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ESTABLISHING KEY ELEMENTS FOR HANDLING IN-SERVICE INFORMATION AND KNOWLEDGE

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ABSTRACT
In-Service support is an increasingly important part of product lifecycles in particular for complex high value, low number products such as in the Aerospace sector. Although there is a significant predicted increase for in-service products the overall in-service experience is expected to decrease increasing the pressure upon design repair engineering teams. There is additional requirement to capture and transfer expertise, thus innovative knowledge management is required to continue to support this activity. It is important to understand explicit knowledge for In-Service design repair and two pilot audits are conducted. Approaches for the effective transfer of information and knowledge for reuse are discussed including the use of spatial information visualisation or visual information elements to present In-Service knowledge. The application of human computer interaction principles and organisation of information by temporal product theme is discussed together with its potential in document content understanding. The purpose is to understand aerospace In-Service repair design knowledge elements and to suggest the applying new methods for developing knowledge management support.

Keywords: knowledge management, in-service, visualisation, knowledge transfer

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1 INTRODUCTION

In-Service support is an increasingly important part of the overall product proposition or sales offering for a number of industries due to customer demand for combined product and service contracts (Jagtap, S. & Johnson, A. 2011). This is particularly true for repair design service for complex high value, low number products (compared to consumer products) such as in the Aerospace sector. Current market predictions estimate that 19,890 aircraft were in service in 2011 and this is expected to increase to 39,780 by 2031 (Boeing, 2012). The increase in number of products in service and accumulation of product data effectively reduces the in *In-Service personnel experience per product*. This leads to an increased information burden carried by the engineering teams, which also require a diversity of experiences and knowledge that are difficult to capture. This includes a clear understanding of company procedures, technical information and in-field capabilities. Thus additional requirement is placed upon the In-Service teams themselves to capture, transfer and inculcate expertise using explicit knowledge assets and their associative tacit dimension. It is clear that innovative approaches for knowledge management (KM) are required to continue to support this activity. This highlights the importance of understanding the information collections and data sources available to In-Service repair design teams to enable their effective reuse. *The overall purpose of this paper is to understand In-Service explicit knowledge elements thus supporting their effective re-representation for potential application of novel methods in developing KM applications.*

Thus this paper first describes in Section 2 this ever increasing pressure faced by In-Service design engineering teams and highlights current practice for KM. It uses previous related research to highlight the significance of the industrial repair design and further raises gaps in knowledge capture and transfer. Requirements from literature for KM support for engineering design is analyzed to draw attention to the most significant challenges. There is little evidence of literature specifically regarding In-Service repair design. In Section 3 In-Service industrial studies are used as example cases to synthesize some of the key information requirements and their hypothetical uses. The objective of these studies is to ascertain a list of explicit in-service knowledge elements and define potentially useful attributes. Example attributes being the time frame to suggest its relevance to repair design. In section 4 a discussion of potential uses for the audited findings follows and suggests appropriate information themes and novel methods for re-representing In-Service information. The focus is development of best practice for designing KM solutions. The potential for application of spatial or temporal visualization, the development of visual applications to support human cognitive behavioral traits and to add context to In-Service knowledge collections is explored within this discussion. The final section concludes the overall findings and suggests the future work for developing support.

2 IN-SERVICE DESIGN INFORMATION REQUIREMENTS

The area of KM has increased in popularity as implementations in industry are becoming more widespread. The literature covers the entire knowledge system spectrum, including defining knowledge types, their purpose (Satyadas et Al. 2001), methods for storing and reusing knowledge (Markus, L M. 2001), possibilities for classifying knowledge (McMahon et Al. 2004), the technologies for implementing knowledge support systems (Gopsill et Al. 2011) and measurement of knowledge and support system quality (Lila Rao, A. & Kweta-Muata, O. 2007).

