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Visually Informed Support for Design Engineering Decisions

Carey, Emily

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Visually Informed Support for Design Engineering Decisions

Emily Carey

A thesis submitted for the degree of Doctor of Philosophy

University of Bath

Department of Mechanical Engineering

May 2016

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Abstract

It is a truism that the amount of information being generated in the modern digital world is increasing at an exponential rate. This is influencing engineering as it is in other forms of business, as well as everyday life. Engineering has a significant visual dimension to it: drawings, diagrams, sketches, photographs, graphs are the everyday language of the engineer. Despite the prevalence of such visual information, the role that such information plays and how it affects, for example, how documents can be reused is an under-researched area. This thesis thus proposes the important role of visual representations and images for supporting informed decisions, in particular for complex domains such as Engineering Design. The particular context for this research is associated with in-service design knowledge and information requirements. The increasing number of actual products in-service, the requirement to create safe design solutions quickly, the amassment of service data and the importance of product services to organisational competitiveness are all increasing the information pressures upon Design teams. The pervasive nature of visual representations in Engineering Design and prevalent document information suggests that they are an important asset within document information resources. This research focusses upon the purpose of Engineering Design image utilisation for information processing, and hence supporting efficient decision making.

Some of the additional challenges identified throughout this research are the immaturity of current image recognition technologies and thus limitations of automated media extraction tools for supporting Design Engineers. This is significantly contributed to by the complexity of the information media and formats that constitute design engineering information and the current knowledge management trend to capture information without clear "reuse" purpose.

The methods used to conduct this research demonstrate the merits of underused techniques in design engineering such as storyboarding. This storyboarding method is used for investigating the facets of tacit knowledge and the underpinning cognitive processing of document information resources for critical Design Engineering informative content. The innovative research method developed provides a useful framework for the collection of rich data using simulated tasks. The data collection is a rich multi-stream recording of design engineers in industry conducting work based scenarios. In particular the focus is upon conducting efficient research in industrial working practices with minimal facing research time with design engineers and the rich data that can be collected from them in situ.

This thesis illustrates that there are a number of pressing difficulties in reusing image media, both technical process related in nature. This is currently limiting the usefulness of valuable information resources in practice, but also significantly raises the information burden for design engineer. This thesis has attributed the value of reusing visual representations due to their important role in design engineering decisions. It has provided evidence of the intuitive and important human need for visual information to provide mental stimulation in particular for making *confident* design decisions. The storyboard research method has outlined an industrial data collection and decision coding framework that is reproducible and can be used to better understand human information processing, and thus supports the development of document information systems. Additional rich information utilisation patterns for design engineering document information have also been evidenced in the empirical research results provided. This thesis also provides practical industrial examples to suggest techniques that could overcome the current technological shortfalls limiting the "reuse" of visual information in documents for Design Engineers.

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Title: Visually Informed Support for Design Engineering Decisions

Table of Contents Outline

Table of Contents	
1	Introduction.....14
1.1	Engineering Design Issues14
1.1.1	Design Engineering Research.....16
1.2	Engineering Design In-Service Service Context and Challenges17
1.3	Data, Information and Knowledge.....18
1.3.1	Information Overload for Design Engineering Teams18
1.3.2	Current Data, Information and Knowledge Provision.....19
1.3.3	Nature of Design Engineering Information Resources.....19
1.3.4	Design Engineering Information Representation and Visual Information 20
1.4	Informed Decisions for Design Engineering21
1.5	Wider Research and Design Engineering21
1.6	Research Problem Summary22
1.6.1	Overview of Research objectives22
1.7	Thesis Structure23
2.	Literature Review25
2.1	Design Engineering Research27
2.1.1	Summary of Key Concerns for Design Engineers29
2.2	Knowledge for Design Engineering29
2.2.1	Data, Information and Knowledge for Design Engineering Research....32
2.2.2	Capturing Knowledge to Enable Transfer34
2.2.3	Knowledge Capture and Facilitating Knowledge Reuse36
2.2.4	Design Engineering Needs and Explicit Knowledge Reuse38
2.2.5	Summary of Knowledge Reuse Concerns for Design Engineering40
2.3	Characterising Design Engineering: Information Research40
2.3.1	Information in Design Engineering Research.....41
2.3.2	Engineering Information Research Design Methods and Studies43
2.3.3	Information Need and Design Engineering Dimension49
2.3.4	Design Engineering Information Research and Technological Progression 51
2.3.5	Design Engineering Documents, Information Formats & Visual Content 52
2.3.6	Wider Research for Design Engineering.....54
2.3.7	Human Visual Perception and Design Engineering Information54
2.3.8	Summary of Implications for Design Engineering Research.....55

2.4	Information Related Decisions in Design Engineering	56
2.4.1	Theoretical Studies in Complex Decision Making.....	57
2.4.2	Information Processing for Making Decisions	59
2.4.3	Information Processing and Relevance Decisions.....	60
2.4.4	Summary of Concerns for Informed Design Engineers	60
2.5	Research into Decision Making Theory	61
2.5.1	Naturalistic Decision Making	61
2.5.2	Recognition Primed Decision Making	62
2.6	Summary of Literature Contributions	64
3.	Research Approach and Methods	66
3.1	Domain Tensions and Research Paradigms.....	67
3.2	Mixed and Multi Method Approaches.....	68
3.2.1	Design Research Methodology	68
3.2.2	Cognitive Work Analysis.....	68
3.2.3	Classical Approaches	69
3.2.4	Discussion.....	69
3.2.5	Proposed Approaches	69
3.3	Practical Considerations for Industrial Research	70
3.4	Aim and Objectives of the Research	71
3.4.1	Research Objectives	72
3.5	Research Methods Design and Empirical Studies.....	73
3.5.1	Survey Approach	75
3.5.2	Participatory Approach.....	76
3.5.3	Alternative Approach	76
3.5.4	The Chosen Mixed Method Approach.....	77
3.6	Research Methods Summary	77
4.	Industrial Case Observations and Practical Influences	79
4.1	Industrial Research Context	79
4.2	International Knowledge Management Operations.....	79
4.2.1	Knowledge Management Strategy	79
4.2.2	Knowledge Management (KM) Services.....	80
4.2.3	Business Information Search and Retrieval Strategy (IS&R)	82
4.2.4	RISE & KCP, & Extra Services and Industrial Knowledge Reuse	83
4.2.5	Knowledge Management Summary	83
4.3	In-Service Operations	85
4.3.1	In-Service Activities and Workflow Management	85
4.3.2	In-Service Teams and Responsibilities	86
4.3.3	In-Service Repair Process and Workload Management	87

4.3.4	Historic Repair Case Information Management	89
4.3.5	Document Management	89
4.3.6	In-Service Knowledge and Information Intervention	91
4.3.7	Summary of Key Issues for In-Service Departments.....	93
4.4	In-Service Characterisation Studies	94
4.5	In-Service Information Resources and Task Audit	95
4.5.1	Purpose of Audit	95
4.5.2	Conducting the Audit	95
4.5.3	Results and Key Highlights of the Audit.....	96
4.5.4	Discussion of Audit and Summary of Findings	98
4.6	Case Study of Engineering Repair Design Documents.....	99
4.6.1	In-Service Historic Document Collection	99
4.6.2	Audited Sample Description	100
4.6.3	<i>Visual Information Media Features</i>	100
4.6.4	<i>Historic Case Document Collection Analysis</i>	101
4.6.5	<i>Individual Sub-Document Analysis</i>	104
4.6.6	Audit Reliability Considerations	106
4.6.7	Repair Case Content Audit Discussion and Summary of Findings	106
4.6.8	Repair Case Content Audit Summary of Findings	107
4.7	Document Information Technical Reuse Considerations	107
4.8	Summary of Industrial Challenges	108
4.8.1	Summary of Challenges for Operational Industrial Knowledge Reuse	112
5.	Design Engineering Information: Seeking, Understanding and Utilisation	114
5.1	Constructing the Questionnaire	115
5.2	Data Collection Strategy	117
5.3	Conducting the Questionnaire	117
5.3.1	Preliminary Questionnaire Directions	118
5.4	Results of the Questionnaire	118
5.5	Reflection of Findings and Reliability	130
5.6	Discussion and Key Outcomes	130
6.	Storyboarding Design Engineering Information Reuse	133
6.1	Decision Analysis Framework for Engineering Design.....	135
6.2	Storyboarding Information Relevance Decisions.....	135
6.3	Storyboarding Workshop Proposal	136
6.3.1	Storyboard Approach Theory	137
6.4	RPD for supporting Informed Design Engineering Decisions.....	138
6.5	Storyboard Capture, Decision Decomposition & RPD Encoding	140
6.6	Summary of the RPD Analysis Framework.....	142

6.6.1	Storyboard Experiment	143
6.6.2	Data collection and Experimental Set Up	144
6.7	Detailed Data Collection Strategy	146
6.8	Conducting the Workshops	147
6.8.1	Storyboarding Trial Using Document Information Elements	149
6.9	Results of the Workshops	150
6.9.1	Detailed Analysis.....	151
6.9.2	Initial Results	154
6.9.3	Results - Knowledge Resources.....	154
6.9.4	Results - Use Strategies.....	155
6.9.5	Results - Process Analysis	156
6.9.6	Results - Final Part of Workshop	163
6.9.7	Further Results and Considerations	165
6.10	Considerations for the Reliability of Findings.....	166
6.11	Discussion of Key Outcomes.....	167
7.	Evaluating Information Relevance Decision Making for Design Engineers	169
7.1	Constructing the Experiment for Evaluation of Hypothesis.....	170
7.1.1	Evaluation - Theoretical Basis	170
7.1.2	Evaluation - Experimental Approach	171
7.1.3	Evaluation - Experimental Operational Considerations	174
7.1.4	Evaluation Supporting Interviews.....	177
7.1.5	Evaluation - Industrial Constraints	177
7.2	Data Collection Strategy	178
7.3	Conducting the Research	179
7.4	Results of the Studies	180
7.4.1	Reduced Document Features Impact	181
7.4.2	Evaluation Survey	182
7.4.3	Descriptive Results Evaluation	182
7.5	Considerations of Reliability of Results	184
7.6	Discussion and Key Outcomes	185
8.	Information Requirements for Engineering Design Decisions	187
8.1	Review of Key Research Outcomes	187
8.1.1	Issues for Design Information Support.....	190
8.1.2	Overview	191
8.2	Establishing Value for Design Engineering Research	191
8.2.1	Summary.....	193
8.3	Mapping Key Outcomes to Knowledge Reuse.....	193
8.4	Industrial Implications and Potential Impact.....	194

8.4.1	Knowledge Reuse Intervention 1 in In-Service	196
8.4.2	Knowledge Reuse Intervention 2 in In-Service	197
8.5	Information Decision Making in Design Engineering	199
8.6	Reiterating the Wider Importance of Imagery.....	200
9.	Conclusions, Limitations and Further Work.....	202
9.1	Summary of Research Objective Contributions	202
9.1.1	Summary	203
9.2	Contributions to Knowledge	203
9.3	Thesis Reflections	204
9.4	Future Work for Design Engineering Research	205
9.4.1	Decision Utilisation Patterns and Visual Elements for Reuse Efficiency 205	
9.4.2	Visual Document Representations for Improved Transfer and Quality	206
9.5	Wider Research Opportunity	206
10.	Bibliography	208

Table of Figures Outline

Figure 1.1: Common Design Engineering Challenges	15
Figure 1.2: Thesis Chapters Overview	24
Figure 2.1: Publications by Keyword Topic (2015 inclusive).....	25
Figure 2.2: Typical Publication Type Distribution	26
Figure 2.3: Scoping the Literature	27
Figure 2.4: Knowledge Flows for Design Engineering	32
Figure 2.5: Explicit Knowledge Reuse Flows	39
Figure 2.6: Robinson (2010) Relative Information Seeking Behaviour.....	43
Figure 2.8: Themes in Decision Making Theory	58
Figure 2.9: Hicks et al. (2002) Knowledge, Information and Data	59
Figure 2.10: Diaz (2010): Simplified RPD.....	63
Figure 2.11: Yen et al. (2013) Patent Application RPD Process.....	63
Figure 3.2: Research Findings and Data Collection Development.....	74
Figure 3.3: Summary of Research Approach for Filling Literature Gap.....	78
Figure 4.1: The Wheel of Knowledge Management Services	81
Figure 4.3: Overview of In-Service UK Teams, Tasks and Workflow.	87
Figure 4.4: In-Service Operation and Workflow Management.....	88
Figure 4.5: Historic PDF case file growth 2005-2015.....	91
Figure 4.8: Desktop Resources Organisation for Novice Engineer	97
Figure 4.9: In-Service Engineers Personal Checklist	98
Figure 4.10 Example of visual audited information features.....	101
Figure 4.12: Historic Case Document Type Count.....	103
Figure 4.13: Summated Document Type Proportions.....	103
Figure 4.14: Total Number of Pages by Document Type.....	104
Figure 4.16: Sub-Document Media Composition.....	105
Figure 4.17: Correspondence Informative Composition.....	106
Figure 4.19: Summary of Industrial Knowledge Reuse Challenges.....	112
Figure 5.0: Expected Outcomes for the Knowledge Utilisation.....	114
Figure 5.1: Respondent Location.....	118
Figure 5.2: Respondent Work Pattern	118
Figure 5.3: In-Service Experience	119
Figure 5.4: Prior Experience	119
Figure 5.5: Expertise Distribution	120
Figure 5.6: Purpose of Documents	120
Figure 5.8: Information Practices.....	120
Figure 5.9: Accessibility Perception	120
Figure 5.10: Information Seeking Strategy Perception.....	121
Figure 5.11: PDF Access and Utilisation for Decision Making.....	121
Figure 5.12: Time Spent Searching	122
Figure 5.13: Time Spent Shortlisting.....	122
Figure 5.14: Text Terminology Indicating Case Relevance.....	123
Figure 5.15: Understanding Repairs	123
Figure 5.16: Time Viewing each Case	123
Figure 5.18: No of Times Viewed	124
Figure 5.19: Time Spent Viewing	124
Figure 5.20 Relevance Viewing Time	124
Figure 5.21 Understand Documents	124
Figure 5.22: Number of Views	125

