Knowledge use in an advanced manufacturing environment

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It is now widely accepted that the active utilisation of a company’s knowledge is vital to maintaining competitive advantage in today’s knowledge based economy, particularly within design and manufacturing environments. Despite the rising popularity of Knowledge Based Systems [KBS] to support design reuse, designer’s interaction with these systems is still poorly understood. This paper presents the results of a longitudinal ‘diary study’ to evaluate the role of a KBS in designer’s activities. The results demonstrate the potential for a KBS to operate as the primary source of codified knowledge for designers and can be a viable alternative to verbal knowledge sharing with experts. A KBS is therefore found to be a significant asset for a Small to Medium Enterprise.
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As the world increasingly moves towards the knowledge based economy predicted by Bell (1974), so the reuse of knowledge to create competitive advantage is becoming increasingly commonplace (Zack, 1999). This is particularly important in design and manufacturing environments, where the use of design knowledge and information has become a crucial factor in product development (Court, Culley, & Mcmahon, 1997).

With the advent of knowledge management, there has been a wide range of approaches and systems developed to encourage and improve design knowledge reuse, such as process based support (Baxter et al., 2007; Blessing, 1994), Cased Based Reasoning (Leake & Wilson, 2001) and indexing systems (Ahmed, 2005). Yet there remains no consensus on how best to support a designer’s knowledge activities and significant challenges to establishing regular design reuse remain (Busby, 1999; Ball, Lambell, Ormerod, Slavin, & Mariani, 2001). Furthermore there has been little research reporting on the interaction...
of designers with these systems and importantly the resulting company-wide impact of Knowledge Management activities (Jennex, 2008; Kim, 2006).

This paper forms part of a longitudinal action-based research project, to evaluate the use and impact of a Knowledge Based System [KBS] to a design and manufacturing Small to Medium Enterprise [SME]. Specifically the paper presents the results of a study to assess designer’s interaction over time with an established KBS. In particular, understanding during which stage of a product’s lifecycle interaction with the system typically occurred and what proportion of time was invested in knowledge retrieval. The understanding of these factors forms an important foundation by which future design support systems can be established. It has been argued that design reuse is process driven (Baxter et al., 2007) and furthermore that that designers require different information and knowledge at different stages (Hicks, Culley, Allen, & Mullineux, 2002). Yet, it is important to understand empirically when designers seek knowledge in order to ensure systems are developed to support design reuse.

1 Studying the information behaviour of designers

Engineering design is a highly knowledge intensive process, from initial specification and requirements to solution and manufacture. It is also accepted that most designs involve some form or redesign or reuse of geometry, techniques or solutions. In a study by Ettlie and Kubarek (2008), manufacturing companies reported 28% of new designs were reuse, while Pahl and Beitz (1988) estimate that up to 80% of new designs are reuse.

It is commonly accepted that design knowledge is highly valuable and its reuse — the re-application of prior design knowledge, concepts and geometry to a new problem — benefits both the designers and the wider business environment. Busby (1998) describes the benefits, summarised as:

1. Reduction of effort, avoiding rework
2. Reduction of error and uncertainty
3. Maximises product familiarity with staff
4. Helps clients maintain consistency using and maintaining products

Supporting the knowledge and information requirements of designers is therefore vital to maintaining competitive advantage for manufacturing businesses.

The knowledge (and information) usage of designers has been studied for many years (Allard, Levine, & Tenopir, 2009; Baya, 1996; Court, Ullman, & Culley, 1998; Demian & Fruchter, 2006; Hertzum & Pejtersen, 2000; Hicks, Culley, & Mcmahon, 2006; King, Casto, & Jones, 1994; Kuffner & Ullman, 1991; Lowe, Mcmahon, & Culley, 2004; Marsh, 1997; Robinson, 2010; Wild, Mcmahon, Darlington, Liu, & Culley, 2010; Yitzhaki & Hammerslag, 2004). These studies have addressed the information ‘behaviour’
of engineers to better understand how knowledge and information is used by designers. The majority, are focused on the ‘what’ and ‘where’, that is, assessing the types of knowledge used and where the knowledge is sought.