However, literature written specifically regarding In-Service repair design is limited, for example Pahl & Beitz (1984) & Hales & Gooch (2004) do not index or cite repair design. The continued In-Service requirement for innovative and multi-facetted information search and retrieval (IS&R) stems from the tendency within engineering to collate and reuse huge repositories of physical knowledge assets over lengthy product lifecycles (McMahon et Al. 2004). Much research emphasis has been placed upon generation of tools for information access and it is assumed that the disparate nature of design teams leads to challenges. However, the requirement to reuse legacy information sources is also a significant limiting factor (Carey et Al. 2012). This disparate nature of design teams and information sources exacerbates the elicitation process for developing support systems as the information sources may be remote, uncontrolled and independent of the In-Service designers themselves (Bennett et Al. 2002).

It becomes apparent that lengthy product lifecycles also leads to accumulation of highly experienced personnel, thus increasing the volume of what is referred to as collative knowledge (Smith, K A. 1988). However, it is agreed that reuse of experiential knowledge facilitates innovation and creativity in design and provides evidence for best practice in using materials and methods (McMahon et Al.

2004). The reuse of knowledge is therefore essential to driving what can be thought of as In-Service design process optimization and this is facilitated by the capture and reuse of explicit knowledge (Wong et Al. 2008). Although interventions have provided support they have not yet completely solved the issue of transferring knowledge from explicit data assets or from tacit knowledge sources to less experienced designers. The requirements for applications or methods to fill this research gap are thus highly compelling.

2.1 In-Service – Current Knowledge Practice

Within the engineering domain it is acknowledged that it takes many years for a designer to gain the experience required to function effectively for product design (Smith, K A. 1988). This is certainly the case within large aircraft design engineering industries and is a significant issue for In-Service repair design teams where it is reported internally that the overall experience of a design team is reducing. This is due to the loss of experienced engineers, replacement with newly graduated engineers and the service expansion throughout the globe as numbers of products and customer demand increases (Boeing & Airbus 2012). Advancing experience levels and retaining tacit knowledge in In-Service teams thus relies heavier upon reuse of explicit knowledge assets as capturing the tacit dimension of a design team is inherently difficult.

2.2 In-Service – Current Knowledge Support Provision

Within industrial In-Service teams the phenomenon of information overload is manifested in the number of specialist information systems developed to support design engineering teams. There are numerous product knowledge systems reviewed in the work of Gopsill et Al. (2011) each of them supporting differing design engineering activity such as document management. Specialist applications exist addressing information management for knowledge retrieval such as IS&R. Current IS&R methods use predefined knowledge elements such as semantic text term to extend search capability (Xie et Al. 2011). Another method is classification schemas such as information ontology for managing data collections or information schemas (Darlington, M., 2005). These can be used to support information search and retrieval or information push to designers (Campbell, D., 2007). Other techniques currently investigate the designers' requirement to communicate and share knowledge (Tenopir, C. & King, D., 2004).

2.3 In-Service – System Users

An important element in any system is the *users* and provision of effective support. In-Service knowledge system users are of particular importance to facilitate understanding of pre-defined knowledge and to proactively support reuse of their tacit knowledge. This includes harnessing the power of any human cognitive behavioral traits (Card, S K., Moran, T P. & Newell, A. 1983) potentially to accelerate learning for experience accumulation or using methods to enable easier synthesis of knowledge from information such as spatial and temporal information representation or effective use of visual interfaces. An example is found in Human Computer Interaction studies, such as Schneidermann, B. & Plaisant, C. (2009), where heuristic rules are applied to design effective user interfaces. It is quite possible that a combination of novel techniques to visualize information and the use of theoretical learning principles are required to accelerate experience inauguration. In particular, for synthesizing knowledge from the large data collections generated by In-Service operations.

2.4 In-Service - Knowledge Gap

However, to enable the application of such principles to the In-Service domain the knowledge elements, sources and users must be clearly understood. An audit of all the possible *physical knowledge elements, attributes* and *knowledge sources* for In-Service information has not yet been undertaken. An audit of this type would be the first step to suggest appropriate or potential encoding for re-representing the information effectively. The next section describes two exploratory studies conducted to investigate the In-Service repair design information sources and their content. A preliminary audit of information sources used by In-Service repair engineers is conducted and the content of historic repair case document collections are analysed. These historic document collections are identified as representative of In-Service repair case information.

