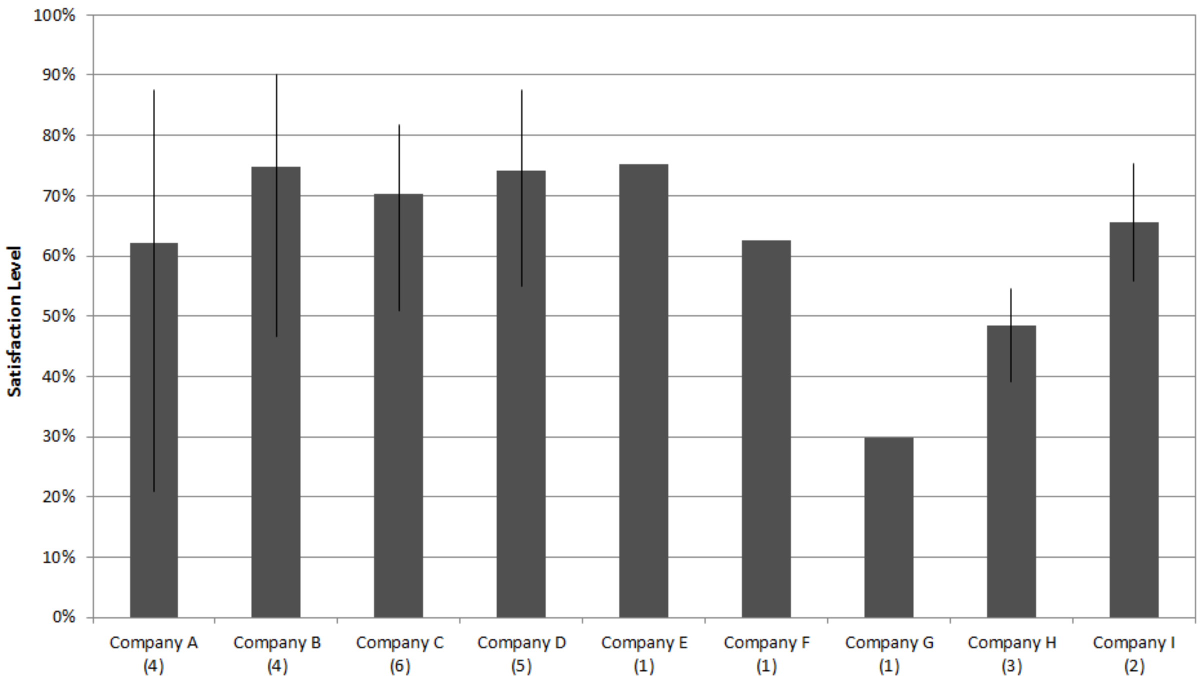

Figure 4. Satisfaction Levels Grouped by Company (number of participants)

PIM practice satisfaction levels were also assessed with respect to the participants highest level of educational qualification, product lifecycle stage and position (managerial or non-managerial). No significant correlations were discovered, although this may be due in part to the limited sample size.

3.4 Common issues

The responses to the final part of the survey (questioning participants on the reasons for their indicated satisfaction level and 'top 3' issues) were analysed and clustered into common themes by the authors. The seven most commonly-occurring issues perceived by the engineers are discussed below.

1 Non-Linkage of Different Technologies or IT Systems

The most common issue raised was the lack of links between various IT systems (26% of participants). The issue had both a software aspect and a hardware aspect. The software aspect arose from different software on computers and systems that do not 'link' (i.e. cannot copy-paste from each other, and/or not possible to edit them together). The hardware aspects related to certain hardware not being connected to the same network, leading to engineers having to manually transfer the data, or re-enter it across different systems.

2 Non-Linkage of Paper-based Systems with IT systems

The second most common issue (22% of participants) concerns difficulties arising from maintaining both paper-based and digital sources of information, and the difficulty of synchronising them – this was summed up by one participant, who reflected that they used "*three types of to-do lists at different times: Outlook™ to-do manager, logbook, Post-It Notes™ but these are not linked or synchronised.* And that they would like to be able to "*convert a logbook entry into electronic format for universal access when not present at my desk."* That this was a common issue is unsurprising, since 35% of the most commonly used PIM tools are paper-based, whilst the resulting formal documents are all produced electronically.

3 Inadequate IT Systems

19% of respondents indicated that inadequate IT systems (slow and/or frequently crashing computers, insufficient storage on hard drives, old and/or unsupported software) were a problem. Such concerns could partially explain the duplication of some sources of information (such as having printed copies of important documents also held on a network resource) and the large number of paper-based sources. However, respondents who indicated this was a problem did not have lower overall satisfaction levels, suggesting that this is an 'annoyance' rather than something that affects their strategy significantly.

4 Lack of Organisation of the Engineer

Five of the engineers questioned highlighted their own lack of organisation. For example, one engineer commented that they were *"…organised electronically but not [when using] paper or physical [tools]. [I] use physical [tools] because it's convenient, but with so many physical tools in use, it is difficult to find what I wrote where*."

