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PROMPTING DESIGNERS TO DESIGN

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1. Introduction

Recent researches suggest that engineering designers need assistance to understand what information is relevant for their particular design problem. They require guidance in formulating their queries and also to understand what information is relevant for them. This paper presents an approach to prompt designers with their design queries. A method that automatically extracts relationships between concepts is described, along with some examples. The method can be implemented as part of knowledge management system and the relationships are extracted form documents that are indexed within the system. The distinctive features of this approach is that all the concepts are elicited from the minds of engineering designers, and the system builds up knowledge as more documents enter the system. The approach is based on an understanding obtained from a number of empirical studies and also from literature related to: 1) an understanding of how engineering designers search for information and 2) an understanding of the nature of experience in engineering design. Hence these are reviewed in the following sections.

2. How designers search for information

Recent empirical research studies carried out in industry to understand how engineers obtain information and knowledge state that engineers need support in formulating their queries. Key findings from these are discussed in this section. A study investigating the knowledge needs of novice engineers who had up to two years of experience in relevant industry, found that they were not always aware of their knowledge needs [Ahmed, 2004]. The study analysed 633 queries made by novice designers to more experienced designers and found that the novice designers were aware of the precise questions that they needed to know in only 35% of all queries, i.e. they asked a specific question to which they received a specific reply. In the remaining cases, the novice engineers designers were either uncertain of their precise query or asked an inappropriate question (around 10% of the queries). In almost a third of the cases, the novice engineering designers made statements instead of asking a precise question and the experienced engineering designer would assist the novice by suggesting additional information to that requested. The experienced designers also provided the novice designer with confidence to pursue a particular approach. From this study, it is suggested that novice engineers approach more experienced engineers to obtain information for many reasons, including:

- Novice designers use the more experienced designers as a means to gain confidence in their design approach.
- They assist in rephrasing the designers original query if it is inappropriate.
- More experienced designers can provide additional knowledge to that requested.
- They can assist in providing guidance in formulating queries.

In addition, a number of studies have established that people are the most common source of information (rather than paper documents or electronic sources for example) [Marsh, 1997; Court, 1996]. One of the reasons that engineers approach people rather a different source of information, is that people often act as a pointer to other sources of information. As engineering designers become more experienced, they are more likely to know which information to search for or to be able to recognise the information when they come across it. Independent research studies have found that experienced designers are also uncertain of what information they are searching for particularly at the start of a search. The experienced engineers often *recognised* the information when they come across it during their search rather than being aware of it at the start of a search episode [Del-Rey-Chamorro, 2003]. The study focused upon the differences between locating information on paper rather than in an electronic format. One of the features of paper-based information, which was identified as important during the study, was the ability to flick through information and recognise important information. These findings present a difficulty when faced with search engines that rely solely on keyword searches.

From the studies reviewed, the key findings relevant for this research are summarised:

- Engineering designers are not always clear of the information they require.
- They may recognise this information when they see it, hence facilities to allow a user to browse for information is important.
- The ability to a prompt a designer with their considerations is important.
- Novice engineering designers need assistance in formulating the search queries.

Hence, a system to assist designers in formulating queries is proposed. In addition, to understanding how engineering designers search for information, an understanding of how experience in build up in engineering design provided a foundation for the proposed system. Therefore relevant literature is reviewed in the following section.

3. Experience in engineering design

One of the characteristics of experienced designers, is that they formulate strategies to approach a design task [Ahmed, 2003; Kavakli, 2001; Cross, 2004]. Part of these strategies include being aware of the considerations (referred to as *issues*) that are relevant for a particular design problem, for example *weight* and also the trade-offs between these issues, for example between *weight* and *stress* [Ahmed, 2003]. The number of issues that a designer is aware of as relevant to their design problem also increases with experience. A study that analysed descriptions of design processes from eighteen engineering designers of varying levels of experience and from two separate engineering companies, found that the number of issues, functions, product interfaces, and relevant design tasks that a designer was aware of as relevant to a particular design product increased with experience [Ahmed, 2005]. In total 652 references to products, issues, stages of the design processes and functions were found. The level of experience of the designers influenced the total number of references to either steps of the design process, components and assemblies, function or issues. The ANOVA test indicated the probability of a null hypothesis, i.e. the probability of no effect of experience upon the total number of references made, of 0.039. On average, the more experienced designers mentioned almost twice as many references (47.3) in their descriptions of the design process than the designers with under 5 years of experience (22.0) (see Table 1).