The studies above demonstrate a variety of methods, both direct and indirect, in the collection of data. For example Marsh (1997) utilised direct observation to complete a time and motion study. Lowe et al. (2004) utilised structured interviews and ‘information audits’, while Hertzum and Pjøtersen (2000) produced surveys asking engineers to rank the sources of knowledge used. These different studies and the primary methods used are summarised in Table 1.

The method used greatly influences the level of detail, accuracy and reliability of the data collected. However, these factors are typically offset by the primary limitation faced by many practitioners in this field of research, namely the limited access and support available from designers (Lowe et al., 2004). Obtaining behavioural data of a high granularity from engineers over a long period of time represents a significant challenge. For example, the study by Marsh (1997) represents a highly detailed and reliable study of designers, yet the high level of effort required limited the study to 17 days of observation due to the time constraints of the observer and concern over the effect of continued observation.

This limitation greatly diminishes the capacity of researchers to conduct detailed studies of knowledge use over extended periods of time and across multiple design projects. As a consequence, of the studies listed above only Marsh (1997), Court et al. (1998) and Robinson (2010) examined the time of designer’s activities and only Robinson (2010) and Wild et al. (2010) conducted contiguous studies.

The majority of these studies are also exploratory, that is considering the general behaviour of designers rather than those introduced to a new method or

<table>
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<tr>
<th>Ethnographical observation</th>
<th>Non-ethnographical observation</th>
<th>Self-reporting</th>
<th>Survey</th>
<th>Interview</th>
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tool. The studies can therefore be further classified into exploratory/evaluative and synchronic/longitudinal illustrated by reforming Table 2 into a matrix.

A requirement therefore exists to evaluate the long term behaviour of designers following the introduction of a new process or tool and specifically to link the knowledge activities to the stages during the design process.

The aim of this study was to address this weakness, specifically examining the time spent utilising knowledge from different sources and the time spent interacting with the KBS. The outcome will be instrumental in determining if the implementation of a KBS provides a measurable benefit to a business.

In order to determine these factors, the activities of the designers needed to be studied on a daily basis. The study would need to be sustainable indefinitely and the study would be required to be of sufficient fidelity in order to try and measure any change in working behaviour over time as a consequence of the systems introduction.

2 Industrial context

The industrial context of the study is a design and manufacturing environment consisting of 6 engineers and a business manager. The company specialises in the supply of high precision fixtures and tooling for the aerospace market utilising the modern fast manufacturing methods of flat bed laser cutting and press-brake manufacture. The business effectively functions as a distinct cost centre within Rolls-Royce but operates from a dedicated facility. For the purposes of this paper it will be considered to be an independent Small to Medium Enterprise [SME].

SME’s represent a unique challenge for knowledge management and design knowledge reuse. The low number of employees significantly limits the number of available ‘experts’, while even a low degree of staff turnover can be extremely disruptive as critical knowledge can be held by a select few (Lovett, Ingram, & Bancroft, 2000).

The SME presented here was faced with a potentially crippling knowledge loss due to a retiring expert. This research was therefore established to develop and

Table 2 Matrix comparing the different styles of study conducted.

<table>
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<tr>
<th>Exploratory</th>
<th>Evaluative</th>
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<tr>
<td>Synchronic</td>
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<td>Longitudinal</td>
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implement a bespoke Knowledge Based System to mitigate knowledge loss and improve future working practice. This provided the needed opportunity to evaluate the longitudinal effect of a KBS to a business and would provide a real-world study of Knowledge Management in Engineering.

A bespoke Knowledge Based System was researched and developed, designed to capture product specific knowledge, including design rationale, lessons learnt, costing and manufacturing knowledge. The system was designed in line with designers existing processes in order to support concurrent knowledge capture and reuse efficiently. The system therefore loosely conforms to Baxter et al.’s (2007) ‘Design information capture and representation’ relationship between product and process knowledge. A more detailed description of the system is presented in Reed, Scanlan, Wills, and Halliday (2009). A screenshot of part of the system can be seen in Figure 1 illustrating the summary page of a typical entry, showing the product photo (a), associated files (b), requirements summary (c), design detail and benefits (d) and the meta-data (e).