3 INDUSTRIAL STUDIES

It is evident from industrial In-Service working practice analysis that the engineers there carry out complex tasks in an increasingly pressured working environment. As experience reduces, the workload pressure upon an inexperienced In-Service designer increases. Information collation practice to support the design repair process appears to differ dependent upon the experience of an engineer and the task they are currently undertaking. Therefore it is necessary to fully understand the information formats, resources available and tasks undertaken by the repair design teams to provide effective support. It is also important to understand the *purpose* of the designer upon seeking information and the reuse requirement for information types and their content. It is evident that repair design engineers both seek and browse information collections. To complete this understanding requires an audit of the information sources, the tasks undertaken and engineer expertise that may seek information. There is also the requirement to analyze the information sources audited to describe their content. Please note that due to sensitivity of the information collected for this research activity, it has only been possible to provide anonomised summaries for this paper. However, it is considered that these provide sufficient support for the arguments presented. There are two audits reported below, one a participative person based study and the second a formal sample based document audit. The two are then discussed together in Section 4.

3.1 In-Service Information Source Audit I

The initial audit was set up to be informal to encourage participation and to collate the perspective of a broad sample of design engineering expertise. Thus the audit was conducted over three two hour lunch time periods using informal drop-in sessions to invite In-Service engineers to participate. As a participative research approach (Dawson, C. 2009) this was very successful as it encouraged active participation, without impacting on the high pressured working environment of the engineers. At the drop-in sessions there were three flip charts available for the addition of annotated post-it notes. Each participant was encouraged to add as many post-it notes as they felt possible. The request asked for the post-it notes to describe an information type that may be sought, the source of information use or the possible tasks that the engineer might process. Where possible it was requested to link an information type or task to the information source. The back of the post-it note should note the number of years' experience the recording engineer had gained.

Surprisingly it is evident from the drop-in discussion that it was not clear to the engineers themselves the differentiation between information type and information source. This illustrates the difficulty a person might have in explicitly representing the practices they might automatically undertake. There were however some interesting and varied examples of methods in the search habits of some engineers.

3.1.1 Study Control

Although the audit was very useful it is by no means an exhaustive or objective study. There was little control over the engineers that participated or how much they contributed to the overall audit. The level of experience of the contributor was attempted to be measured, however, this was unsuccessful as not all participants volunteered this information. Therefore the results provide example of the considerable number (although not exhaustive) of information sources and the purpose of the information source for In-Service repair design.

3.1.2 Results of Audit I

Below are three tables summarizing the results as stated above, these have been anonomised for sensitivity purposes. Table 1 illustrates the information formats identified by the designers themselves as imperative. Table 2 is a list of the processes or tasks that In-Service designers may undertake requiring information seeking support. Finally table 3 is a summary of all the sources identified by the designers as information rich and are regularly searched for In-Service information. The table is a matrix illustrating the identified source format and the informative source theme. * indicates the presence of visual content in Table 1. The results shown are a good initial representation of the opinions of the In-Service designers based on a sample size of 172. They do not present a complete audit of all In-Service information, tasks or sources and it is possible that the sources may be classified into multiple categories. However, it is evident that there is prevalence for In-Service information to be stored in document format.

Table 1: Format of In-Service Information

Information Format	Number of Audited Occurrences
Historic Reference Document Collection*	6
Spatial Data Representation Medium*	4
Tacit Information (Personal Information)	1
Design Standards Reference Document*	6
Design Request Document*	3
Records Database Entries*	1
Communication	2
Reference Text Characters*	3
Total	**25**

Table 2: Purpose of In-Service Activity

Task Classification Description	Number of Audited Occurrences
Extended Design Project	5
Generic Design Requests and Queries	5
Variation Design Request	2
Design Methods and Tools Project	1
Data Administration Task	1
Workflow Management and Distribution	1
Diarized Design Validation	1
Prepare Technical Reports	2
Total	**18**