Figure 5.23: Further Information	125
Figure 5.24: Additional Information Seeking Strategy.....	126
Figure 5.25: Strategies to Seek Document Content.....	126
Figure 5.26: Strategies to View Document Content	127
Figure 5.27: Important Content for Determining a Documents' Relevance.....	128
Figure 5.28: Important Content for Understanding Documents	129
Figure 5.29: Sub-Document Decomposition and Relative Importance	129
Figure 5.30: Most Informative Document Contents	130
Figure 5.31: Knowledge Reuse Survey Findings.....	131
Figure 6.1: Storyboard Research Need for Reuse of Documents.....	133
Figure 6.2: Decision points in Design Engineering Knowledge Reuse	136
Figure 6.4: Klein et al. (1993) Original RPD Process	138
Figure 6.4: Repair Design Process and RPD Stages	139
Figure 6.5: RPD Steps and Design Repair Process	140
Figure 6.6: Zachary et al. (2012) Rapid Cognitive Task Analysis Structure	141
Figure 6.7: Storyboard Work Based Simulation Process	143
Figure 6.8: Storyboard Suitable Case Task 1	144
Figure 6.9: Storyboard Understanding Task 2.....	145
Figure 6.11: Photograph of Example Physical Document Case	148
Figure 6.12: Photograph of Trial Storyboard.....	149
Figure 6.13: Photographs of Completed Storyboards from Group 1	151
Figure 6.14: An Example Story Encoding for Document Information Decision	152
Figure 6.15: Document Information Represented Relevance Decision	152
Figure 6.16: Comparative Information Decision Stories between Groups.....	153
Figure 6.17: Design Decision Decomposition	153
Figure 6.18: Knowledge Resources Utilised	154
Figure 6.19: Group Knowledge Resource Comparison.....	155
Figure 6.20: Historic Case Subdocument Utilisation.....	155
Figure 6.21: Document Information Viewing Strategy	156
Figure 6.22: RPD Decision Stage and Decision Story Chronology	157
Figure 6.23: RPD Mental Simulation Stage and Decision Proximity	158
Figure 6.24: Historic Case Subdocuments for Information Decisions.....	159
Figure 6.25: Proximity of Image Viewing and Mental Simulation for Decisions	160
Figure 6.26: Historic Case Subdocument and Information Type Preference	161
Figure 6.27: Subdocument Type and Requirement for Viewing Strategy	162
Figure 6.28: Viewing Strategy and Associated Information Type.....	163
Figure 6.30: Information Elements Supporting Story Steps	165
Figure 6.31: Key Audio Statements for the Value of Visual Elements	166
Figure 6.32: Alternative Analysis Representations.....	167
Figure 6.33: Relating Back to Knowledge Reuse	168
Figure 7.1: Evaluation of Knowledge Reuse Principles.....	169
Figure 7.2: Evaluation Work Based Simulation Scenario.....	171
Figure 7.3: Repair Design Process for Evaluation Scenario	171
Figure 7.5: Detailed Historic Case Document Information Differentiation	173
Figure 7.6: Photograph of the Historic Case Document Packs for Evaluation	174
Figure 7.9: Evaluation Experiment 1 Data Collection Outline	178
Figure 7.10: Evaluation Experiment 2 Data Collection Outline.....	179
Figure 7.12: Summated Recall Responses per Document Representation	181
Figure 7.14: Interactive Alternative Document Presentation	183
Figure 7.15: Static Alternative Document Presentation	184
Figure 7.16: Knowledge Reuse Informed Decision Evaluation Outcomes	186

Figure 8.1: Evolution of Primary and Secondary Research Findings	188
Figure 8.2: Primary Research Studies and Respective Outcomes.....	189
Figure 8.3: Secondary Research Studies and Respective Outcomes.....	189
Figure 8.4: Knowledge Reuse Map of Research Outcomes	194
Figure 8.5: Information Search and Retrieval Document Intervention.....	195
Figure 8.6: Document Information Retrieval Shortlist.....	196
Figure 8.7: Example Thumbnail Images from One Historic Case Document	197
Figure 8.8: PDF Thumbnail Document Information Patterns	197
Figure 8.9: Example Design Engineering Document Infographics	198

Table of Tables Outline

Table of Contents	4
Table A: Glossary of Industrial Terms.....	13
Table 2.7: Design Engineering Research Study Summary	46
Table 3.1: Objectives, Data Collection Methods and Thesis Outline.....	73
Table 4.2: Knowledge Management Service Purpose	81
Table 4.6: Information Supported Task and Information Source Format	96
Table 4.7: Classified Information Resources	97
Table 4.11: Illustration of Document Complexity and Differences in Cases	102
Table 4.15: Document Percentage Contents	105
Table 4.18: Summary of Industrial Concerns	111
Table 6.10: Design Experience and Participant Sample Replication.....	147
Table 6.29: Chronological Informative Elements for Document Understanding....	165
Table 7.4: Informative Document Element Content Variations for Evaluation.....	172
Table 7.7: Evaluation Document Rotation and Preparation	175
Table 7.13: Results of Evaluation Experiment Part 1	182
Table of Appendices	222

Glossary of Industrial Terms

ICARUS	Airbus In-Service oracle database tool for workflow management.
DAEDALUS	Airbus In-Service excel based information search and retrieval tool.
AIRDOCS	Airbus In-Service PDF Document management tool and summary sheet creation tool.
ISHARE	Intranet based media depositing file structure; for Airbus departmental access.
EASA	European Aviation Safety Agency, the European regulatory authority for the aviation industry.
RMT	Product Service System used within Airbus Customer Service teams in Toulouse

Table A: Glossary of Industrial Terms

1 Introduction

The management of information that is accumulating in a digital society is an increasing concern for organisational effectiveness (Easterby-Smith & Lyles 2003). Extreme market competition and the increasing amounts of information digital technologies accumulate is placing significant increasing pressure upon industry, in terms of time, cost and expertise (Carey et al. 2013).

Large scale and high cost product development projects, such as in design engineering, typically involve huge internationally based teams that are highly expert in multiple domains (Chris McMahon et al. 2004). Hence, managing multifaceted projects for costly products such as these is a significant task, in particular as the product lifecycles typically span many decades and thus also span technological and engineering paradigms (Carey et al. 2012). This thesis is focussed in particular upon the typical design engineering projects that involve large scale high cost products and is associated with Aerospace Design products and projects that are large in scale and highly technical.

Due to customer demand and extreme market competition these products are increasingly provided as product and service packages (Jagtap 2008), thus industrially increasing the need for specialist design teams that look after the design of product services such as repair. An example is the service and repair provision for in-service aircraft, aiming to increase the life span and productivity of large engineered products (Aerospace, automotive manufacture and packaging machinery industry). Throughout the product service lifecycle huge repositories of service data are amassed about products; this data contains important information that potentially enables organisations to improve product performance, service provision and thus optimise their process to retain a competitive edge.

Engineering Design processes involve the ideation, creation, manufacture and maintenance of products at the forefront of scientific and technical engineering developments, creating large and complex product information resources. Engineering Design process is thus an increasingly multifaceted domain requiring a multiplicity of expertise. Design Engineering features highly visual elements and Design Engineers are anecdotally typified as highly visually astute people. The information resources generated and utilised in Engineering Design reflect this visual nature and contain highly visual content such as drawings, diagrams, sketches, photographs and graphs. Supporting Design Engineers to better utilise visual information resources to more efficiently make informed decisions is at the centre of the research in this thesis.

This introduction first considers the core design issues and the role of information and knowledge in supporting design. There are a large number of current challenges for design engineering teams and thus only an overview is given in Figure 1.1. The most important issues for this thesis is significant impact of the knowledge and information challenges for design engineering teams, this is outlined in this chapter to provide the focus for this thesis. One of the key things that the knowledge and information of design engineers is used for is to make decisions (Eppinger & Ulrich 1995). The knowledge and information they utilise supports them to think through choices and strategies, so the nature of decision making and an introduction to some work on information processing concerns from other disciplines are introduced. This introduction is to set the scene and establish the basis for the next section on the research focus on the visual elements associated with engineering design information. The final section introduces the structure of the thesis and of the structure of the research approach adopted.

1.1 Engineering Design Issues

There are some high profile and common themes emerging from design engineering literature describing the core challenges that face design engineering teams. These

three core challenges relate back to a focus upon innovation in design, improving communication and knowledge and information research. These common themes are illustrated below in Figure 1.1 related to the originating design engineering issues. Many of these challenges are interrelated issues and thus they have been categorised in this illustration to demonstrate their interrelated nature.

There are many influential factors for but those listed below are from Figure 1.1 and illustrate a number of the key factors impacting on modern design engineering projects. Citations are given as examples from the literature that has either identified them or sought to address the issues:-

- Internationally based teams (McMahon et al. 2004) (1)
- Cross-disciplinary team working (Carey et al. 2012) (2)
- Rapid product development timescales (Lynn et al. 2003) (3)
- Legacy System integration (Xie, et al. 2011)(4)
- Attrition of Expertise (Ahmed-Kristensen & Vianello 2015)(5)
- Expert knowledge accumulation and management (Wallace & Ahmed 2003) (6)
- Rapid technological evolution (Gopsill et al. 2011) (7)
- Lengthy product lifecycles (Carey et al. 2013) (8)
- Typically large scale, high value and complex product projects (McMahon et al. 2004) (9)
- Extreme market competitive conditions (Jagtap & Johnson 2011) (10)
- Inaccurate or changeable design requirements (Bennett et al. 2010) (11)
- Specialist support requirements for Information and Data rich processes (Harvey & Holdsworth 2005) (12)
- Amassment of large and complex Information and Data collections (Xie 2013) (13)

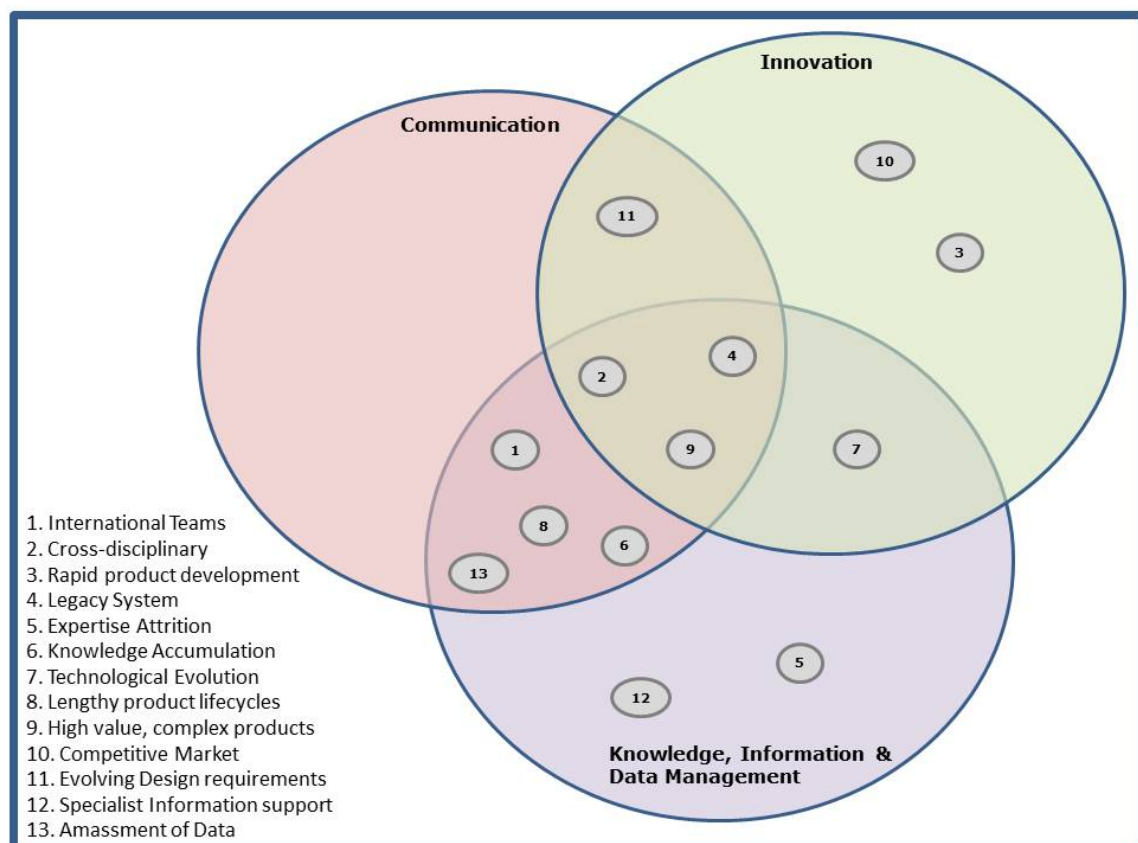


Figure 1.1: Common Design Engineering Challenges

It is not possible to focus upon all of these challenges however; they are outlined as an overview. All of the issues illustrated contribute in some measure to increasing pressure upon the working practices of design engineering teams and a majority of these issues relate to the knowledge, information and data management needs of design engineering teams. Given the scale and complexity of the products being developed and serviced this is not surprising and thus the focus of this thesis is upon the knowledge, information and data challenges that face engineering design teams.