However, whilst some of the responses clearly indicated it was their lack of organisation that was the issue, others suggested that the root cause could be something else. For example, another engineer commented that they *"…often do not put digital documents in appropriate folders and they get mixed up. [I also] write down too many notes on a subject and don't organise them properly so they get muddled*." Whilst the engineer attributed this to their own lack of organisation, other factors could include inadequate systems, a lack of storage space, insufficient training or overload issues (discussed in point 5, below).

5 Information Overload

The concept of information overload is well recognised in the literature (see, for example, [13]) and four engineers made specific reference to the concept of receiving, keeping, or trying to find too much information. For example, one engineer commented that "*Keeping track of everything that's going on and keeping track of shifting priorities…*" was an issue, and that "*time is wasted through collecting information that may not be relevant in the future.*"

That only four engineers identified overload as an issue they faced was somewhat unexpected, given the complexity of the information maps, the average number of sources used and the very variable satisfaction levels. Although more detailed work on this topic is clearly needed, the relative lack of concern in this area could be a consequence of the effectiveness of the complex but highly personalised strategies adopted.

6 Lack of Search Functionality

The issue of search was cited as an important issue for four engineers, commenting that they had "*difficulty in searching through all tools, for example, CAD documents, document management system, network drive… A global search is non-existent*" and that "*Search tools are not robust enough. If you don't know where you are going you will have a difficult time finding what you are looking for.*"

Again, in a similar fashion to the relative lack of issues associated with information overload, whilst there are clearly instances where missing or ineffective search functionality is a problem, other issues (such as the divide between paper and electronic sources, and between individual systems) would appear to be the more important issues in terms of impacting the effectiveness of the engineers' PIM strategy.

7 Lack of Training

Although only raised as an issue by three participants, all were questioned about the level of training received in relation to their personal information management. None of the engineers had received any formal training - Several commented that keeping a logbook was part of their education, or that they had received 'informal' training from colleagues in, for example, how to use document management systems, or how shared spreadsheets were designed. There was also some limited evidence of training for email, although this took the form of guidelines on company policy and etiquette. However, the feeling was that training for more specialist tools would be beneficial, with comments such as there being "*…too many tools to store and manage information, and some of these tools require more training before I can fully use them.*"

4 DISCUSSION

The sheer number and variety of PIM tools/sources identified (61 in total) highlights the complex, personal nature of most participant's personal information world. Additionally (and in common with [4]) there was a very 'long tail' of 38 tools/sources used by fewer than three participants. However, this does not imply that the less commonly used tools are any less important for that individuals' PIM practice. It should be noted that this study did not explore in detail *how* the PIM tools were used, and with what frequency. These results should not, therefore, be used as the sole basis to decide on which PIM tools are 'best', or where efforts to better support PIM tools should be directed.

Given the diverse nature of the participants' organisations, job roles and the lifecycle stages over which they worked, it was somewhat surprising that correlations across these factors were not found, with no significant differences in the number of tools used across the product lifecycle stages or job role. Although not statistically significant due to the sample size, the finding that those engineers with PhD's or chartered (CEng) status used on average more PIM tools/sources in not unintuitive, as these participants were more likely to be engaged in original design and other complex problem solving activities.

Interestingly, there were also no apparent correlations between types of PIM tools used and factors such as organisation type, lifecycle stage over which participants' worked, qualifications or years of experience. This suggests that at least certain aspects of PIM tool/source use may be common across 'knowledge work' in general, providing a potentially rich source of 'good practice'. This idea is re-enforced by the lack of correlation between these factors and participants' satisfaction levels, suggesting the 'personal' aspect of PIM is more important than organisation types, job roles etc.

Another particularly striking finding was just how different PIM practice appears to be compared to findings presented in older research, and research not specifically investigating engineers. For example, [2] found that over 80% of participants used only 'traditional' paper-based 'PIM artefacts', with less than 10% of participants using more than four PIM artefacts, and less than 5% using a digital calendar or diary. These findings are in stark contrast to the average number of 13 tools reported in this study and the widespread use of electronic tools, re-enforcing the argument that older studies do not represent an accurate picture of PIM tool use today. Indeed, those over ten years old appear to bear very little similarity to modern practice, although some studies of specific tools or practices - such as [14] who investigated personal paper archives - may still be of relevance. The type of personal tool/source used by engineers (such as spreadsheets) also appears to be significantly different to what is traditionally thought of as a 'PIM tool'.

More recently, [15] has investigated the 'personal archives' of 48 academics, which (in common with the findings of this research) revealed often very complex personal archives, consisting of both paper and digital sources. Further, [15] notes that many of the participants had little difficulty locating documents, echoing the findings here that only four engineers were concerned with a lack of search functionality, with the disconnect between paper and digital sources being the bigger issue. Indeed, the most highly cited of the seven key issues identified in this paper are similar to those reported in [16], who investigated general information management issues across engineering SME's. The top two reported issues were i) difficulties exchanging information between different computer systems and ii) the subsequent need for manual systems and data entry. Both of these issues are very similar with the top two presented in this paper – the non-linkage between technologies, and between paper and electronic sources. The issue of moving information between programs and systems was also highlighted by [17], who noted that 37% of respondents experienced either software or hardware compatibility problems, or found that files were too large to be transferred.