Table 1. Mean number of references to products; issues; functions; and design process tasks

Level of experience	Product	Issue	Functions	Design Process	Total
Under 5 years	5.17	11.3	0.67	4.83	22.0
11-23 years	7.20	18.4	6.60	5.60	37.8
28-42 years	5.43	27.3	2.43	12.1	47.3

The analysis of variance (ANOVA) test was also carried out to identify any differences in the number of references made to issues, products, stages of the design process and functions based upon the designers level of experience. The designers were grouped into three groups, those with experience of: 1) under five years; 2) between ll-23 years; and 3) 28-42 years (now in management roles rather than design roles). The ANOVA test takes into consideration the sample size, and the three groups of designers, grouped by their level of experience were compared. The results of the test indicated that the probability of assuming the null hypothesis was found for 0.021 for issues, 0.018 for functions and 0.018 for design process. Therefore, there was a significant difference in the number of references made to issues, functions and stages of the design process due to the differing level of experience of each of the three groups (refer to Figure 1). However, the test did not show a significant effect due to the level of experience on the number of references made to products between the three groups of designers. The number of references for issues and stages of the design processes increased with the level of experience. The number of references to functions increased with experience, however the designers with 11-23 years of experience mentioned the highest number of references (refer to Figure 1). The designers with 11-23 years experience had a mean of 6.6 references per designer, the designers with less than 5 years of experience mentioned 0.67 references, only one of the six novices referred to any functions. The designers with 28-42 years of experience mentioned 2.43 references (refer to Table 4). The 11-23 years of experience were experienced designers who were actively designing, whilst the 28-42 years of experience had moved on to more managerial roles which maybe an explanation for this.

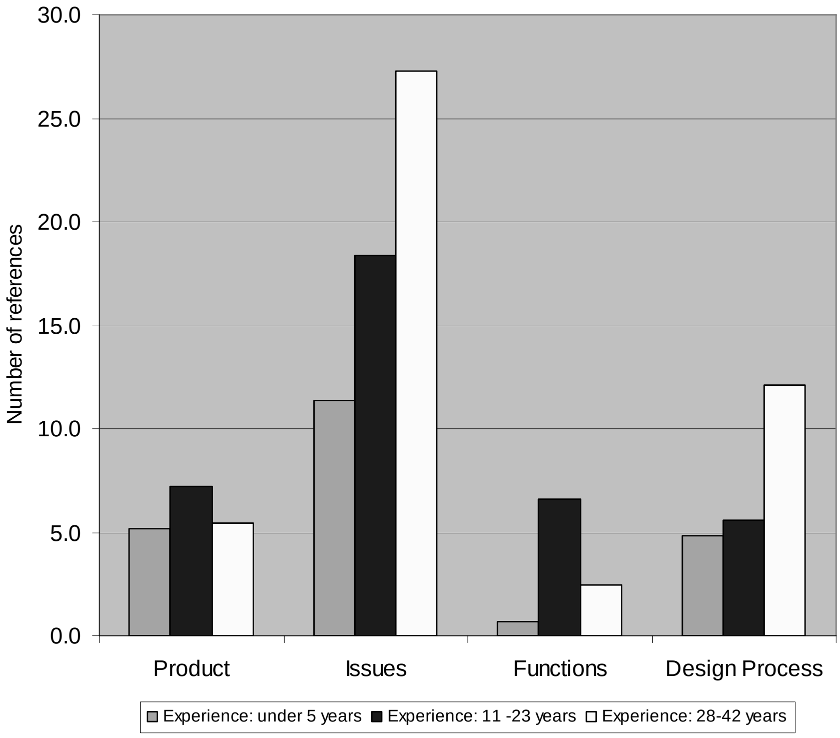

Figure 1. Mean number of references per designer versus experience

Experiments conducted by psychologists have shown that the short-term memory store is not limited by the number of individual physical units of data but by the number of *chunks* or units structured in a meaningful way [Johnson, 1992]. Miller states short-term memory capacity is limited to holding between five and nine chunks [Miller, 1956]. Experienced designers were found to hold larger amounts of information in a single chunk in memory. Waldron *et al* observed the abilities of experts, semi-experts (graduate designers) and novice designers to reproduce mechanical engineering drawings [Waldron 1987]. The experienced designers' ability to draw for longer before referring to the original drawing was attributed to holding larger amounts of a drawing in a chunk and this finding is consistent with those described in the study earlier in this section.