Hence, the pressing knowledge and information needs of design engineering teams are described in the next section and this forms the focus of this thesis upon the pressing information challenges facing design engineering teams.

The research in this thesis has a strong design focus. However the research participants use a variety of descriptors, as does the extended literature. The work is applicable to all large engineering teams that have to use large data collections or artefacts for their work.

1.1.1 Design Engineering Research

Much research and technological support effort has been focussed on improving the overall design engineering process and developing individual applications for managing information throughout a products lifecycle. This could be in terms of process improvements for manufacturing, inspiration of innovative product designs, information and knowledge management services and tools. A more detailed appraisal of the relevant technical support efforts for design engineering projects are contained in the literature and industrial review chapters 2 and 4.

What the summary in Figure 1.1 reinforces is that information, knowledge and experience are critical to the success of design engineering projects from design inception to product service stages of the lifecycle. Thus experience, information documentation and effective communication clearly influence the outcome of a project. However, difficulties in using project information resources for example those inherited from legacy information systems present challenges for project integration and utilisation (Xie et al. 2011). Hence capitalising upon information resources remains critical but is increasingly difficult. It is the capitalisation of these resources that are key to the success of organisations and thus projects (Easterby-Smith & Lyles 2003). This is highly relevant to engineering teams working on products that have lengthy lifecycles (Carey et al. 2012). Advancements in technologies such as web 2.0 technologies have attempted to provide data integration platforms for large data collections, however, this is not always appropriate for the large scale industrial design projects legacy data is prolific (Liu et al. 2008).

Communication is seen as one key component in engineering design teams (Figure 1.1) and as a contributor to the success of large and complex design engineering projects that by nature host internationally based, multidisciplinary expert teams (Hicks et al. 2008). In the initial ideation and creation stages of a project the communication of ideas and potential issues is critical to fostering rapid and innovative developments (Lynn et al. 2003). In later project stages such as manufacture and maintenance the collection, feed forward and availability of performance data facilitate the design of effective modifications or design of maintenance and repairs (Jagtap & Johnson 2011). It would not be possible progress and improve future product design or maintain product performance what has been learned (including personal tacit or experiential knowledge (Wallace & Ahmed 2003)) is not reused and thus the importance of information utilisation is recognised in design research studies (Harvey & Holdsworth 2005; McMahan et al. 2004).

Due to the disparity of the teams, information media often facilitates communication between expert teams and stages in the design process (Henderson 1991), thus engineering design documentation is a critical aspect of the design process. The international nature of teams typically involves sharing by email, teleconference meetings and communication via documented assets that can be shared electronically (Hicks et al. 2008). Large engineered products and design process typically creates and utilises huge amounts of data and information, meaning the document repositories quickly amass (Carey et al. 2012). These information resources typically form the historic record of the project design and are retained to capture the expertise of a design project. Engineering teams that are internationally based frequently deal with disparate information sources and large complex data sets and their disparity forces them to become more reliant upon documented information resources. Hence this work focuses upon the efficiency of the reuse of these informative documents and understanding their critical knowledge content that is important for improving design engineering information process.

Due to the lengthy product lifecycles of these information assets they often span technical paradigms for both engineering and information management tools which exacerbates the challenges raised for communicating effectively (Xie, 2013). The issue thus becomes about accessing and communicating the right information at the right time to support a current design task. Exacerbating these challenges in information communication is the differing levels of expertise and variety of skills or competence that influences the effective understanding of knowledge and information amongst teams (Wallace & Ahmed 2003), as it is important to convey complex process and ideas in formats that are understood by both technical experts and non-technical members of the same project teams (Carlile 2004). Expert workers are noted to have difficulty communicating their expertise as much of it remains tacit in nature (Nonaka 1994); this increases the difficulty in conveying complex ideas and process, hence the importance of shared visual representations (Henderson 1991). However, important as it is to overcome these challenges and as intuitive as it may seem, much of the research into design engineer information and knowledge needs have overlooked the role and importance of the visual information content.

The key influential issues being addressed by this work are synthesised and discussed further in chapter 2, Section 2.2 & 2.3 where the literature basis is addressed in more detail. Some of the issues described above are not solely applicable to the engineering domain and thus solutions and literature from other domains can potentially also be of benefit. Thus associated literature relating to project management and systems are also discussed in chapter 2, Section 2.1 & 2.4 to highlight where research findings from other domains may be useful to design engineering.

1.2 Engineering Design In-Service Service Context and Challenges

The industrial context for this research is the in-service engineering team of a large aerospace company that is outlined further in Chapter 4. There are a number of additional challenges that face in-service design engineering teams that exacerbate the current design engineering challenges, in particular for knowledge and information management.

It is predicted that the number of aircraft products in-service are set to increase significantly, hence pressure upon service and repair design teams will continue to rise. Current market predictions estimate that 19,890 aircraft were in service in 2011 and this number is predicted 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 ever increasing knowledge and information burden being carried by the latter stage engineering design teams (Carey et al. 2013). This is in terms of their

requirements for diversity of experience and knowledge, a clear understanding of company procedures, technical information and continuing in-field capabilities. There are thus additional requirements placed upon the in-service teams themselves to capture and transfer their expertise using explicit knowledge resources to retain and reuse their tacit knowledge dimension (Wallace & Ahmed 2003). It is clear that innovative approaches for knowledge management are required to continue to support this activity (Xie 2013). This highlights the particular significance of understanding and using the information collections and data sources available to in-service teams more efficiently to enable their effective representation and efficient reuse. Hence understanding the character and role of the information resources used by in-service teams is important to this research.

1.3 Data, Information and Knowledge

The challenges raised by the need for data, information and latter knowledge are one of the critical challenge categories highlighted in Figure 1.1. The amount of information being created in general and from project activity is set to continue (Jagtap & Johnson 2011), thus optimisation of its reuse is critical and numerous tools, technologies and methods have sought to improve information searching and browsing (Xie 2013). Technological methods have further sought to resolve information flow and quality issues by improving search methods utilising user contextual cues to push relevant information to design engineers (Duncan 2007). These methods and their relevance are discussed further in chapter 2.

However, the respective value of data available is not directly proportional to the benefits of its reuse or the efforts required to sift through it. Thus large amounts of information have to be appraised to decide upon the most relevant. The cost of these efforts to industry is of equal concern and perhaps the burden even more so as new products and projects compete for efficiency and an optimal place within the market place (Lynn et al. 2003).

1.3.1 Information Overload for Design Engineering Teams

It has been evident for some time that the reuse of knowledge and information can be harnessed to improve company output in terms of product innovation, process and product improvement, cost reductions and thus the overall productivity of design teams (Easterby-Smith & Lyles 2003). This also applies to engineers and the service design teams that work with predefined products and work within a much more constrained design remit, working with materials, tools and methods that are the output of the initial design and production phases. Interestingly the impact of these predefinitions (restrictions) for large products such as aircraft, where product lifecycles span multiple decades, is even more problematic. However, customer expectation remains the same; expecting low initial costs and repair costs to be minimal throughout the product lifespan. It is now accepted (Ahmed-Kristensen & Vianello 2015) that this is only achievable to improve engineering design with the reuse of historic product learnings to influence current maintenance practice and thus the focus of this project. These large and complex products result in unwieldy collections of historic data that accumulates over decades of product in service (Carey et al. 2012). Design Engineers are thus overloaded with significant data and information that is imperative to be re-utilised to improve current design engineering practice

The overload issue has been hypothesised to be relevant to industrial design engineering projects, where practice involves information rich process and the accumulation of product data. This issue is exacerbated by the need to utilise historic information to improve the design of industrial products and services (Jagtap & Johnson 2011). Thus, understanding design engineer information processing and creation of process improvements are highly relevant to this thesis.

1.3.2 Current Data, Information and Knowledge Provision

Knowledge is accepted to enhance design engineering activity and thus is an important prerequisite for the design process. Knowledge combines human understanding with underpinning information and data, thus is different to raw information and data that is stored in design artefacts. Defining, capturing, storing and thus supporting the transfer of this "understanding" is difficult and is recognised to be significantly hard for individuals to express, especially as experience increases (Wallace & Ahmed 2003). It is this knowledge that is recognised to enhance and optimise decisions for complex and information rich design process, thus the management of this knowledge is recognised to be important (Hicks et al. 2002).

The lengthy lifecycles of complex products increase the size of the information collections and the extent of experiential knowledge due to the number of years over which they amass (McMahon et al. 2004). This in turn makes the data and information management for design engineers more challenging with large and unwieldy collections of data available for reuse. Information flow, transfer and utilisation practice has sought to be improved using automated technologies and communication methods to simplify information retrieval (Xie 2013). Some of these methods are becoming embodied in software applications for supporting design engineers. Research has developed communication techniques and supporting applications created specifically to address the knowledge needs for expert teams such as design engineers (Gopsill et al. 2012). In recognition of its importance, industrially working teams exist that are dedicated to the function of supporting wider knowledge management deployment.

Some of the automated techniques include provision of tools to optimise information search, the automatic addition of context to data search methods, workflow management tools and product service systems that aim to exploit historic product information and further utilise it to improve information reuse (Xie et al. 2011). Methods to interact and facilitate with experts aim to capture and document tacit engineering knowledge in an attempt to capture and re-use best practice (Wallace & Ahmed 2003). Each of these techniques has in its own way provided some solution to specific knowledge availability problems for engineering design; however, they remain isolated solutions with variable uptake due to their efficiency and limited scope (Carey et al. 2012). This is also exacerbated by the rapidly changing technological environment, where new technology and techniques are continually deployed to retain competitive advantage.

The theoretical basis for knowledge management and its research application to design engineering is discussed in chapter 2 and examples of industrial embodiment of the theory are described in chapter 4 of this thesis. The effectiveness of the current provision is not currently keeping up with the growth of the data, requirements for knowledge reuse and transfer (communication) of expertise challenges for engineering design. The effects of this upon Engineers are apparent in industry, making this a highly relevant issue for this thesis to address. However, the technologies discussed and literature discussed above does not address the specific format or nature of design engineering information resources. this thus remains an important and under-addressed issue.

1.3.3 Nature of Design Engineering Information Resources

Information format and flow in engineering is diverse, due to the complex and multifaceted nature of the projects. They thus require heterogeneous information media, data and methods. Supporting such processes is a dynamic requirement for information in image or textual forms that can be unstructured and multi format such as engineering log book notations, participant signatories or formal CAD drawings (McAlpine et al. 2006; Carey et al. 2013). The multifarious nature of design increases the information challenges associated with providing the right information at the right time for the right process.

It is important to understand the informative contents and purpose for engineering design information assets to be able to understand how it can be effectively utilised to support faster production of better design solutions. There are studies that have in some measure attempted to list the information requirements of Design Engineers from both technological and knowledge perspectives.

The actual information media being utilised remains to be audited in full as is not specified in detail. This is due in part to tacit experiential knowledge that remains undescribed and is inherently difficult to capture, and also to the diverse number of information media and data formats that are cited as relevant to the engineering design process. To be able to accurately list the requirements of Design Engineers effectively, their information utilisation must be deconstructed to isolate and assess its respective value scientifically within the design process (Bennett et al. 2010). This approach to empirically test the prevalence and respective value of information and data within engineering design processes is important for providing evidence to support system developments to support future projects.

In chapter 4, results are demonstrated to suggest typical information media contents that are utilised by a Design Engineer. This is the result of empirical investigation that is conducted as part of a feasibility study for further work conducted in later chapters.

1.3.4 Design Engineering Information Representation and Visual Information

Visual media is commonly utilised within both design and engineering to communicate complex ideas and processes. It is suggested that images are utilised as informative boundary mediums between design engineering experts (Henderson 1991). It is an inbuilt human perceptual ability to understand pictorial representations in more depth than their textual counterparts (Cavanagh 2011) and thus it is recognised that data in this form supports understanding, in particular for complex information. It is often noted that human sight bandwidth is higher than our other senses, making it the medium of choice for representing ideas and supporting understanding.

'Visual representations' is a collective term for methods for presenting large collections of data in visual forms to make their latent meaning easier to view and to support human users in utilisation of large data. The purpose of a visualisation is to represent the data and the connections making patterns and correlations easier to perceive. It is particularly useful for spatial data such as geographical mapping and much research into methods for visualisation of data has been conducted in multiple domains. However measuring the effectiveness of visual methods remains challenging, and there is little evidence of research dedicated to understanding how users utilise visualisations. Thus the uptake and success of such solutions is questionable as users still utilise traditional methods of interacting with information. It is also possible that industrial implementation of such solutions is not financially or practically viable, thereby limiting their usefulness for design engineers.