Table 3: In-Service Information Classification

	Number of Audited Occurrences for Information Themes				
Information Source Format	Product History	Product Family	Design Standards	Current Design Task	Information Format Total
Documented (e.g. PDF)	33	40	24	9	110
System Recorded (e.g. database entry)	22	23	36	5	86
Other (e.g. training courses or site visit)	5	15	54	8	82
Total for Information Theme	**60**	**78**	**114**	**22**	**172***

Table 2 illustrates the heavily design related activities undertaken by In-Service repair teams, as 13 of the 18 identified tasks are considered design activities. Table 1 illustrates the significance of visual information formats for In-Service as 22 of the 25 formats recorded contain visual elements. The sources of information also demonstrate four required themes for design information. These are product design history, the overall product family design details, the design standards for methods, tools and materials and the current design request information. The significance of design standards information being stored in the category "other" formats may require further investigation. It could indicate that design standard information is difficult to find due to knowledge of the subject being personal (tacit) or stored disparately and thus difficult to find. The summaries do not indicate specific information requirement themes for each task identified, but suggest that all of the information sources may be required for all In-Service activity. The immense number of information sources and disparate locations identified does reinforce the complexity of In-Service information seeking practices.

3.2 In-Service Document Content Analysis Audit II

For each repair design undertaken the resulting and investigative information is stored in a collection of documents per repair case. This forms the basis for capturing historic design information and is reused in this format. The reuse of these files is identified as key to prepare the design for a current repair case and therefore the information contained within these collective documents will be of significant value. The purpose of this study is to analyze a sample of these files for content to understand better their informative content value and the format of the information.

3.2.1 Document Sample Description

Analysis of the historic case files illustrates that they consist of a number of sub-documents that are representative collections of information media for In-Service. A representative sample of historic repair case files have been audited to investigate the main content that the data comprises. Due to document formats it is required that the audit was conducted manually and therefore eleven cases have been analysed for this study.

3.2.2 Document Sample Analysis

The historic document collection sample is more than 90,000 files. The file storage sizes ranged from 855Kb up to 20,482Kb, with the median file size being 5,916Kb. The age of the files in the data repository spans many years. However the sample used were taken from more recently processed cases from 2008 onwards. It is also evident from the audit that the historic cases consist of a number of visual information elements (referred to as media features) and therefore these were used as one scheme for content analysis. The following is a list of the easily identifiable media audited; *Reference Fields (Text format); Natural Language (Strings of Text); Photographs; Handwritten Documents; Calculation Patterns; Drawings or Sketches; CAD Drawings; Secure Objects (personal signatures); Additional notation*. The list is not exhaustive but representative for the sample audited.

Each historic case comprises a number of documents collated together to be stored as one case. The time taken to process each historic case ranged from 3-411 days, a significant difference in processing overhead. The number of individual documents within each case averaged 27, however, the range found varied from a minimum of 4 documents to a maximum of 50 documents. Overall a number of 37 individual document types were identified, with an average of 2 A4 pages per document.

The full result records a wide variety of data recorded about the historic cases, illustrating the complexity and varied nature of the repair data being stored. For example Historic Case 9 appeared upon auditing to be the most complex case processed (even though the time taken or processing was lower at 15 days), as can be noted from the substantial file of 133, consisting of a large number of annotated drawings and testing measurements/results. However, Historic Case 1 also contained an increased number of drawings and measurements also. The processing time for Historic Case 8 and 10 was very large at 266 and 411 days respectively. However the variety of drawings, annotations, measurement types within the file do not appear to increase as would be expected.

On average there were 60 A4 pages per Historic Case, of that number only 9 pages were used purely for internal use (15% overall). The number of incoming correspondence (57%) was not significantly higher than that of outgoing correspondence (43%). The most popular correspondence method used was twice as much sent by fax(71%) rather than email (29%). The file text indicated telephone corresponding is aparent but not recorded regularly, thus it is not possible to measure communication preference.