The system was established 8 months prior to this study and all designers were given adequate training on the system. At the start of the study the system was used on a routine basis, and contained 257 project entries, each with 67 data

![Figure 1 Screenshot of a typical entry in the Design System.](image)

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fields or text boxes, and a further 761 files such as photographs, CAD geometry and reports associated with the projects.

3 Assessment method

A review of the measurement methods used for time/activity based studies is given in Starren, Chan, Tahil, and White (2000). These can be summarised as:

- Time and Motion Studies (observational)
- Personal Activity Logs (self-reporting)
- Work Sampling (self-reporting)
- Surveys (retrospective)
- Application Logs (automated)

The methods range from the most intrusive to the least. Time and motion represent the most accurate and reliable method measuring employee tasks and activities (Starren et al., 2000). Yet observational studies are the most disruptive to the subjects and are the most time consuming for researchers. Minimum intrusion is achieved using Application or System logging which can automatically track activities, but relies on the subjects interaction with the system and usually contains little contextual information. A summary of these methods, together with their advantages and disadvantages is given in Table 3.

The primary aim of the assessment was to determine, not just how long designers spent using knowledge but whether they used the KBS and at what stage during a project they typically sought knowledge.

Of the above methods, the requirement to capture chronological data discounts the use of Work Sampling and to some extent the use of Surveys. The longitudinal nature of the study would be too much of a drain on resource to implement a Time and Motion study. Finally use of automated logging, while potentially supplementary would not capture inter personnel knowledge transfer. Therefore it was concluded a ‘Diary study’ method would be the most appropriate.

Diaries have been commonly used in research, typically in fields such as social and psychological research, and are particularly suited towards extensive capture where scale, access or ethical issues prevent the use of direct studies. A summary of previous studies and their fields is given in Reis and Gosling (2009).

Diaries permit the examination of events and experiences in their natural context, the capture of ‘life as it is lived’ (Bolger, Davis, & Rafaeli, 2003). There are different strategies and methods within diary studies, reviewed by Toms and Duff (2002) and listed as: the intimate journal, the memoir, the log, the research log, and the diary-interview method. Typically these vary the degree of detail, some using use semi-structured forms and capture continuous prose, other ‘log’ type studies simply capturing event data (Burgess, 1994).
Diaries can capture significant detail, incorporating the rationale and context behind events. Their primary benefit however is in minimising the time between event occurrence and reporting, significantly reducing the effects of retrospection and the likelihood of bias (Shiffman et al., 1997). Pedgley (2007) also argues that Diaries satisfy the four requirements for longitudinal capture of design activities: Solo Effect, Subject Delimitation, Mobility and importantly here, Endurance.

### 3.1 Approach taken

The engineers were all asked to complete a pre-structured form at the end of each day (Interval-contingent recording (Wheeler & Reis, 1991)), summarising the total time spent on any activity during the day and matching this against different projects. The engineers were asked to subdivide their time into 15 min intervals, but to sum up activities to ensure that for example three, 5 min conversations would be recorded.

The use of prose to capture greater depth behind events was considered. However, the endurance required from the longitudinal nature of the study necessitated a simple and highly structured means of capture. Wildemuth (2002) argues the greater the burden, the less compliance. Therefore, the study was