Engineering information media is heterogeneous in nature; this includes data in visual and textual forms or electronic and physical forms. It is equally important to test scientifically the value of information representations to suggest an optimal efficacy for human understanding ability. It is this human quality to understand visual data that has driven the research into visual methods for data mining, analysis, information presentation and usability design. This is noted in research and development such as visualisation techniques (Andrienko et al. 2007), visual methods for data presentation (Spence 2002) and usability techniques (Shneiderman 1996). Broadly it is assumed that optimal data formats are visually presented due to the human capability of sight and visual mining. This thesis empirically tests the value of imagery for design engineers.

1.4 Informed Decisions for Design Engineering

It may seem strange to introduce the topic of decision making as the focus for engineering design, but "to design is to make decisions" (Eppinger & Ulrich 1995) and the discussion above about knowledge and information is all about providing sufficient of either to proceed to the next stage of the design engineering process. Making optimal engineering design decisions are a critical part in engineering design processes. The processes combine engineering technologies with creative design methods to produce products that are fit for purpose. Underpinning those design decisions are the Knowledge, Information and Data that support them. The abundance of engineering design data demonstrated above significantly adds to the pressures upon design teams in making optimal decisions.

When utilising information Design Engineers typically access numerous information sources of varying formats. The format of this information ranges still from the original paper based formats or microfiche historic documentation, up to technologically supported CAD design solutions and SQL database engines to support information storage and provision. It is sifting through this data and information that takes time and effort, but is important to support design thinking, thus making the decision which information is most relevant to the task in hand. The focus of this thesis is upon characterising the mechanisms and information that underpin these informed decisions. This is to enable a clear specification of the relevance of information processing that is conducted by engineers in the advent of an information era and for best practice for information provision to emerge.

A products lifecycle is lengthy and informed design engineering decisions occur throughout the entirety of a lifecycle. In the early stages, the challenges differ to those in later stages of the lifecycle. During developmental phases designers may be constrained by the materials and technologies available to them and in later stages the physical design constraints, considerations and pressure may become more pressing, thus increasing the demands of time and cost to engineering design projects. These increased pressures are absorbed by the design engineers as they make more complex and pressured design decisions. Decision making theory becomes more relevant in those constrained decision scenarios and much research in this area has potential relevance.

In particular, decision making theory from the area of naturalistic decision making bears resemblance to the scenarios in which design engineers in the later product stages find themselves. Thus it is an important part of this thesis to understand how designers think when making decisions, to understand the steps that need to be taken to support them in this role, and the relevance of theory from decision making domains. The research and evidence for the applicability of naturalistic decision making frameworks to engineering design decisions is discussed further in Chapter 2. This is further built upon in Chapter 6, where decision making frameworks are used as a framework by which to analyse the results of empirical investigation.

1.5 Wider Research and Design Engineering

There are a number of other areas that impact on the engineering design process, for example Human cognitive processing studies have long since been the subject of psychological theoreticians and are widely reported, but not associated with design.

Design Engineers bring together technical skill and human creativity using predefined, but loose methods and evolving process. The design domain is at the forefront of human advancements, is cross discipline and requires a plethora of skills and information sources. The nature of design is thus multifaceted, as is the information and data required to support the complex design thought processes. For this reason it is not uncommon for designers to have a large number of years' experience in the field, thus accumulating a large repository of tacit knowledge.

Capturing this knowledge and understanding the complex human thought process has long been a subject for research, which has only been filled in small measure. Seeking to understand how design engineers think, understand information and conduct design process is critical to be able to support them effectively.

Strikingly, there is little research found to address the issue of cognitive studies for Design Engineer information interaction, especially with the vast amounts of technologies with which they are required to interact. However, this is not as surprising as first found as engineering design studies would have to be conducted internationally and with industrial subjects, whose time and intellectual property could prove costly to the industry itself. However, these studies could serve to fill a large research gap, with studies that could provide insight into how engineers think and what their information requirements to support their processes are.

1.6 Research Problem Summary

There are a number of trends that have emerged from the summary review of the state of the art, dealt with in the previous sections. These are the issues that are particularly associated with overload and decision making (section 1.3). The critical point seems to be the provision or availability of appropriate and relevant information. The use of the word is quite deliberate, as in the very visual world of engineering and design it is apparent that understanding how and by what means visual elements can be made available as part of browsing or search activities is an under researched but potential valuable piece of research. Thus, the aim of the research is to understand the role of visual document content for making informed engineering design decisions.

The context of this research is related to the needs of the industrial In-Service Design Engineer at Airbus UK where the pressure to perform has been seen to be increasing in line with the aircraft in-service. Adding to these pressures is natural engineering experience attrition (due to retirement and job progression) that proves to be detrimental to the wider design engineering team knowledge base. This is a common issue with design and manufacturing teams and a wide variety of product support teams.

This research will bring together literature, developments and empirical techniques from computer science, engineering, design, naturalistic decision making, investigative cognitive methods and concepts. However, in context, one of the key research dimensions has been to produce supporting evidence to further intuitive knowledge about the role of visual information in supporting engineers (in this case in-service design engineers), particularly by working closely with the users themselves.

1.6.1 Overview of Research objectives

The overall guiding aim is to investigate and thus understand the role of visual information in documents to support Design Engineers to make information based decisions.

To be able to understand the role of design engineering information for its reuse it is necessary to identify what is currently making it difficult for design engineers to utilise it and what is the valuable content that enables its reuse. There are six objectives that arise contributing to improving document information reuse for design engineering. These are further explained and detailed in Chapter 3.1. The six objectives that guide the research conducted in this thesis are to:

- i) Identify current theoretical and industrial challenges for design engineering information reuse.
- ii) Define an industrial case study that includes a typical large heterogeneous collection of data and information resource for design engineering.
- iii) Characterise the current difficulties facing design engineering practitioners in the case study.

- iv) Identify key document content (information elements) and, in particular, the role of visual representations in design engineering decisions.
- v) Describe information strategies, patterns of use and thinking processes used by design engineers in the case study.
- vi) Recommend and evaluate approaches for improving practice.

As stated, the overall aim of this thesis is to understand the role of visual information in supporting informed design engineering decisions. It is this understanding of the role of such informative (visual) document content to easier discriminate the relevance of such information resources that supports the development of document representations to better portray their informative contents and thus ease design engineering information reuse.

If design engineers better present their information resources, the task of information processing should become less onerous hence reducing cognitive overload (Busby 1999) and become much faster. Thus the need for accessible and easy to use information can be much improved (Fidel & Green 2004; Carlile 2004). This expedites the reuse of captured design engineering knowledge from explicit forms and facilitates faster reuse and synthesis of new knowledge.

This thesis also includes understanding some of what can be thought of as the “thinking and processing” or cognitive processes that Design Engineers undertake using information media and then to suggest an information and format framework to support complex design engineering decisions in particular when reusing data and information assets.

One of the main visions for the future of this research is the provision of better engineering information systems to support the processing required of Design Engineers, thus expediting crucial design and information decision making. In particular this is the nature and form of engineering design data and the sub-processes that are information rich in requirements. It seeks to begin to describe some of the process, cognitive, operational, system, etc. that underpin engineering design information flow, and map them to information format support requirements for design engineers. In the future this should provide a solid grounding for provision of better knowledge supported decision systems.

1.7 Thesis Structure

The introduction to this thesis has provided an overview of the research subject, the research gap and the aims and objectives to be met by the work that has been conducted. The decomposition of the work is illustrated visually in Figure 1.2 highlighting the structure of the chapters in this thesis and how they relate. Figure 1.2 shows that the literature review follows this introduction in Chapter 2. Here, the guiding relevant theory and literature has been reviewed to support elicitation of the gaps in the research and related topics to provide a focus for the work in this thesis. This is then followed in chapter 3 with further discussion of appropriate research methods for achieving the aim and objectives reiterated in Chapter 3. This chapter provides a mapping of the methods utilised for the empirical research studies in this thesis to the research objectives thus providing clarity in describing the study methods and illustrating any overlap in the methodologies followed and the rationale for so doing.

Figure 1.2 illustrates that the findings from Chapter 4 contributes to the overall decisions for the research method for this research and outline the practical aspects and feasibility for any solution provision. This chapter addresses the practical reasoning for some of the project technical (further detail available in Appendix 6) and industrial (Chapter 4) limitations and scope. In Chapter 2 and Chapter 6 the relevant literature for understanding the construction and analysis of the overarching research method is brought together to explain the framework for conducting the overall industrial research studies. Chapters 5, 6 and 7 describe the

empirical studies as they were conducted and their respective contributions to the overall aims, and the triangulation of their findings. Chapter 8 then brings the collective findings of the literature throughout this thesis and discusses them in relation to the data collected and results presented in the preceding chapters.

The meaning of the results and outcomes for this thesis are discussed in Chapter 8 and finally in conclusion (Chapter 9) reviews the contributions of this thesis to the original objectives from Chapter 3. Chapter 9 also details the main knowledge contributions of this research, and discusses the potential for future work.

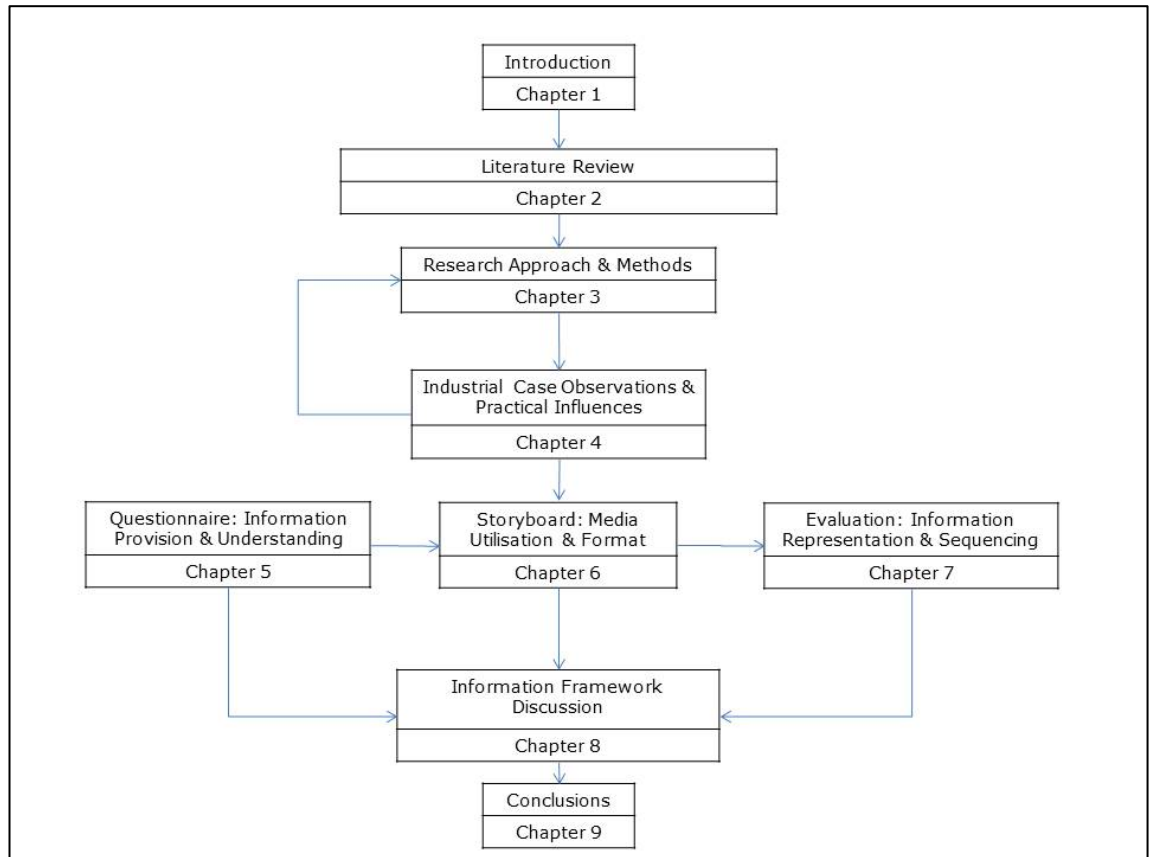


Figure 1.2: Thesis Chapters Overview

2. Literature Review

The literature discussed in this section establishes the current issues facing engineering design with regard to concerns about information and its utilisation.

Once the focus of this research has been established, the latter part of this chapter discusses the potential research from other domains that is applicable. This discussion is to synthesise the additional theoretical principles and research that need to be understood to underpin the development of any possible solutions derived from this work.

However, before considering the content of the literature it is necessary to highlight the size and scale of the potentially relevant literature. When conducting searches related to the keyword "information" a search in the University of Bath library retrieves 13,592,681 results (see Figure 2.1)! The chart shows the literature results for a number of related keywords. It would not be possible to precisely review of literature on this scale hence a strategy to enable appropriate focus for the review is first outlined. This enables the scope of literature sources to be defined from the outset and an insight into any important historic research trends to become evident. Therefore, initial keyword searches and resulting publication numbers have been collated utilising the wider databases, documents and further resources linked to the University of Bath's library and the consequence of any searches analysed and retained to infer or interpret any recent trends. This is followed by a more comprehensive content review of design engineering journals and abstracts from recent design engineering focussed conferences.