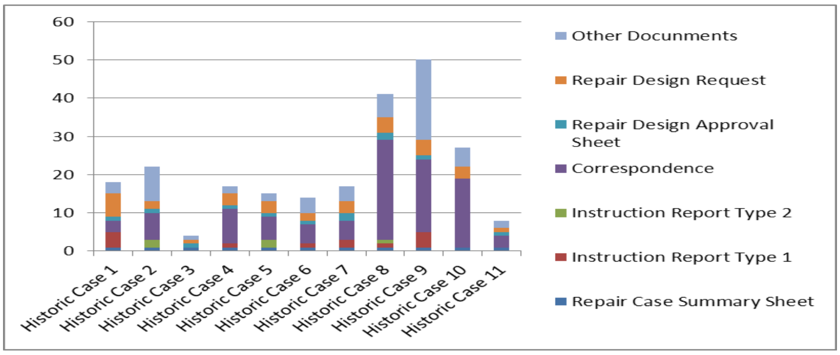

Figure 2: Historic Case Document Type Count

There was a large number of documents types identified (37 total), however, the main categories identified were as shown in the legend above. There were a number of documents (29 document types) collated in the “Other” category as they were individual instances and low in volume. It should be

noted that these were not deemed to be insignificant and appear to increase in individuality as the complexity of the file increases. The composition of each Historic Case shown in Figure 2 illustrates the increase in correspondence and other documents recorded in each file as the length of the Historic Case increases. However the proportion of document contents recorded for any other types remains largely the same.
The proportion of document types found is illustrated in Figure 3 below. A significant proportion of the file consists of Correspondence (43%). A large proportion of the document type is the category Other (25%), suggesting that at least a quarter of the Historic information stored is complex and individual in nature.

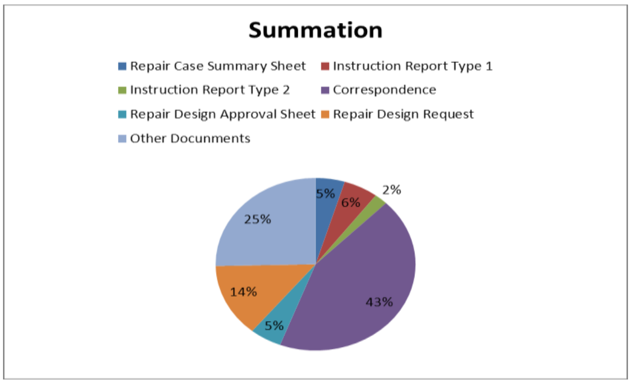

Figure 3: Proportion of Document Types

Individual document types have been analyzed separately to that of the Historic Case files. This illustrates the comprising content for individual Document Types. It is misleading that a majority of the documents contain more faxed information than emailed as it appears that information is first faxed to centrally, then scanned and emailed on to In-Service.
Figure 4 illustrates the document breakdowns into sub-composition of media types. The media is measured by instance found on an A4 page and subsequently counted for each document type. It demonstrates the differences between each document standard found. Every document type can be seen to contain text media. The Summary Document contains very little but text. The Repair Design Request consists as expected mainly of measurements, images and drawings. The Document Other appears to be rich in media type including a proportion of calculations, drawings and measurements. Further mining would be required to ascertain the useful nature of each document and media type.

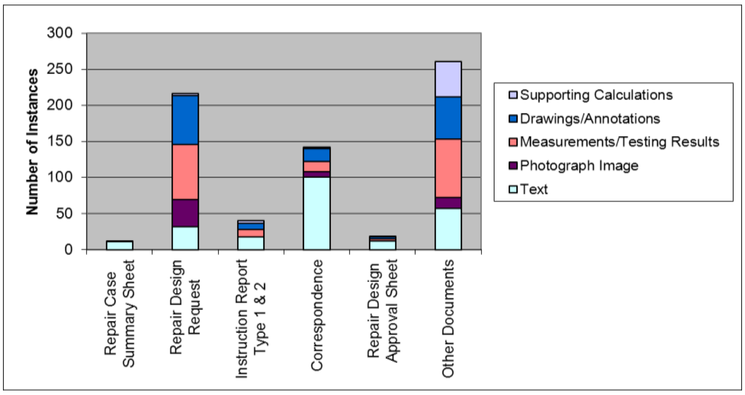

Figure 4: Document Composition

A significant proportion of the Historic Case file contains correspondence documents. The breakdown in figure 5 illustrates the content of the correspondence document which is mainly text. However, a majority of the documents including correspondence all contain other media types. This suggests that there is a significant need for illustration to aid in the understanding of a Historic Case.