<table>
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<th>Method</th>
<th>Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tr>
<td>Time and motion</td>
<td>Researcher follows and observes subject with a stopwatch, recording the duration of activities.</td>
<td>- Data collected is both accurate and reliable.</td>
<td>- High labour requirement.</td>
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<td></td>
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<td>- Can cause Actor-Observer or ‘Hawthorne’ effect (Mayo, 1949).</td>
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<td>Diary studies</td>
<td>Diary or activity logs are kept by subjects over the period of study, recording their daily activities.</td>
<td>- Chronological data is captured.</td>
<td>- Dependant on subject participation.</td>
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<td>- Data can be highly accurate.</td>
<td>- Open to some subject bias or manipulation (Starren et al., 2000).</td>
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<td>Work sampling</td>
<td>Discrete sampling of subject’s activities is used to build a statistical model of proportions of time (Ampt, Westbrook, Creswick, &amp; Mallock, 2007).</td>
<td>- Highly detailed data can be captured.</td>
<td>- Large sample population required for high confidence (Finkler, Knickman, Hendrickson, Lipkin Jr, &amp; Thompson, 1993).</td>
</tr>
<tr>
<td>Surveys</td>
<td>Subjects respond to pre-set questions.</td>
<td>- Little intrusion on subject’s activities.</td>
<td>- Cannot report on chronological changes.</td>
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<td>- Can capture rationale behind responses.</td>
<td>- Subjective responses affected by personality and memory.</td>
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<tr>
<td>Departmental logs</td>
<td>Automated tracking or logging is embedded into systems allowing subsequent analysis.</td>
<td>- Highly accurate data is produced.</td>
<td>- Subjects often try and provide the ‘right’ answer (Robson, 2002).</td>
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<tr>
<td></td>
<td></td>
<td>- Logging does not intrude on subjects activities.</td>
<td>- Requires interaction with a system to capture activity.</td>
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</table>

Diaries can capture significant detail, incorporating the rationale and context behind events. Their primary benefit however is in minimising the time between event occurrence and reporting, significantly reducing the effects of retrospection and the likelihood of bias (Shiffman et al., 1997). Pedgley (2007) also argues that Diaries satisfy the four requirements for longitudinal capture of design activities: Solo Effect, Subject Delimitation, Mobility and importantly here, Endurance.
chosen to be purely quantitative, adopting the ‘log’ method described in Toms and Duff (2002). However, surveys and structured interviews would also be conducted with the designers to capture the depth behind their user patterns.

Activities were classified into 36 different activities, grouped into 8 sections of: Communication, Meetings, Travel, Management & Administration, Technical Design, Production, Maintenance/Upkeep, and Design System. Part of a typical entry can be seen in Figure 2.

The 8 generic sections were developed based primarily on the two previous time studies in Rolls-Royce by Marsh (1997) and Robinson (2010). These studies represent a useful benchmark with which to compare and contrast the results of the study.

The study by Allard et al. (2009), highlights the potentially large information usage behaviour between different environments and organisations. Thus the similar culture and working habits of the engineers studied in previous studies of the SME’s parent company provides the closest means for a corroborative comparison of technical activities to other studies. Therefore by dividing the activities into similar categories a direct comparison can be made.

The specific details, particularly with respect to the Technical Design and Production activities were based on the design and manufacturing process by Pahl and Beitz (1988) and combined with existing activities in the business (such as ‘validation measurements’). A ‘general’ job was included for each day, as it was acknowledged that some activities are not project specific.

A one week pilot study was conducted using the lead designer and appropriate changes made to the classification system, including clarification of activities with call out descriptors. Following this initial trial, the study was launched with all engineers.

The activities primarily relevant to this study are those under the communication section, specifically those involving discussions with colleagues or the technical specialist, ‘knowledge access’ involving the search and access of codified knowledge and finally time spent accessing the Knowledge Based Design System. Here codified knowledge refers primarily to documents, manuals, and other recorded lessons learnt but may also include the use of photographs, videos and CAD files.

4 Results
The diary study was run for a total of 6 months, over which period 464 working days were filled out by up to 6 manufacturing engineers (although two joined midway through the study), accounting for a total of 4421 working
hours. Twenty-six different projects were recorded, although not all were com-
pleted during the course of the study.

Once established as a regular part of each day, the diaries were generally filled
out consistently by engineers, some opting to keep the diary open in the back-
ground to work during the day. However, during periods of high work load
they were occasionally left to the end of the week and completed using logbook
notes. This represents a concern in terms of the accuracy or results; however,
overall it is believed that the proportions of time are correctly reflected.

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4.1 Overall breakdown of the engineer’s activities

The global proportion of time spent on the 8 different sections is shown in Figure 3. Here, ‘technical activities’ refer to design and geometry generation activities, which include knowledge access. ‘Production’ refers to the manufacture and assembly of products.