A system is proposed, based on the findings described, that builds up knowledge automatically from the indices assigned to the document. The system is described in greater detail, in the following section.

4. Method to prompt designers

The method is part of a feature of a document management system, where indexed documents are entered into the system (or are automatically indexed by tools within a system). The method builds up a network based upon indices assigned to documents. There is an assumption that indices assigned are related to the knowledge in the document, and therefore the indices too, are related. The network (or chunk) is presented back to the user once a search for knowledge has been completed. The network contains four different types of nodes. Each of these nodes represent one of the concepts of the four taxonomies which form part of EDIT (Engineering Design Integrated Taxonomy) and were elicited from an empirical study described in the previous section [Ahmed, 2005].These are: 1) the *physical product* (i.e. components, assemblies, sub-assemblies); 2) *issues*, i.e. considerations the designers must make when designing, e.g. weight, cost, manufacturability: 3) *functions* that must be fulfilled by the particular component or assembly that the designer is working on and; 4) *design process*, a description of the relevant tasks at each stage of the design process. The network is build up as indexed documents are entered in to a knowledge-based system. The documents are indexed using the concepts from the ontology. A minimum of one index is required for the document to influence the network. However, any number of indices from a minimum of one of the taxonomies to all four of the taxonomies that form EDIT, can be used to index a document.

The system draws the relationships between the indices used to index the knowledge and these are represented as links between the nodes, for example, if a document is indexed against *turbine_blade* (from the product taxonomy) and *weight* (from the issues taxonomy) and a second document is indexed against *turbine_blade* and *cost* (from the issues taxonomy), part of the network represented by the system would include a link from *turbine_blade* to *cost* and also a link to *weight.* The strength of the relationships is related to weighted criteria, based upon the number of documents indexed with these nodes and can be used to remove weaker relationships. The strength of the relationship is currently represented by a number, between the nodes, the higher the number, the stronger the realtsionship (refer to Figure). The network grows as new knowledge is indexed and therefore new relationships between indices are established. The network employs a number of rules when forming the relationships between different concepts. These are based upon logic and are described below, together with the reasoning behind them:

- Function – product – function: to identify additional functions a product (component or assembly) needs to achieve.
- Product – function – product: to identify alternative products that carry out the same functions, these could provide alternative solutions or relevant knowledge.
- Product – issues – product: to identify the issues that should be considered when designing a particular component or assembly. This can also be used to identify knowledge of how a similar problem has been solved in the past for a different product to the one the designer is working on.
- Issues – product: (see above)
- Product – product: to identify product interfaces, these can be physical or functional interfaces.
- Issues – issues : to identify additional considerations that are related to a particular issue, these can be a trade-off between issues.
- Issues – design process: identifying design tasks for which particular issues are more relevant.
- Design process – issues: considerations that are relevant for a particular stage of the design process
- Issue – function: identify issue that are relevant when designing a product to achieve a particular function.
- Issue – function: see above.

5. Using the system to retrieve knowledge

When using the system to retrieve knowledge, the user searches for knowledge using either a keyword search or navigating using the four taxonomies. An engineering designer who is aware of his or her precise query can use the keyword facility, whereas a designer is uncertain of his or her query may browse the navigational structure to select a query. The user may search using a combination of concepts from the taxonomies, for example, *weight* and *unit cost* (i.e. two concepts from the *issues* taxonomy). All of the documents relevant to the search is returned by the system. The relevant portion of the network of relationships is also graphically displayed, i.e. all the links from the indices the user has searched for, to other indices (see Figure 2).The network can be used to immediately see what else can be searched for and, hence expand/narrow the users search. The relevant portion of the network is used to prompt the user to think about other issues; products; function; steps of the design process related to the search query. The example of such a network in Fig 2 is based on a set of 92 documents, and hence are preliminary results. It is expected that as more documents are added to the system, the relationships become stronger as the less relevant relationships are screened and no longer presented. The implementation of the system allows the users to view different relationships, for example the user can choose to view only the issues (refer to Figure 3). In Figure3 the unit-cost is associated with maintainability, assemble, geometry and material, manufacture, inspect and monitor and manufacture and build. All of these considerations are highlighted as relevant to a designer who is trying to understand the unit-cost. All of these factors have a bearing on the cost of a product.