3.2.3 Results of Document Content Analysis Audit II

Initial analysis of the content of the historic cases and sub-documents demonstrate the complexity in interpreting any informative elements. There could be a considerable number of issues for inexperienced personnel. It is not possible from this analysis to suggest with any certainty how the In-Service designers might use the recorded information. This is the focus of a current study soon to be published. However, this aside, it is evident that the historic cases are rich in media and visual elements to aid in repair case understanding. Other than the correspondence document there is a significant majority for visual information media types. Analysis of the correspondence documents suggests that approximately 71% of the content is textual media. This does not suggest that the text is not useful for presenting repair design technicalities; however, Repair Design Documents do contain a significant amount of visual information elements. This core data and profile of the historic cases is very important to inform the design of future KM support systems and the issues arising are discussed below.

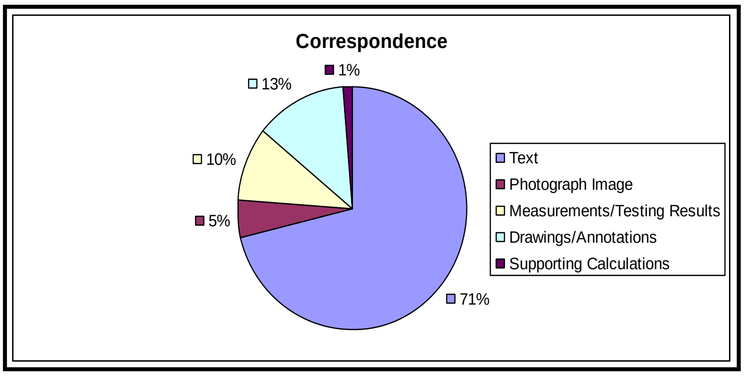

Figure 5: Correspondence Media Composition

4 DISCUSSION

The In-Service document investigations of Jagtap & Johnson (2010 & 2011), suggests there is still significant need for the continued development of KM support in particular for design related documents. This is especially true for In-Service repair design activities where the nature of design information related to the project remains disparate, complex, profuse and utilised by a broad user audience. The utilisation of the information by such a broad audience often means that the source of the data is not controlled by the In-Service users themselves. The applications currently developed focus upon specific attributes of knowledge elements for supporting individual knowledge types. One such attribute for example is the contextual elements facilitating a users understanding of the knowledge element (Xie et Al. 2011). However, additional knowledge attributes should be explored for their potential to support information understanding to exploit them in knowledge management supporting techniques. The analysis of In-Service repair design documents is a one to identify their informative content properties.

The studies described above are an important initial step and do not provide sufficient controls for consistent sampling or large sample numbers for content analysis or data capture method reliability (Dawson, C. 2009). Further studies are of course required to formalize this analysis and to rigorously test the findings. However, they do provide a unique and valuable initial descriptive insight to describe and hypothesize the important research challenges. The development of a consistent analysis schema for automating the document content extraction will be necessary to provide a statistically significant sample. Further involvement of a wider design engineer audience for auditing information forms and sources would need to be collected using quantitative questionnaire research method (Dawson, C. 2009).

4.1 Key Points from the Industrial Studies

The key points from the content analysis and audit findings are listed below;

1. There are common information themes being sought for In-Service activity. Those identified for classifying information sources in this study are shown in table 3*; product history; product family; design standards and current design*.
2. There is a significant amount of In-Service information stored in *document format* (table 1 & 3)
3. The significance of *visual information elements* is identified by designers as important (table1).
4. In-Service repair is considered to be a heavily *design related activity* (table 2).
5. The documented information for *product history and product families* is often stored in

document collections, as sub-documents, images and in database linked entries.