In order to determine how much time was spent accessing or providing information, the detailed classifications were utilised and all, non-knowledge activities were grouped together.

For simplicity it will be assumed that all communication is the exchange of knowledge and information, while exceptions do exist the majority of recorded activities within this sector were ‘Discussions with colleagues’ typically project or problem focused discussions. Meetings are shown separate but are not strictly knowledge transfer activities (Figure 4).

Figure 3 Proportions of different activities taken over the study period.

Figure 4 Proportion of time spent seeking or providing knowledge or information.
According to these figures, the time invested in information and knowledge exchanges is significantly less than that previously determined in the previous studies by Marsh (1997) and Robinson (2010). Specifically the time spent; accessing or supplying knowledge and information was determined as 10% of activities, compared to 24% (Marsh) and 30%\(^1\) (Robinson). This also appears low compared to other studies of activities, such as 18% in Court et al. (1998) and 40–66% cited in King et al. (1994).

Comparing codified knowledge use alone (3%) does correspond strongly to the 3.73% determined by Robinson. This suggests that even using the diaries on a daily basis, the designers may have under reported the time spent discussing their work, either with clients or colleagues.

These figures also highlight that despite the emphasis and provision of the Knowledge System a relatively small proportion of time is actually invested in codified knowledge, compared to verbal knowledge exchange.

Surprisingly too, a large degree of difference can be observed between the different engineers. Figure 5 indicates the proportions of time spent on knowledge activities against the different engineers.

Designer A represents the team leader and, as expected spends a larger proportion of time in meetings. However, Designers B, C and D would be expected to have relatively similar proportions of activities. While they spend approximately equal amounts of time accessing codified knowledge, Designers B and C interact primarily from the Design System while Designer D primarily accesses knowledge from more general sources. Designer E is relatively new to

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**Figure 5** Plot of the knowledge activities of different engineers.
the business and as expected has spent a larger proportion of time accessing the Design System.

4.2 Knowledge use during the design process

It is commonly accepted that knowledge is typically utilised the most during the initial stages of a design (Pahl & Beitz, 1988). Shneiderman (2000) in particular argues that all creative work involves a four-phase model, Collect (previous works), Relate, Create and Donate. It is understandable why a designer would want to understand either a previous project or to deepen his existing knowledge of the projects domain prior to starting design. Yet designers frequently encounter problems during a design’s development, the question was to what extent do they then search for more knowledge or simply try and solve through their own expertise or experimentation.

Thirty-three distinct knowledge interaction days were recorded and these can be seen plotted in Figure 6. To develop this plot, all of the days when knowledge interactions occurred were extracted from the diaries, together with the associated job. While many interactions could occur during one day, a day is the smallest division of time possible. The start and end dates of the jobs were then used to determine the point (as a percentage of project duration) that each of the interactions occurred. Those projects that are ongoing were plotted using predicted end dates and are coloured red, but clearly these may not be as accurate as the projects already completed.

The plot clearly indicates the majority of interactions occur in the first 20% of a project’s lifetime. This confirms the commonly held view that knowledge use primarily occurs during early and conceptual design stages.

Plot of the point of knowledge access as a proportion of projects time

Figure 6 Plot showing the number of instances of knowledge access as a function of the project duration.
Five interactions occurred towards the end of the projects lifetime and correspond to knowledge capture activities. The plot also indicates several knowledge interactions during the middle of the projects, indicating that some knowledge is sought during the design and development of projects. The roughly 4:1 ratio of initial knowledge interactions and mid project interactions indicates that in the majority of cases, designers either do not need or do not wish for codified knowledge during the design process.

To provide a more detailed analysis, the project with the most recorded interactions with the knowledge base was examined. Figure 7 shows a plot of the activities of the designer over the project’s duration — knowledge access is shown in red, while knowledge input is shown in green.

The plot supports the findings above, that is, the majority of knowledge seeking activities occurs during the initial project activities, but mid project knowledge access (and input) does occur. Although only the daily totals are known, the plot also indicates that technical work occurs alongside the initial knowledge seeking activities and meetings i.e. it is not a distinct activity, nor is all knowledge seeking completed prior to initial technical work. This highlights the need to ensure knowledge support and knowledge systems are not seen as distinct to technical work.