Similarly, in a study of "*information scraps*" it was observed that information such as Post-It™ Notes and text files currently "*elude*" electronic PIM tools [4]. It was further argued that there is a significant volume of such information not managed in conventional PIM tools (for example, appointments scribbled on Post-It™ Notes, not contained in a diary) that suggest current electronic PIM tools do not fully meet the needs of their users. That the study presented in this paper also reveals a combination of paper and digital sources - despite the apparent problems of working in both domains - appears to support this view.

Finally, [18] discuss the most frequently cited reasons for abandoning a PIM strategy, with the top two reasons being a lack of i) visibility and ii) integration with other systems. The need for permanent *visibility* of some information (such as calendars, or To-Do lists) could help to explain the stubborn persistence of paper-based tools for some tasks, which [19] argue afford a more flexible spatial layout (arranging various papers all over one's desk and walls) compared to the amount of information simultaneously visible on a computer screen. The issue of *integration* is again similar to the most common issue revealed by this research, and give an indication of potentially fruitful future research directions.

These findings also suggest practical steps that organisations could take to mitigate such issues, including:

1. ***Bridging the 'digital divide'*** – Exploring ways of better linking paper and electronic tools, as well as integration of the various electronic tools already in existence.
2. Taking a ***more strategic view of PIM practice*** at an organisational level, to contain the proliferation of PIM tools & practice. However, any such strategy must balance the needs and desires of individuals to use tools and strategies that work for their particular circumstances, with [15] noting that *"… 'best practices' in this domain resist standardization: Personal archiving is by nature a personal system…"*
3. ***Better training*** – although only raised as an issue by three participants, it is argued that better training has the ability to simplify the complex and heterogeneous nature of most organisations' PIM landscapes, make the engineer feel more organised and satisfied with their PIM practice, and may help to prevent or reduce information overload [13].

4.1 Further Work

As well as seeking to further enlarge the sample size (particularly for lifecycle stages with fewer participants), further work will concentrate on a more detailed secondary analysis of the nature of the PIM tool use, and the links between the personal and formal tools/sources. The links revealed by this analysis will then be used as the basis to i) suggest how and why the most commonly used personal tools/sources may be more effectively integrated and ii) create a strategy for the more effective management of personal information by incorporation into formal systems – an approach which has shown some promise for specific information types. For example, [20] present a case-study with a framework for embedding design rationale in formal Product Lifecycle Management (PLM) systems whilst [21] present a possible method to integrate informal sketches into PLM systems. In both cases, the critical trade-off is retaining the affordances that make personal, informal information so valuable, whilst leveraging the significant benefits of formal, structured and universally accessible product models.

5 CONCLUSIONS

This paper argued that whilst the study of Personal Information Management (PIM) tools and practices has received considerable attention, most research was not specific to the engineering domain. Further, it was argued that rapidly changing working practices meant that studies more than a few years old would likely not give an accurate picture of today's PIM practice. This paper therefore presented a detailed investigation into the PIM practice of engineers working in a range of organisations, and across various stages of the product lifecycle.

Twenty-seven detailed interviews with engineers from a range of organisations and lifecycle stages were undertaken to investigate informal, personal information use (logbooks, email etc.) and how such information is used to create the 'formal' output of the organisation, such as CAD drawings and reports.

The key findings were that most engineers' 'personal information worlds' were very complex, with an average of 13 personal tools/sources being used, and numerous interlinking between both personal and formal sources. Interestingly, no significant correlations were found between PIM tool use and satisfaction, and factors such as organisation type, or lifecycle stage at which the participant worked, re-enforcing the very *personal* nature of PIM.

Further, questioning participants about levels of satisfaction with their current PIM practice revealed a mean satisfaction level of 66%. Seven key issues that most negatively influenced satisfaction levels of the participants were synthesised from the large number of issues and suggestions raised during the interviews:

1. Non-Linkage of Different Technologies or IT Systems
2. Non-Linkage of Paper-based Systems with IT systems
3. Inadequate IT Systems
4. Lack of Organisation of the Engineer
5. Information Overload
6. Lack of Search Functionality
7. Lack of Training

Many of these issues were similar to those found by previous research in PIM and other fields, particularly *integration* issues. To this end, potential areas for further research involving the more effective integration of personal, informal information with formal enterprise systems such as Product Lifecycle Management (PLM) systems were suggested. Finally, several recommendations to industry to help mitigate the issues raised were made, including

- Trying to bridge the 'digital divide' between paper PIM tools and formal digital systems, as well as between digital systems
- Taking a more strategic view of PIM
- Introducing or improving training in the use of existing PIM solutions.

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Hamish McAlpine's Ph.D. thesis explored the use of paper-based logbooks in engineering. His current research interests include Personal Information Management and knowledge re-use in engineering design.