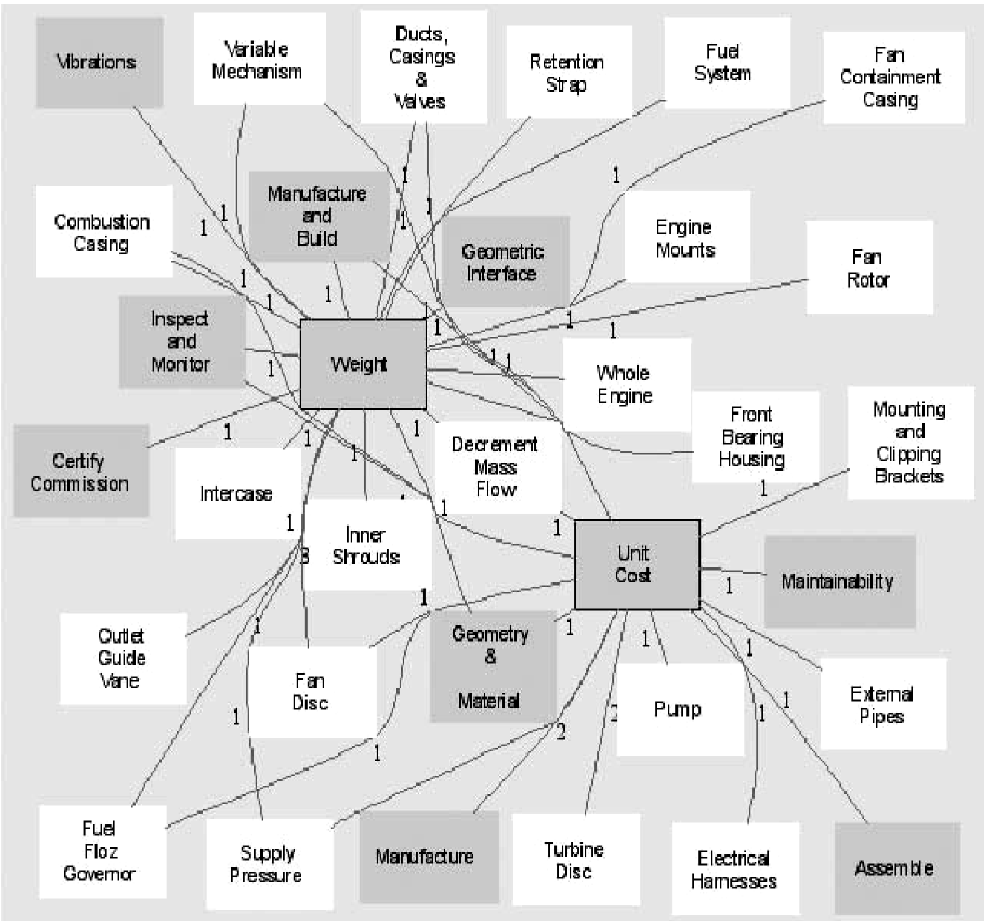

Figure 2. Example of a network for Weight and Unit Cost

The diagram can also be filtered in a number of a different ways, based on the type of node: issues, products, functions, design tasks or any combination of these, and also based on the strength of the relationships. In figure 4, the strongest relationship presented is that between *weight* and *unit cost*. These relationships are extracted from documents within the aerospace domain, where low weight is one of the most important criteria for a product and hence the relationship seems to be a likely one. The visualization and choice of filtering of the method is to be evaluated (see Section 0) and recommendations to made based upon the outcome of the evaluation.

The visual display of the network assist designer to search for knowledge. The provision of a network of relationships (refer to Figure2) allows the user to immediately see which other nodes may be relevant and hence, widen or narrow a search. The network also acts as a prompt for designers by graphically displaying other components or assemblies; issues; functions that a component needs to fulfill; and steps of the design process that should be considered, in a similar manner to how an experienced designer builds up associations into a *chunk* of information.