4.3 Knowledge use across multiple design iterations

Over the course of the study, one project went through three major design iterations, (where a design iteration is defined as the, design, manufacture and

![Plot of a project’s activities against time](image)

Figure 7 Plot of a single project’s activities over time.
Due to the complexity of the design problem, the design required significant trial and development work. Each complete product manufacture and trial was defined as the end of each version development.

A total over 700 h was invested in the technical design activities of the project, (including knowledge access) the breakdown of which can be seen in Figure 8.

Several observations can be made from the plot. Clearly the first version required a significantly higher investment of time compared to the other versions, notably for ‘CAD generation’. The CAD generation work can be attributed to the high level of upfront CAD detailing work, such as establishing parametric models of the parts to facilitate subsequent modifications.

The three other modelling activities: Full Concept, Finalising and Outputting all demonstrate decreasing levels of time as the versions evolved. This is to be expected as less large scale changes were required and the product becomes more refined.

From a knowledge utilisation perspective however, the changes across the three versions are significant. During version 1, a large period of time is invested in accessing prior codified knowledge (approximately 9 h). During the second and third design iterations this drops considerably. Conversely, while discussions with the technical expert were low during the early development work, it increases to 4 h by the third iteration.

Overall however, the knowledge utilisation still appears proportionally less than expected, a total of just 12 h was spent utilising codified knowledge,

![Plot of the Technical Activities and Knowledge Use over product design iteration](image)

*Figure 8 Comparison of activities over three design iterations.*
compared to 90 h spent in discussions with colleagues and the technical expert (a breakdown of this is shown in Figure 9). In comparison, the project consisted of a total hourly investment of 1300 h. Codified knowledge access therefore accounts for less than 1% of the total time invested.

It is therefore argued that codified knowledge is typically only perceived as useful for providing an initial understanding of the project, reinforcing the findings of the preceding results section. Personal knowledge sources such as discussions with colleagues and experts are more sought after during design future iterations. This is to be expected, given the need for designers to access more detailed knowledge, and the accepted richer provision of knowledge through verbal discussion (Daft & Lengel, 1984) and does support the findings of Yitzhaki and Hammershlag (2004) that verbal knowledge use increases during mid project knowledge seeking.

4.4 System perceptions
To evaluate the user’s perceptions and understand the rationale behind their usage patterns the designers were surveyed and interviewed. The survey was split into two sections (one addressing the system functionality, the second addressing the system content), each section was then further split into two parts. The first part assessed against single quantities, such as accuracy, quality and content using a purely linear scale (1−5). The second using a likert scale to assess the designers feelings towards the systems integration with their work and the relevance and quality of the knowledge captured (Likert, 1932) (Figure 10).

The survey was completed by four of the designers and a business manager. To summarise the results the likert results were numerically coded according to the study by Braunsberger and Gates (2009). The average of the results for the two sections were then taken, giving an overall rating out of 5 of 3.5 for system usability and 3.4 for the knowledge content and quality. Overall the results were a positive, but clearly there were concerns.
In discussions with the engineers it was felt the system lacked detail. While project level knowledge was useful and provided a valuable source for the engineers addressing repeat or similar projects, when faced with a specific and detailed problem the system did not contain sufficient knowledge. This was highlighted by the lowest scoring question, asking designers to rate on ‘Completeness’ receiving a mean score of 2.6.

5 Discussion and review

The overall evaluation of the KBS was positive based on user perceptions and system usage. All five designers used the system over the evaluation period, totalling around 70 h of use, and represented the primary source of codified knowledge for the designers. The system had clearly been successfully adopted as part of designer’s activities.

The use of the system to provide the initial understanding for the project referred to in section 4.3 and the willingness of the designer to spend 9 h reading and studying material from the system (rather than discussing the project with a technical expert) can also be taken as success of the system. That was, to provide a viable alternative to expert advice given verbally, minimising business reliance on individual knowledge holders.