6. The complexity of the documented information is stored in a *multitude of media* requiring interpretation (suggesting the requirement for design expertise).
7. There is much evidence of the number of information sources overloading In-Service designers and the *complexity of the information formats* presented to them for interpretation.
8. The *preliminary studies* suggest hypotheses, but do not evidence how the information is used in practice by design engineers.
9. The document contents analysis evidences the *rich visual media* content such as photographs; drawings & annotations; calculation patterns; text; and measurements or testing results. These are often found to be *spatially represented*.
10. A majority of the documents contain *text references* to aid interpreting the product and product family.

4.2 Potential Uses of the Key Findings

There a number of potential uses for these findings to develop support to enable engineers to deal with large amounts of In-Service knowledge. Further understanding is required to indicate how the visual information elements are reused (thus transferred) within In-Service. Key point 1 indicates that In-Service information can be classified into common themes. It is possible that In-Service information reuse is based upon the identified theme attribute of product information, current design standards or historic product information. The product information sought could be related to parts of the product lifecycle and suggests possible new temporal information classifications. It is possible that the coding of knowledge assets using timelines *and* information purpose *facilitates some new information views.* Viewing information by temporal theme could provide clear context to speed understanding or to enable easier information browsing for In-Service activities.

The prevalence of documents as a storage medium for knowledge assets is evident in key point 1 & 5. This suggests that the reuse of document content is imperative for In-Service activity and a comprehensive understanding of document content is required. It is possible that the identification, classification and representation of the rich visual media elements using the key points 3, 5, 6, 9 & 10 could provide the basis for developing *spatial representations of In-Service information* or *visualization of informative elements.* It is demonstrated within learning theory and in studies of human vision capacity that visual presentation of information improves a person's ability to deal with information from large data sets, thus increasing the possibility of *accelerating knowledge synthesis* (Cavanagh, P., 2011.), thus addressing the issue of information complexity acknowledged in key point 7. In key point 3, the design engineers identify that visual information elements are important for their understanding. It is also possible that further understanding the use of these visual elements could enable the utilization of human cognition and behavior techniques for accelerating knowledge synthesis and thus transfer of In-Service information to support the rapid gain of experience, this is the subject of further study.

5 CONCLUSIONS

This paper has demonstrated from literature that KM support continues to be required and developed for In-Service engineering repair design. Market outlook figures predict that the number of aircraft in service will increase approximately 5% each year and double by 2031, exacerbating the in-service experience issue as it is deemed by In-Service teams to take 10 years or more to gain full competence. The studies of In-Service information conducted for this paper, have provided initial findings of the In-Service repair design information sources and prevalent information formats. It has also analyzed the content of example document collections to identify the informative elements for storing In-Service knowledge.

The key findings from these pilot studies shown in Section 3 & 4 are that reuse of documented information for In-Service activity is an important part of their current transfer and synthesis of knowledge. The 10 key points suggest that it is possible that In-Service engineers seek information based upon some product lifecycle themes (temporal) and use highly visual elements to describe knowledge. The knowledge elements should therefore be organized to support browsing these themes and use visual representations of the information to enable easy interpretation.

The use of usability and human cognitive methods to accelerate knowledge synthesis from explicit data sets has not yet been explored for In-Service application. However, the strengths of human visual capability and the visual document contents are evident and should be supported to aid knowledge transfer and synthesis. The use of the key findings, human computer interaction principles and accelerated learning theory to present spatial, visual and temporal views (classified product themes) for In-Service information could enable faster synthesis of knowledge from information repositories that already exist.

Future work will focus upon the automation of extracting informative elements from document contents for producing content summaries, the development of appropriate views of product knowledge for In-Service (utilising the visual document contents) and spatial or temporal mapping of informative elements, thus also expediting information understanding.

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