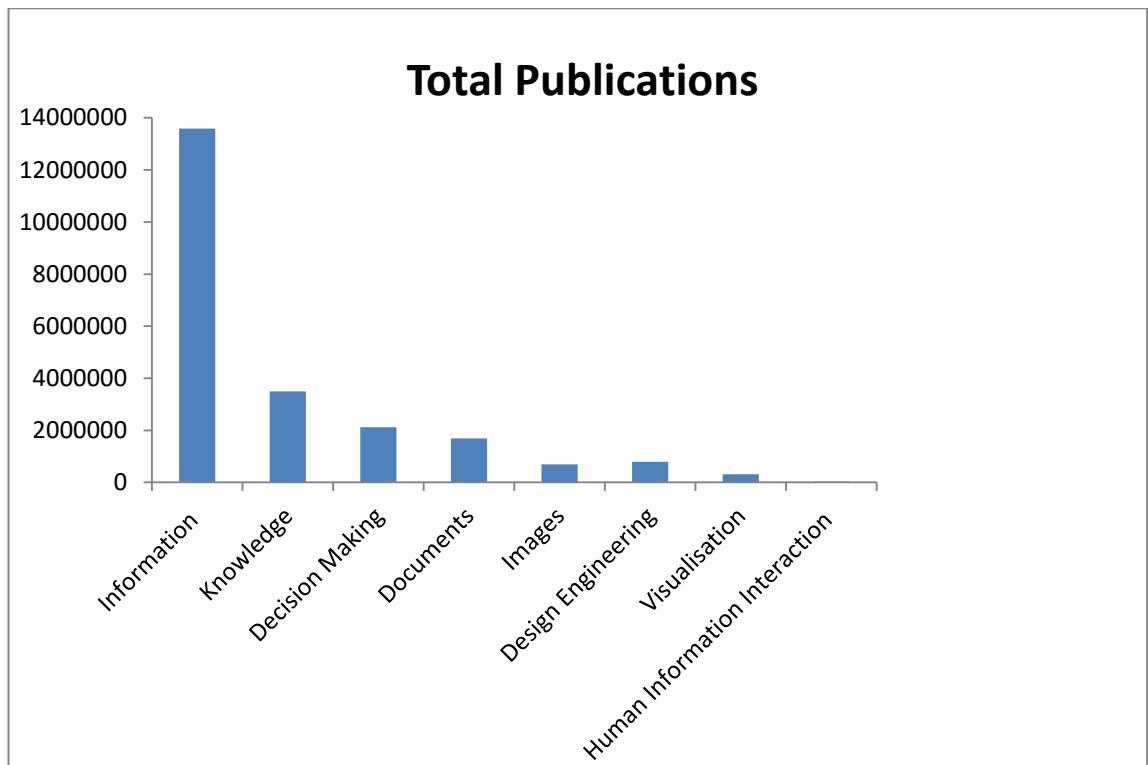


Figure 2.1: Publications by Keyword Topic (2015 inclusive)

In Figure 2.1 the respective time of first publication for each research area is evident, the first research evident was into "information" and this theme continues up until 2015. This is not surprising since a majority of areas can be related back to the information basis upon which they reside. This apparent research interest rapidly diverges into more specific areas of "knowledge", "decision making", "documents" and "images". Interestingly all of these topics can be related back to

be containers of or derivatives of “information”, such as the information stored within “images or “documents”, or the information that results in “decision making”. It is relatively surprising that the advent of “human information interaction” research does not appear until a much later date, this could be the result of a new approach being taken to understand information or simply a coining of new expression. For this reason drawing inference from this type of analysis must be exercised with caution.

It is also possible from such summaries of key terms to derive the types of research being undertaken in such areas. For example in the Figure 2.2 below it is evident that little research in decision making is from detailed thesis based work and although human information interaction is a recent area of research there are already a considerable number of books and conference papers published upon this topic, highlighting its current focus within science. The higher proportion also of newspaper articles in this area also raises the question whether this is currently a research area of high public concern or relevance.

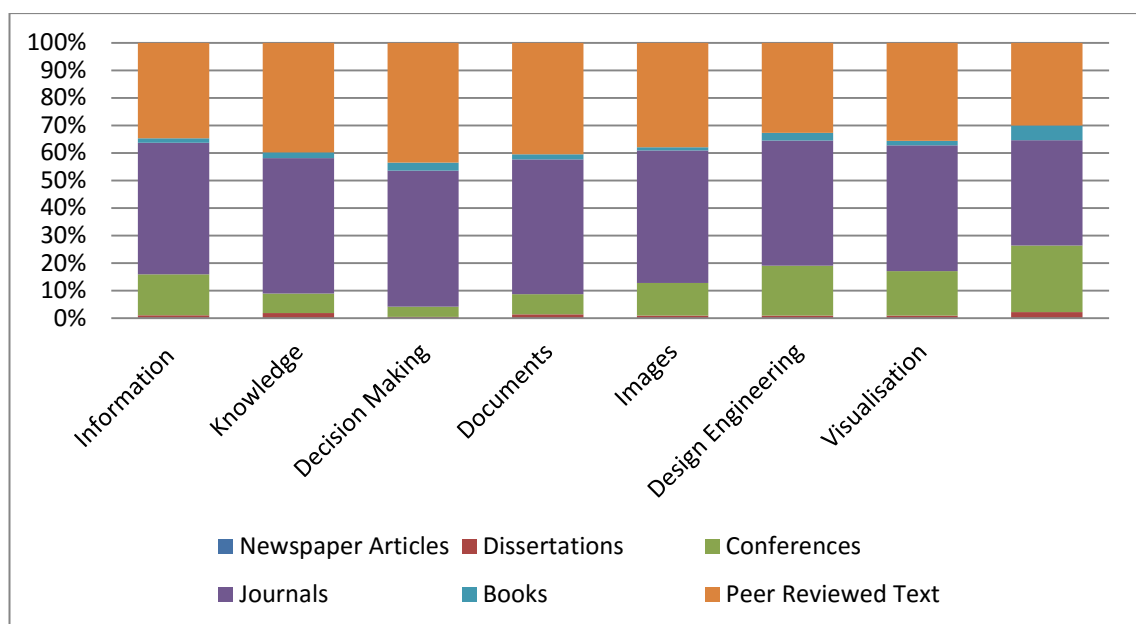


Figure 2.2: Typical Publication Type Distribution

This research involves extensive areas and thus Figure 2.3 has been generated to give structure to the review and should be referred to for overview and guidance throughout. The pink elements illustrated are the areas that are included in this literature review and considered of importance to the focus of this thesis. The green elements highlight where topics have included state of the art reviews (see Appendix 6) of further literature, tools and technologies to support this research and include the industrial case study in Chapter 4 of this thesis. The items shown in white highlight the areas that although related to information and knowledge topics are not dealt with by the work in this thesis as they are considered outside of the scope of this work. The five descriptors on the left hand side of the illustration represent the classification and navigation through the topics. An explanation of the justification for excluding any such research topic is provided throughout the latter subsections.

As illustrated in Figure 2.3 below, this literature review follows the topics outlined in chronological order. The earlier subsections of this literature review discuss engineering design research and the factors that influence the current research trends; this includes areas that are closely related, such as the management of knowledge. This is then progressed to address concerns that are more specific to the character of design engineering information and knowledge challenges.

The early elements of the literature and important publication resources are reviewed systematically to ensure a comprehensive perspective of the concerns has been generated. The latter sections of this chapter explore the focus of wider literature categories to illustrate their applicability to design engineering information support solutions. A sampling approach has been taken to the discussion of wider literature as the scope of the review was really to identify potential areas of research that could be applied.

The chapter is then concluded with a summary of the key challenges that drive the focus of this research and highlight the wider literature concepts that are considered appropriate to utilise to investigate the design engineering support requirements and to develop suitable solutions.

Further literature related specifically to individual objectives for this thesis are raised in subsequent chapters and appendices that specifically address certain challenges, for example media extraction tools and technologies are discussed in Appendix 6 and literature relating to the decision making theory are included in Chapter 6, where the analysis framework for the studies is discussed.

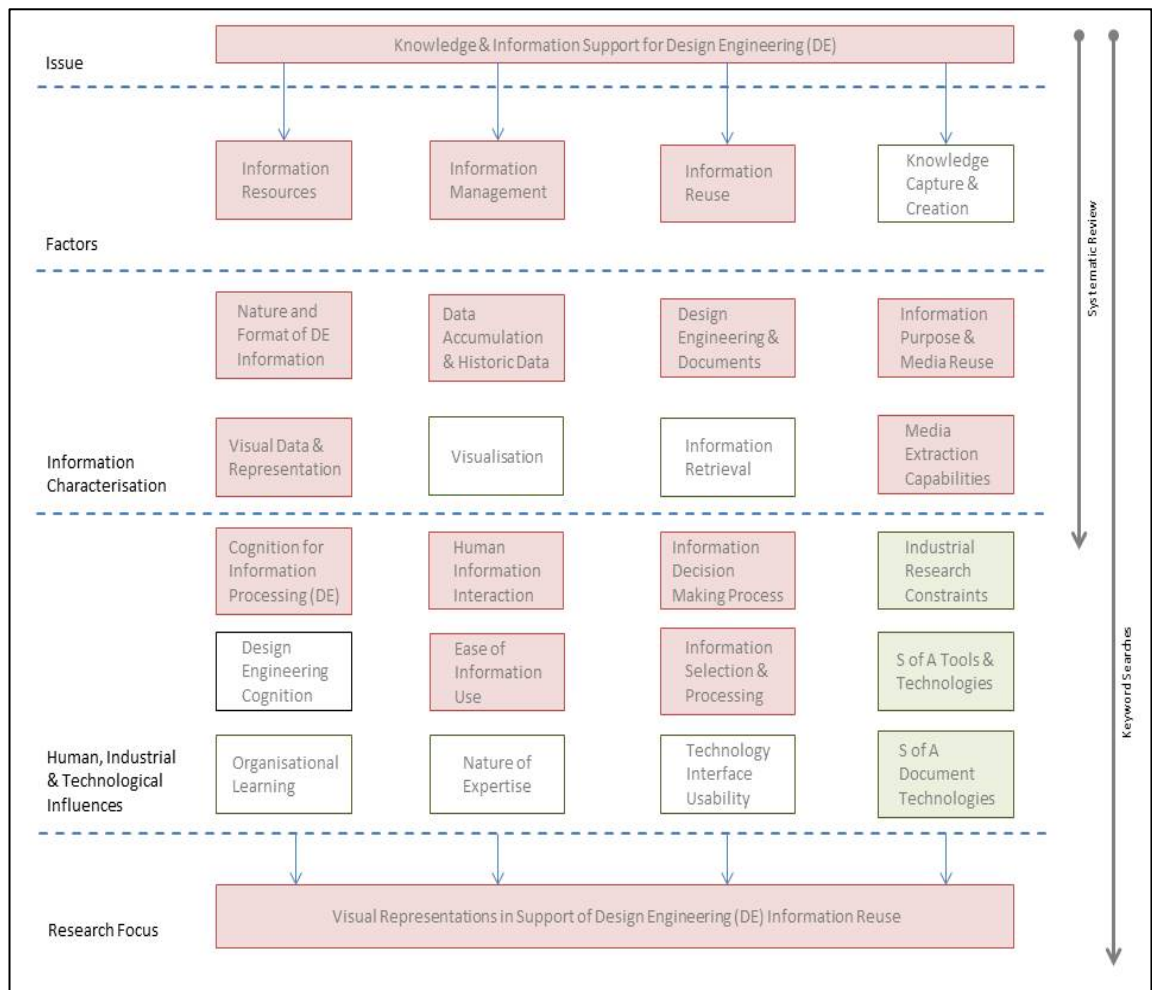


Figure 2.3: Scoping the Literature

2.1 Design Engineering Research

(Liu & Boyle 2009), suggest that the key challenges going forward for engineering design are increasing profitability and market share by being competitive. This industrial need has driven support to develop knowledge and information provision for product development and facilitating communication across projects and teams

throughout the product lifecycle and beyond. It is not possible to focus on all of the issues identified for design engineering teams and thus the focus of this research is upon those concerns affecting the information requirement of the design engineering processes. The industrial focus of this thesis is upon in-service teams in the aerospace sector, although the principles will be applicable to similar design engineering activities where there are common knowledge and information management issues, and reliance upon historic documented information.

The need for Design Engineers to re-use past or historic design information has long been established (Duffy et al. 1995). Vijaykumar & Chakrabarti (2008) reiterate that "70-90% of design work could be facilitated by reusing and reconfiguring existing components, solutions and knowledge." They further state that the industrial uptake of methods for re-use is minimal and thus this remains a critical research issue. The need to reuse knowledge is also identified by Hicks et al. (2002) to be a critical factor for design engineering and is highly dependent upon the rigorous capture of knowledge and process. However, it is noted by both Markus (2001) and Hicks et al. (2002) that this need to capture information and knowledge is also driving the difficulties faced by workers when trying to effectively reuse information and knowledge. This difficulty for information and knowledge reuse is specifically characterised by Markus (2001) to be as a result of the capture of information and knowledge not only in copious amounts, but also without specific purpose, or consideration of the intended re-use purpose.