Overall, however, the use of codified knowledge represents a significantly lower proportion of time compared to verbal knowledge sharing through discussions with colleagues and technical specialists. Section 4.3 also demonstrates that while the system initially provides adequate knowledge, the KBS does not provide sufficient richness to replace expert opinion and discussions, during complex and multiple iterative design development. This view is corroborated by the results from the survey and the discussions with designers, indicating a desire for more detail and depth in the system.
There remain some issues that must be overcome however, in particular improving the systems integration and knowledge capture during design. Little workflow change had been observed and as illustrated in section 4.2, little knowledge capture took place. Of the 14 projects completed during the study, knowledge capture activities were only recorded in 5 cases. Thus despite the overall positive reflection on the system by the designers and their willingness to utilise it as their primary knowledge source, there was less success in capturing and inputting project knowledge. Interestingly this is at odds with views of the designers that the system would be more valuable if there was greater detail and knowledge added. When queried, the engineers typically cited pressure to deliver new hardware as the primary reason for the limited knowledge capture.

Its capacity to minimise designer’s reliance on technical experts can be seen above. Yet its successful use is reliant on detailed knowledge capture and population of the system by the engineers. It can therefore be argued that the use of a KBS is entirely determined by the business. That is, the business must be willingly to sacrifice short term output in order to allow the engineers to document the system, in order to lower long term risks of knowledge loss through staff mobility.

5.1 Reflection on methodology

Use of the self-logging or ‘Diary’ method resulted in a large volume of rich and continuous data on designer’s activities. The two tiered classification and structured method of capture, was of minimum impact to the engineers, and yet was of sufficient detail for longitudinal relationships to be derived between projects and knowledge use.

There are weaknesses with the approach taken. In particular, inherent in the methodology is the reliance on self-reporting by the engineers. Despite the usually regular completion of the diaries, reporting at the end of each day is still dependent on the subject’s self-assessment and recollection of their activities, thus issues of retrospection as discussed in Shiffman et al. (1997) do remain. Previous studies such as Collopy (1996), have observed individual biases when self-reporting of up to 46% error. Yet despite large individual errors, observations indicated an overall trend towards the accepted mean.

In discussions with the engineers, most described their usage as frequent, typically weekly for short periods of time. These views are correctly reflected in the results. It is therefore felt that while the precise values should be treated with caution, the overall breakdown of time is accurately reflected in the diaries.

The use of the diaries provided the only realistic means for the long term study described. The low impact approach ensured they could be completed quickly and regularly by all participants, and as a consequence over the 6 month study only 5 days were not completed. In a future study the use of automated logging
could provide a means by which to validate data from a diary study, accepting that non-system activities would not be captured.

6 Conclusion
The research behind this paper demonstrates the potential for a Knowledge Based System as a designer’s primary source of codified knowledge and a viable alternative to reliance on verbal knowledge exchange from technical experts.

Use of a longitudinal 6 month ‘diary’ study of designer activities found that codified knowledge use accounted for 3% of a designer’s time of which 2% was utilisation of the KBS. Verbal knowledge exchange was reported at 10%, lower than previous studies, but still the primary means of knowledge interaction. The study also confirmed that common understanding that the majority of knowledge is sought in the first 20% of a project’s duration, but that mid project reference does occur. Furthermore a plot of a project timeline demonstrated a non distinct knowledge access phase — that is, knowledge access occurred alongside initial technical activities rather than as an initial upfront phase.

A detailed case study examining a designer’s activities over three major product iterations demonstrated an increased reliance on discussions with technical experts and a rapid decrease in the role of codified knowledge over progressive design iterations.

User surveys highlighted a positive view of the KBS and a willingness to retrieve and utilise knowledge from it. However users felt that the system could be improved through greater knowledge capture and depth to the knowledge.

The study therefore concludes that a KBS can be a significant asset to a Small to Medium Business and can successfully reduce the reliance of the business on critical knowledge holders. However, it was also concluded that the systems long term success was dependant on its continued use and population of knowledge. The study therefore recommends that knowledge capture activities should be established as a recognised and necessary part of projects, to ensure adequate and detailed knowledge is captured and re-used.

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1. Taken as the sum of ‘Discussion’ and ‘Solo technical information search’.

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