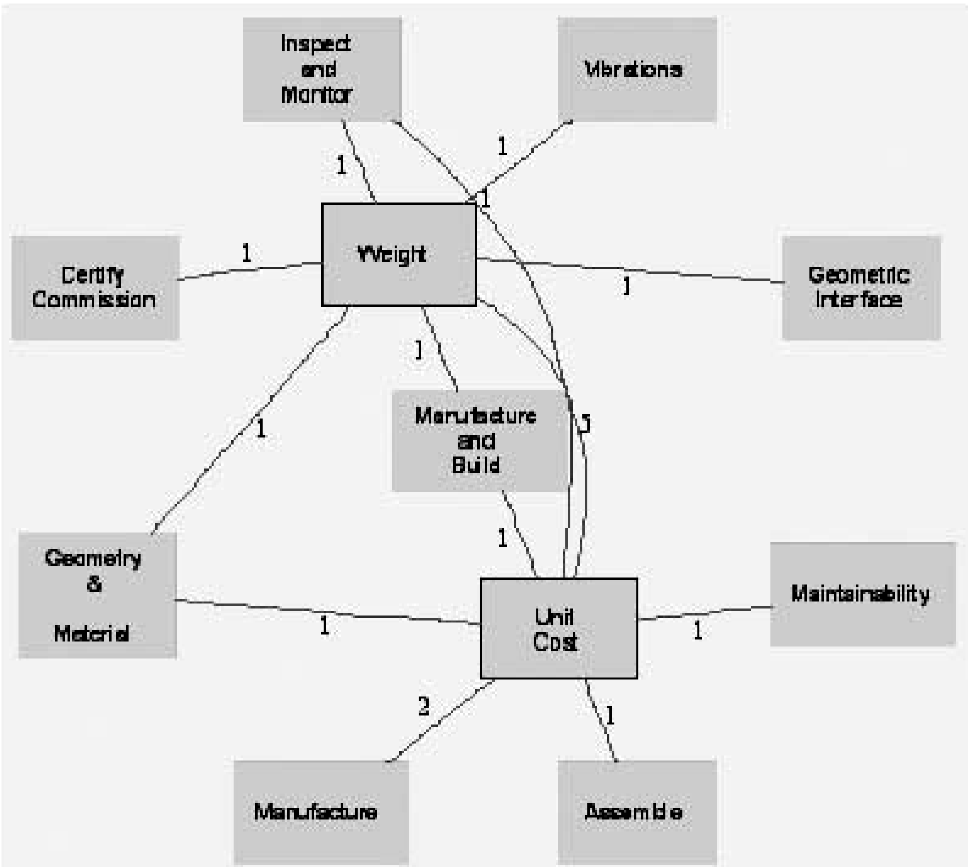

Figure 3. Network filtered for issues related to Weight and Unit Cost

6. Evaluation

An informal evaluation has been carried out with engineering designers working in an aerospace company. The method along with initial examples was presented to a small informed group of designers, to obtain the feedback to the method. These examples were based upon relationships obtained from only 92 documents that had been indexed. The initial feedback provided was positive, the general feeling amongst the designers was that the example relationships obtained were meaningful. Hence, further documents are currently being indexed to strengthen the relationships obtained from the method. Currently, 157 documents have been indexed, an extensive evaluation is planned with engineering designers with a database of around 300 indexed documents. The evaluation will investigate how the visual information presented to the designer can be filtered. The evaluation will also investigate whether the relationships described are useful for the designer in both: prompting the design task and; to formulate or reformulate their search for knowledge.

7. Conclusions

Empirical research studies investigating how designers search for information have been described. The findings have highlighted that engineering designers are often unaware of the precise query when searching for information. Hence, a system has been proposed to assist designers in formulating their queries when searching for knowledge. The system generates associations between concepts from an ontology. A network of associations is generated based upon indexed documents. The network can be utilised to refine a search for information through prompting the designers with the queries. The network can also be utilised to prompt designers with their design tasks and is based on an understanding obtained from empirical research and an understanding of the characteristics of experience. An informal evaluation has been carried out and a further extensive formal evaluation is planned.

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