The later stages of the product lifecycle are cited by Jagtap & Johnson (2011) and Vianello & Ahmed (2011) to be ever more impinged upon by this need for the re-use of information. In particular the later stages of product lifecycles feature an amassment of service information that could be reused for the improvement of the next product generation (Jagtap 2008), and expert product knowledge needing to be transferred and not lost due to expert attrition (Wallace & Ahmed 2003). Wallace & Ahmed (2003) assert that facilitating this knowledge transfer relies upon the re-use of knowledge amongst such teams and thus reuse of knowledge is a critical part of capture and transfer processes.

The effective transfer of captured knowledge between people is considered by Fidel & Green (2004) not only as a result of the need for accessible information and knowledge resources but also for the usability of such information and knowledge resources. This means that not only should research focus upon the physical accessibility of information but also for the efficiency of the transfer of knowledge from resources to the design engineering users. This usability perspective is also highlighted in the work of Henderson (1991) and Carlile (2004) that focusses on the specific needs of design engineers for visual or common lexicon representation of information and knowledge between experts and expertise boundaries.

The typical resources that are required to be utilised for the reuse of knowledge are cited by Wong et al. (2008) to be highly heterogeneous, for example documents. Such documents are likely to have ill-defined metadata exacerbating the information search and retrieval mechanisms required for reusing them. Hence it is not surprising that Jagtap & Johnson (2011) find that a significant issue with reusing knowledge from the service phase is due to its unavailability, unreliability and inappropriateness of such experiential resources. This is also reiterated in the work by Darlington (2005) in the studies conducted to define document information structures for navigating the informative content of design engineering documents. In Darlington (2005) there are defined a number of decomposition schemas for documents that are useful for understanding their content and the utilisation patterns of design engineers when reusing information resources.

Two of the areas Liu & Boyle (2009) identify as areas of increasing research focus for future years are the underpinning design engineering cognition and the support required for making decisions. Both of these areas relate in some measure back to

the issue of information utilisation and for the focus of this thesis the interest is upon the thinking or cognitive processing of information in the form of documents and need to make informed decisions about utilising such common place design engineering artefacts. Hence other areas of interest arise for this thesis such as decision making theory and the study of human information interaction. The research methods for understanding design engineering thinking such as McNeese (2004) are discussed in Chapter 3.

Decision making theory that is relevant to design engineering information processing are such as those from naturalistic decision making literature, with a focus upon the types of decisions that are made in highly time constrained and pressured circumstances. One suggested decision theory includes the recognition primed decision making process defined in the work by Klein (2008). The relevance and detail of decision making is discussed further in section 2.4 and (in relation to the experimental results)

2.1.1 Summary of Key Concerns for Design Engineers

Throughout section 2.1 the current concerns facing design engineers has been outlined using the recent literature as evidence to support its substantiation. This has been followed by highlighting the additional pressures that surround in-service design engineering and the limits in focus of research upon the latter stages of design. This raises concerns over both gaps in the wider literature application to ongoing design engineering problems. A summary of the current concerns for design engineering research is listed below;

- Prevalent visual information forms for design engineering, but lack of use of wider methods for understanding representation their importance in utilisation (Henderson 1991).
- Significant predicted rise in products in-service, lengthier lifecycles and increasing service demands amasses more data, strategies for reuse of information critical (Jagtap 2008).
- Difficulty in integrating and using historic data collections in longer product lifecycles (Xie, S. J. Culley, et al. 2011; Carey et al. 2012).
- Increasing need to capitalise upon service data to drive creativity, improve early design process and provide services (Vianello & Ahmed 2012).
- Accumulation of expertise and knowledge retention difficulties lend to reliance on explicit information (Jagtap & Johnson 2011) especially in use of latter stage product information.
- Acknowledgement that human intervention is required in design engineering to interpret and make complex judgements but poor understanding of the decision process or types of information required (Liu & Boyle 2009).
- Lack of research into the design engineer information interactions to truly understand their comprehensive information needs.

The next three subsections discuss in more detail the specific concerns raised within the literature resources for design engineering in knowledge management for knowledge reuse, engineering design information studies and the character of design engineering information requirements and the information relevance decision making that Design Engineers surmount in an era of information overload.

2.2 Knowledge for Design Engineering

Knowledge has been a subject of interest since the advent of philosophy yet definitions of its components are yet to be agreed upon. In (Polyani 1966), the much acknowledged but intangible dimension of tacit knowledge, or the human "know-how" is defined. The idea of knowledge is further extended in the work of (Nonaka & Takeuchi 1995) to define explicit knowledge that is considered to be the physical resources or assets that contain knowledge such as information and data in documents (Markus 2001). These explicit resources or assets could be digital such as CAD models or physical paper sketches, but are categorised as

physical because unlike tacit knowledge they can be viewed as concrete objects (Kremer et al. 2004).

The relationship between explicit and tacit forms is later modelled by Nonaka & Takeuchi (1995) in their theory of a social transition between knowledge forms. They apply the notion of knowledge and its transitions to understand how organisations process and the functions of such knowledge. The principles and constituent parts of knowledge have continued to be argued and refined since, with different understanding of the meanings for different application (Stenmark 2002; Rao & Osei-Bryson 2007) maintain that organisations now view knowledge as one of their key organisational assets that needs managing for capitalisation in a similar way to other company assets. However fluid the definitions, it is widely acknowledged that organisations must capitalise upon knowledge as it is cited to be the key differentiator for organisation optimisation (Alavi & Leidner 2001), hence the continued focus for knowledge in research.

One debate over meaning is the existence of implicit knowledge, (Frappaolo 2008), states that this is the third possible state of knowledge, being implicit. (Greco & Cangelosi 1999) refer to this third dimension as the potential within explicit knowledge resources for supporting human perception and information assimilation. Implicit knowledge appears to represent the transition between that which is tangible in physical information assets and the intangible contained in the heads of experts (Nonaka & Takeuchi 1995). Early knowledge research does not refer to implicit forms of knowledge and (Stenmark 2002) suggests itself is non-existent but it potentially represents the social interaction between human perception and data as referred to in (Davenport & Prusak 1998). In this thesis a pragmatic view of this implicit state is taken and we use this to simply represent the human perceptions, assumptions and the assimilation that we wish to investigate in particular for human processing of information in design engineering.

Arguably implicit forms could represent the contribution of context to explicit knowledge that is required to reinstate tacit knowledge (Chris McMahon et al. 2004). However, technical solutions to recreate the transitional steps between explicit and tacit knowledge forms have not yet resolved by researchers and thus knowledge is still the subject of much research in particular for design engineering purposes (Hicks et al. 2006; Wild et al. 2009). This in part is likely due to limited understanding of the human aspects and knowledge needs of design engineers (Vijaykumar & Chakrabarti 2008). The human aspects of information and understanding needs are considered further throughout this chapter and in particular for human reasoning purposes in section 2.4.

Many working models (E. Abou-Zeid 2002) apply the notion of knowledge systems to organisations (M. Easterby-Smith & Lyles 2003; Nonaka 1994) have since followed in quick succession, building the theoretical frameworks for creating management techniques to maintain organisational competitiveness (Alavi & Leidner 2001). Knowledge management literature involves a fusion of expertise from many disciplines, such as psychology, cognition, education and management theorists (Stenmark 2002). This theoretical basis is now being employed in many more specialist domains for developing essential knowledge processing and constructs, such as capture, sharing and potential for further reuse (Hicks et al. 2002). Other literature such as (Grundstein et al. 2003) suggested that capitalising on knowledge methods by providing desktop tools to surmise is the key to making better decisions although (Mancilla-Amaya et al. 2012) suggest quantification of knowledge quality is needed to optimise decisions, in practice a combination of both approaches is required. Not only does this evidence the diversity of application for current knowledge methods

but that knowledge for decision support is a common theme (Xie, S. J. Culley, et al. 2011; Tang et al. 2010; Giess et al. 2007).

(Eppinger & Ulrich 1995) describe the design engineering process as formidable, consisting of thousands of complex decisions further challenged by a constantly changing environment. This is reflected in complex organisational constructs evident in the design engineering working knowledge needs in formal and informal information rich process (Bracewell et al. 2009). A suggested approach for representing the flow of information for design engineer information processing is outlined in Figure 2.9 below. This utilises the key constructs and concerns highlighted in the literature and provide a common ground for understanding the terminology used in the discussion throughout this thesis. A later subset of this diagram is proposed in section 2.2.5 to narrow the specific focus for this research and serves as the basis for relating the outcomes of each Chapter. The illustration covers the key knowledge terms and flows that are related to design engineering in literature, these flows are also echoed in the work by (Hicks et al. 2002) in his synthesis of the knowledge processes and concerns for design engineers.

However, recent and more pressing information needs for the design engineering communities are the focus of much research, evident in literature describing investigations into information needs and outlining potential solutions. Figure 2.4 has been created to structure the multiplicity of issues outlined above to enable the correlation and further discussion of points throughout this thesis for the knowledge aspects illustrated. The three columns here are the three types of knowledge, tacit, implicit and explicit discussed in this section and the three major rows show the titles, the actions and the expected processing for knowledge. This has been further subdivided into suggested action steps from the literature for managing organisations knowledge. This illustration is further reduced at the end of this section to focus upon the specific knowledge actions that are important to the content of this research and utilised throughout this document to highlight the importance of the findings of each chapter in an overview of the complete research topic.

The green coloured boxes in Figure 2.4 present the key knowledge supported tasks undertaken by design engineers (Hicks et al. 2002). These could potentially be split further into subtasks such as transfer of knowledge could involve the capture and sharing of tacit knowledge, the task of sharing knowledge is implied in the "reuse" of knowledge. A suggested decomposition of the human focussed tasks that knowledge management techniques seek to support are shown in the illustration in blue and orange, such as "understanding" or "browsing". The transition from explicit, physical forms of knowledge such as information documents to tacit and intangible knowledge resources such as experience and their associated functions are clarified in the central subtasks shown. Support for these intermediary steps can be technology solutions or human intervention; however efforts within research thus far demonstrate a lean for technological solutions for the more explicit forms of knowledge such as information management (McMahon et al. 2005).

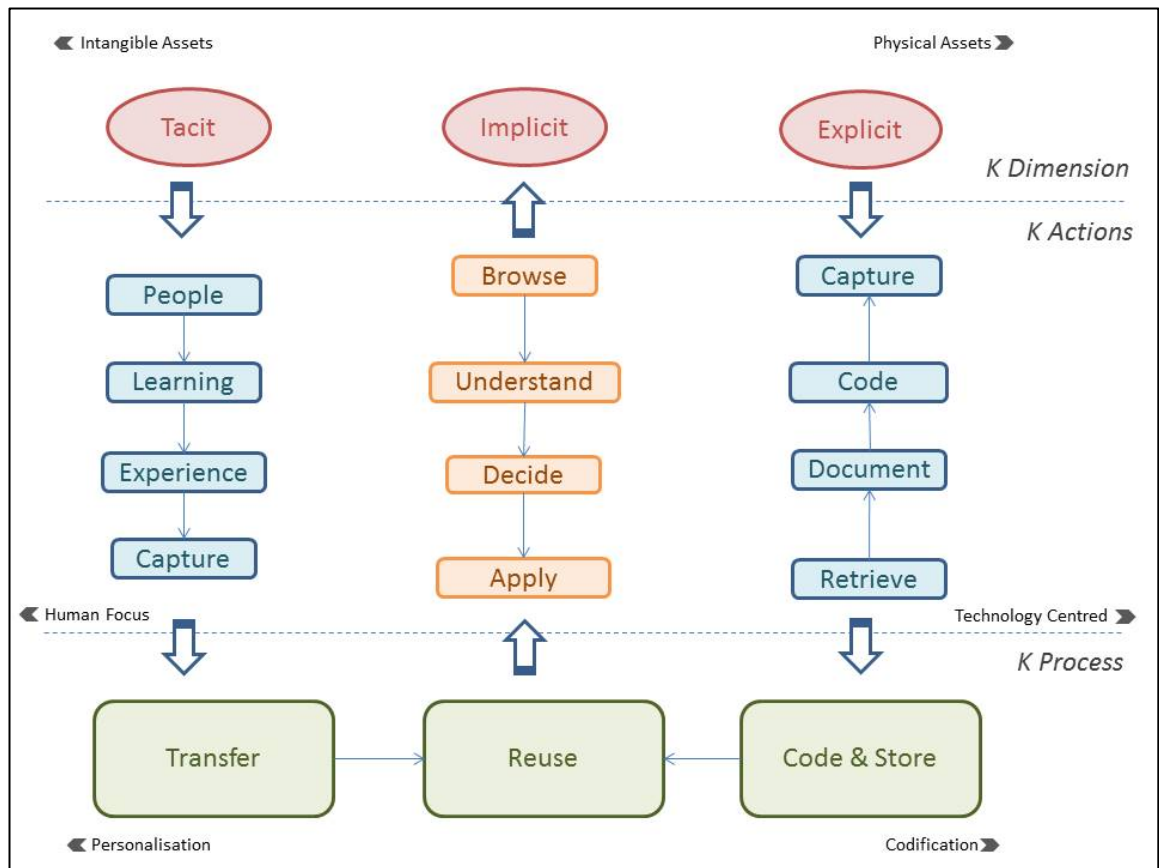


Figure 2.4: Knowledge Flows for Design Engineering

Of particular interest to this thesis are the forms in which data, information and knowledge reside for design engineers to utilise, potentially tacit, implicit or explicit and the industrial challenges presented that have not been solved by current supporting methods. Given the debate in literature regarding definitions of knowledge (Zins 2007) it is first sensible to define the knowledge system concerns as they apply to design engineers and thus for this thesis. Hence below we define the terms data, information and knowledge as they apply to this research.

2.2.1 Data, Information and Knowledge for Design Engineering Research

It is worth clarifying the differences between data, information and knowledge in relation to engineering design. In domains such as Computer Science, the notion of data refers to streams of signals or 0's and 1's, or to their raw representation in some numbering system (Bennett et al. 2010). In wider human context (Zins 2007), deem data to be signs or symbols, for design engineering purposes this definition is extended to mean raw unprocessed elements such as database entries or text lexicons (Hicks et al. 2002). Information for most domains is the combined representation of data elements that depict meaning, such as the combination of text lexicons to form words that connote some meaning (Stenmark 2002). Given the broad nature of data and information in design engineering (McAlpine et al. 2006) the definition of data includes raw CAD data, individual text characters or mathematical results and this is thus relevant for the purposes of this thesis. Information has a meaning (Zins 2007), for example collective CAD data that forms a CAD model or a complete word from text characters. Applied to the content of design engineering documents the data content refers to individual text and information relates to the combined semantically enhanced informative elements such as graphs, sentences or CAD drawings (McAlpine et al. 2006; Court et al. 1993). It is thus possible to decompose collections of information into informative elements and types such as a photograph or descriptive text term (Darlington 2005). This has been referred to as the "what" or concrete facts about design engineering that can be collected (Burkhard 2005).

A general consensus is that knowledge is conceived to exist only within an individual (Stenmark 2002; Polyani 1966) and is the combined meaning of signals as interpreted by the human cognitive state (Zins 2007). However, (Floridi 2010) explains from earlier work by Shannon and Weaver that it is the influence of human behaviour that changes what internalised knowledge is to individuals. Comprehending this means that although there may be an understanding that information and data make-up knowledge it is not possible to interchangeably assume what the information and data knowledge is comprised of, due to the human characteristics that underpin it. Across the literature it is evident that the human characteristics that influence "what" knowledge is are still unclear (Zins 2007) and a number of potential views on the human influence arise when seeking to support its management. Hence this thesis thus does not attempt to define the dimensions of knowledge but seeks only to explore the influences it has upon the information "understanding" behaviour of design engineers.

Key knowledge management processes suggested by (Alavi & Leidner 2001; E.-S. Abou-Zeid 2002; Satyadas et al. 2001) and the organisational concerns of (M. Easterby-Smith & Lyles 2003; Burkhard 2005) are included in Figure 2.9. Explicit knowledge is the externalisation of knowledge from its tacit and human influenced forms (Tang et al. 2010). In (Nonaka & Takeuchi 1995) theory this externalisation is the capture of knowledge into explicit knowledge forms, however, for much research this explicit knowledge is interchangeably described as explicit information that can be stored (Satyadas et al. 2001). For explicit knowledge (or information) the transition from data to information is tangible, but the further coding to represent knowledge remains one of the challenges for coding captured knowledge (Zins 2007).

(Hicks et al. 2002) and (McAlpine et al. 2006) identify that formats of knowledge and information directly affect its potential communication medium or representations and these mediums or representations (particularly or expertise boundaries) are cited to be key to facilitating effective transfer of such knowledge (Carlile 2004; Henderson 1991). In (I. Nonaka 1994) & (Nonaka & Takeuchi 1995) this is the interaction or explicit format dependencies driving the socialisation *capability* of knowledge. This poses an interesting question for information research into design engineering into suitable information formats that involve the transformation of knowledge from explicit forms to facilitate their reuse (transfer and sharing from physical mediums).

In the work by (Hicks et al. 2002) the authors seek to find the limitations within engineering for capturing, storing and thus reusing. The "reuse" referred to includes the transfer and sharing of explicit knowledge assets that involve reusing of the knowledge of others that has been encoded for example into document to enable the transfer or capture of their expertise. As previously stated, the contribution of human knowledge to the interpretation of such coded expertise cannot easily be defined and this thesis seeks to explore "how" to support engineers to efficiently utilise it. Enabling the coding of information and data into forms that support human knowledge assimilation is an important investigation for this work and for such purposes the explicit knowledge we refer to forthwith are the explicit information and data assets that are stored within an organisation that are potentially available for reuse.

Knowledge, information and data transformation are accepted to be critical for the optimisation of design engineering activity (McAlpine et al. 2006; McAlpine 2010) and thus its management an important prerequisite for design engineering projects. In more recent research and as information resources increase the ICT challenge of managing explicit information and data are of high profile (Hicks et al. 2006; Tang et al. 2010; McAlpine 2010). In this section knowledge is defined as a combination of human understanding (tacit) with underpinning information and data (explicit) and the aspects of human understanding that are applied to explicit

assets or information and data are not yet fully understood. Defining, capturing and thus supporting the reuse of this "combined knowledge" is difficult and it is cited to be significantly hard for individuals to articulate, especially as experience increases (Karlsson & Torlind 2011). It is the use of this explicit knowledge (information and data) that is sought to be reused to enhance and optimise decisions for complex and information rich design process, thus the retention, capture and processing of design engineering project knowledge is critical (Gopsill et al. 2012). The next section is devoted to discussion of the design engineering literature concerns for transferring and sharing such knowledge to retain it.

2.2.2 Capturing Knowledge to Enable Transfer

In the previous sections it has been shown that for engineering project teams to capitalise upon their knowledge it must first be passed on or made available. Many methods and tools have been researched and devised to support this theoretically and practically (Knowledge Transfer Guidelines 2006 is an established industrially focussed example).

The term "transfer" is ambiguous and is used interchangeably to mean the personal exchange of knowledge between people (Ahmed 2001) or the assimilation of knowledge from explicit resources (Wong et al. 2008). This convolutes the purpose of knowledge transfer methods and makes the organisational task of employing effective methods more difficult. Arguably (Wong et al. 2008), suggest a knowledge "reuse" strategy is the solution to a knowledge "transfer" issue. In (Chris McMahon et al. 2004) they create a distinction between personalisation methods for the transfer of knowledge and codification for the storage of knowledge. It is important to understand the difference as the latter codification solutions thus far in literature relate much to the application of information management techniques that support the reuse of information.

(Weber et al. 2007) describe the outline of an industrial method for the personal transfer of expertise and (Huet et al. 2007) observe the lessons that can be learned for project teams from meetings facilitating communication. Both of these examples seek to capitalise on knowledge by finding opportunities to capture and are being used currently within a large aerospace company (see section 4.2). This personalised transfer of knowledge (Chris McMahon et al. 2004) is the focus of this section and is extended to include tools that are designed to support communities of practice that seek to connect experts to facilitate knowledge transfer to occur (Gopsill 2014).

(Tang et al. 2010) & (Markus 2001) surmise that, a majority of the efforts thus far to transfer expertise have to some extent required the capture and coding of explicit knowledge for later utilisation. It is not possible when considering knowledge transfer needs to ignore this requirement for longer term knowledge capture and hence the blurring between the transfer of knowledge and its need to be coded and for capture (Chris McMahon et al. 2004). (Jastroch & Marlowe 2010) identify that for coded knowledge "Clarity and unambiguity of knowledge transferred thus become essential requirements" but acknowledge the difficulties that experts have in explaining and coding their tacit knowledge. This difficulty capturing and coding has effect upon the quality of knowledge outcomes and frequently result in the collection of lengthy informal documents that capture as much as possible without specific audience considerations (Markus 2001). (Rao & Osei-Bryson 2007) & (Hicks et al. 2002) suggest that this quality dimension of knowledge should be a key research focus to enable its effective transfer, capture and re-use.

Engineered products are lasting longer and thus managing the accumulation and transfer of experience for over longer lifecycles raises further challenges for retaining that experience for enabling its reuse (Ahmed & Wallace 2004). This also means that transferred knowledge needs capturing for potential future need without

understanding “what” and “whom” of the specific need (Markus 2001) reusability is thus further compromised. This drives not only an environment for capturing prolific amounts of data but also for the capture of unfocussed information simply to leave it available if required in the future (Markus 2001). This amassment of multipurpose data and information and has further created the need for product lifecycle information management refinements and leads to more recent research into development for new Product-Service Systems (McKay et al. 2009).

In the early stages of engineering, human experience is rapidly accumulated as products evolve, this experience relates to both the product and the current supporting technologies. As projects evolve natural attrition of expertise is the result of extended product lifecycles, that are longer than the working lives of the design engineers working on them (Vijaykumar & Chakrabarti 2008). This means that this experience is only available if has been captured in explicit information as access to the original expert is no longer possible and methods focus upon information storage and management to ensure the experiences are not lost (Coffey et al. 2003). The progression of experts in to new roles or retirement of an expert also potentiates a significant loss of expertise in large scale projects. This issue of knowledge retention is particularly prevalent in large international projects such as in aerospace (Weber et al. 2007), due to the sheer variety and number of experts working on projects.

The majority of the knowledge transfer research has focussed in particular upon the transfer or feedback of project knowledge into the earlier stages of design engineering projects to facilitate improved design (Wong et al. 2008; Vianello & Ahmed 2012; Jagtap 2008; Jagtap & Johnson 2011). The findings of these studies indicate the key concern being that there is a lack of transfer of knowledge from latter stages. (Jagtap 2008) and (Wong et al. 2008) also suggest that this transfer of knowledge does not work internally within the service stages and is the result of cumbersome data formats and unusable document information collections. The large number of information format and accessibility problems for design engineers is discussed further in section 2.3 and also conclude that creating “useful” explicit knowledge assets remain a significant problem.

Vianello & Ahmed (2012) examine the transfer of knowledge literature and point out that most research studies have focussed upon the information and knowledge level but still have a lack of focus and understanding of the data level of information need, this is true of the studies in particular for the latter stages of design (Wong et al. 2008; Vianello & Ahmed 2012; Jagtap 2008; Jagtap & Johnson 2011). The research conducted by (Xie 2013) is one exception and the focus for this research has been the optimisation of information utilisation for latter stage design engineers.

Harsh (2014) estimates that only 20% of an organisations knowledge management efforts currently relate to technical solution support, this leaves a remaining 80% of knowledge management effort in organisations as human focussed tasks. In practice this is likely due to the complexity of transferring knowledge from person to person and means that a huge effort in research should be used to improve human aspects and requirements for knowledge to fully realise optimal solutions. Alternatives seek to understand information from a different perspective to enable more human views of the data to be available for transfer, such as the capture of design rationale (Bracewell et al. 2009) or the utilisation of knowledge visualisations for presenting knowledge from differing perspectives (Burkhard 2005). Wallace & Ahmed (2003) also sought to understand information requirements from the perspective of alternative audiences such as novice engineers meaning transfer of knowledge is altered to meet the provision of need different purposes. These examples of illustrate alternative views of knowledge accessibility that influence transfer capability in wider design engineering

communities. The human aspect of understanding can thus only be solved using human focussed research studies rather than technical solution.

Given the issues discussed in this section and the pressing issue of an explosion of explicit information resources being available for design engineers, effective utilisation of resources is a key concern (Ahmed-Kristensen & Vianello 2015). Hence in the next the specific information and knowledge capture activities that affects the capability for design engineering information utilisation are considered.

2.2.3 Knowledge Capture and Facilitating Knowledge Reuse

The previous section has highlighted that the need to transfer knowledge in design engineering affects the quality, amount and type of knowledge captured by design engineers. It also suggests the interrelated nature of transfer and capture of knowledge. In this section the additional influencing factors for capturing knowledge that affect the capacity for knowledge reuse are illustrated from literature studies. This section discusses effects that capture of knowledge has upon its effective reuse and raises difficulties that are specific to the capture of knowledge creating further problems.

The drive to capture as much information and knowledge as possible to solve the issue of enabling knowledge to be transferred results in the collation of lots of additional explicit information or knowledge assets (Markus 2001). Few guidelines exist for "whom" and "how" this generalised knowledge should be applied and in the main technological solutions for information management are deployed (Tang et al. 2010). Hence the utilisation of knowledge poses information management issues and human management (Fidel & Green 2004a). These challenges in explicit asset utilisation are added to by the amassment of service data in the latter stages of design and contribute to the difficulties that capturing knowledge pose for providing the right information at the right time.

The current trend in industry is to capture as much knowledge as information resources as possible this amassment is to facilitate and support its reuse. However it heavily encourages a multipurpose data and information strategy for information management (Tang et al. 2010). The case study in (Xie, S. Culley, et al. 2011) suggests that capture of information in industry (lessons learned) is still being driven by those capturing and not those requiring the information further down the knowledge chain. These resources remain available for decades to be accessed and utilised by numerous often disparate or global audiences from multiple expertise. In (Vianello & Ahmed 2012) they find that 20% of their knowledge encodings for the purpose of knowledge transfer alone are collected for multiple audiences and this represents only a small proportion of information from experts. The illustration provided by (Ishino & Jin 2001) state that the end of the capture problem is "accumulate & reuse" making the assumption that if capture happens reuse automatically follows, demonstrating a limited understanding and thus contributing to exacerbate the issues. Hence the capture of knowledge into explicit resources faces additional challenges.

There have been a variety of older attempts in this space. For example, the need for "design reuse" is described by (Duffy et al. 1995) as having few guidelines and little research support to enable this to be done effectively, although they identify many scenarios reuse is taking place such as in "case based reasoning". They identify three general use cases reuse of design, being "design reuse", "domain exploration" and "design for reuse". Similarly Markus (2001) further categories the use cases into "shared work practitioners later reusing their own knowledge", "shared work practitioners that reuse others work", "expertise-seeking novices" and "secondary knowledge miners". The types of knowledge that is being reused in each of these cases differs and thus multipurpose or generalised information collections become difficult to find "what" needs reusing. One of the evident difficulties for the captured latter stage design engineering information is that it arguably supports all

of the “reuses” identified by both (Markus 2001) and (Duffy et al. 1995). This forces latter stage design engineering collections into the remit of “repurposers” of knowledge collections, with little incentive or resource to ensure that information is accessible, or fit for efficient re-use.

At the re-use end of the spectrum, the representation of the captured knowledge or lack of common terminology can render meaning ambiguous and difficult for all “reusers” to competently understand (Carlile 2004; Henderson 1991). These issues can undermine the re-use of captured knowledge as they breed mistrust of knowledge reliability, exasperation of users when seeking information and misinterpretation of knowledge intent leading to errors in judgement. Hence, Markus (2001); Hicks et al. (2002); Burkhard (2005) and many more agree that the capture stage of knowledge should consider first the **purpose** of any reuse to ensure that reuse is possible and efficient. The wider research into technical development also echoes the need for understanding the specific needs of the specific user before developments progresses (Bennett et al. 2010; Laudon & Laudon 2000; Carey et al. 2012).

Easterby-Smith, M. (2003) maintains that competitive advantage for organisations is from capitalisation or reuse of the knowledge in such resources but it is known that using these resources is a difficult task. Illustrating this difficulty, 40,000 documents were created as the result of one engine’s design (Ahmed & Wallace 2006), this does not include service data and (Khadilkar & Stauffer 1996) suggest that design relies upon reuse 70% of the time, thus facilitating document information reuse on this scale is a mammoth task. Similarly (Jagtap & Johnson 2011) and (Vianello & Ahmed 2012) also present case studies that suggestive that latter stage information is the most needed to be reused. As projects progress McKay et al. (2009) recognise the increasing scale and difficulty the use of resources pose and suggest that the efficient use of service data, quality and accessibility are the key requirements to support information reuse. Markus (2001) and Fidel & Green (2004) also conclude that quality and accessibility of information are key motivators for successful information reuse and thus these requirements should be the focus of information provision.

There is strong evidence suggesting that the need for support for explicit information reuse is higher in the latter stages of design engineering. The high accumulation of product service data and capture of experience into explicit forms (Coffey et al. 2003) leading to a change in the balance or a tipping-point between reliance upon explicit knowledge or tacit knowledge sources in early and latter stages of product design. In the latter stages of design engineering they become more heavily reliant upon the explicit information resources that have been captured throughout in capture for transfer, product documentation and service data amassment. This tipping-point and the already increasing information overload challenges for late stage design engineers makes the task of finding the right information at the right time ever more difficult.

It is evident that the trend to capture information and knowledge without specific purpose has been bred by the difficulties in capturing and coding of experience over lengthy timescales. This is contributed to by the disparate nature of design engineering teams, their expertise and amassing resources. The result is an explosion of explicit information and knowledge in cumbersome document assets that are difficult to trust and access. This reuse of latter stage explicit information resources for facilitating their efficient reuse by design engineers is critical for design engineering communities to capitalise upon their knowledge and thus the findings of similar knowledge management solutions for this task as discussed in the next section.

2.2.4 Design Engineering Needs and Explicit Knowledge Reuse

In the last section, a tipping-point for reliance upon latter stage design engineering information resources was highlighted. (Smith 1988) studied design engineering learning and experience accumulation; noting that 95% of the time design engineering problems had been solved before. Reusing this experience must be more efficient than creating new design. Hence, this section looks at what knowledge management research has already learned about engineering needs for explicit knowledge re-use. More recently, Ahmed-Kristensen & Vianello (2015) also suggest that for companies to maintain competitive advantage they must re-use existing knowledge and information resources.

In knowledge management literature, the re-use of information and knowledge is cited in the main to be addressed in research into information management (Tang et al. 2010; Chris McMahon et al. 2004) and the discussion below reflects this. The design engineering information literature also highlights a prevalence for document information formats in design engineering (Wild et al. 2006; McAlpine et al. 2006; Carey et Al. 2013; Jagtap 2008; Lowe et al. 2004; Robinson 2010), hence a particular emphasis is placed upon those studies utilising the information from documents.

Documents for reuse

Contents of engineering design documents have been the subject of many studies (Liu et al. 2007; Lowe et al. 2004; McAlpine et al. 2006; McAlpine 2010; Jagtap & Johnson 2011; Giess et al. 2008; Heisig et al. 2010). It is not such a surprise then that for knowledge management solutions that the utilisation of document contents has been a particular focus (Liu et al. 2007; Xie 2013; Chris McMahon et al. 2004; McAlpine 2010). Although investigations into the contents of documents are clearly relevant this is discussed in section 2.3 and the heterogeneous contents are widely recognised for design engineering.

(C McMahon et al. 2004) investigates methods to improve design engineering access to documented information collections. The strategy utilised used both decomposition of document content (Darlington 2005) and the assimilation of document facets identification for creating navigation tools from knowledge ontologies (Wild et al. 2009). It is recognised in the document collection search prototypes Waypoint and ECDMS, (C McMahon et al. 2004) and (Liu et al. 2007) respectively, that mechanisms for search or for browsing are both required to meet the needs of the users. In Chapter 5, the scoping studies by Humphrey (2013) also assimilates this multifunctional requirement. Although Liu et al. (2007) enable search to include the retrieval of visual elements, this is facilitated by text metadata constructs and thus limited by the quality of such text retrieval results. The capability for searching and browsing in this way was limited by any metadata and for formally constructed documentation only. Hence the value for visual elements and the informal document resources were limited, in particular due to the value attributed to informal documentation for design engineering (McAlpine et al. 2006; McAlpine 2010).

The limits of current document technologies continue to impede the utilisation of informal and formal visual document information (see Chapter 5) and thus knowledge solutions have thus far mimicked information management capabilities (Tang et al. 2010) and have been based upon textual information search and retrieval. The work by Xie (2013) utilised semantic enhancement of text based search to improve the results from such information search tools. However, similar to McMahon et al. (2004) and Liu et al. (2007) this ignores the respective value of the heterogeneous data resource contents of documents, such as images, sketches, handwritten notes and more (McAlpine et al. 2006; McAlpine 2010). Although the studies of McAlpine highlight that 61% of capture in logbooks is to facilitate re-use. To automate the utilisation of such elements would require further research and

(Hicks et al. 2006) that rarely do solutions attempt to integrate all of the concerns due to technical risk.

In studies such as (Wong et al. 2008), it appears that a text based solution is again deemed appropriate and the focus is much upon "what-can" be used, rather than a "what-needs" to be reused approach. In (Kremer et al. 2004), they look to discover "what-can" be used but rather than seeking text the focus is upon "relevant information objects". This leads to the assumption that "information objects" have more value than plain text which is apparent in the limitations of previous technical solutions. While the work utilising text based approaches have supported reuse to some extent it has largely ignored the value of the wider design engineering content.

Formats for reuse

(Dias et al. 2003) stated that the capture of information for reuse lacks between expertise boundaries and the suggested formats for communicating between boundaries are common symbolism (Carlile 2004) and visual representations (Henderson 1991). Given the highly visual nature of design engineering documentation (Lowe et al. 2004) this suggests that the purpose of such documents is to overcome those boundary constraints in particular as a project progresses and thus the value of such visual elements in communication of content for reuse should not be thus be ignored.

Echoing the words of (Ding et al. 2009), that support for reuse in the latter stages of design requires further work, the direction of further research should be focussed upon the complex contents of both formal and informal design engineering documentation, to explore the potential "relevant information objects" that are required by Design Engineers to optimally reuse their content. The reduced figure 2.5 below, shows a subset of the knowledge flows identified that are critical for understanding to enable the effective reuse of explicit knowledge and information resources for Design Engineers.

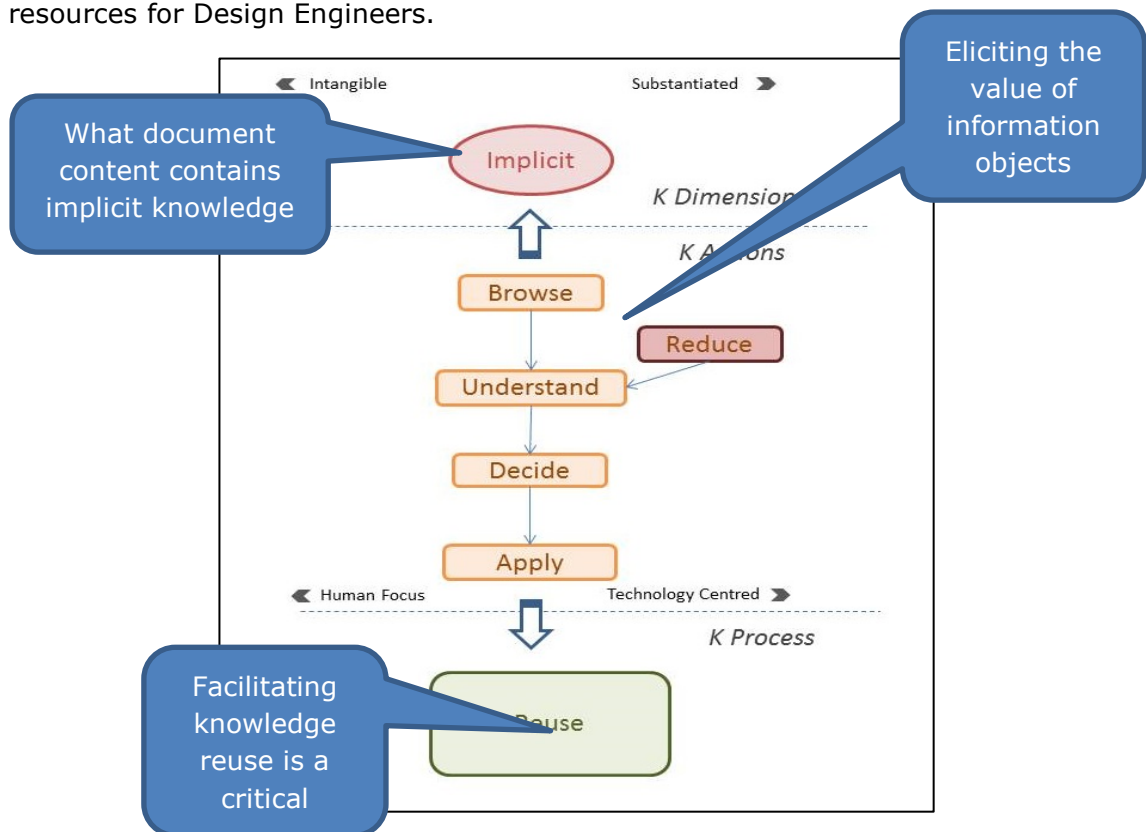


Figure 2.5: Explicit Knowledge Reuse Flows

2.2.5 Summary of Knowledge Reuse Concerns for Design Engineering

The reuse of knowledge is unquestionably relevant to the needs of engineering design organisations and in Figure 2.5 the critical concerns for design engineering knowledge research are outlined, based predominantly on the work (Duffy et al. 1995), (Vijaykumar & Chakrabarti 2008), (Ahmed-Kristensen & Vianello 2015) & (Markus 2001). However, the specific needs of Design Engineers across the spectrum of product lifecycle stages are dynamic and highly influenced by a number of dimensions.

Those significant factors affecting knowledge reuse for engineering design that have been identified throughout this section are summarised below:

- Explicit knowledge and information asset growth is exponential and expected to continue to keep rising (Xie, S. J. Culley, et al. 2011; Jagtap & Johnson 2011; Carey et al. 2013). Hence methods are needed to make document contents and *information more accessible and easy to understand*.
- The lack of literature focussing on the core information and data contents that are required to effectively reuse it (Vianello & Ahmed 2012). *Meaning little is understood about the information formats at a data level* that design engineers need to facilitate reuse. Hence, an understanding of the data contents and its respective value are required.
- The trend to capture knowledge and information without consideration of the reuse purpose (Carlile 2004; Markus 2001) means that large collections of information make finding the "right" information for "reuse" a significant challenge that even current technologies have not yet solved. Hence, *identifying the purpose of utilisation of informative objects and reuse patterns of design engineers* is critical to efficiently provide support.
- Consensus upon the *role of knowledge, information and data formats and the subsequent representations* that are required to facilitate effective reuse are not yet agreed or principles comprehensively tested for engineering design (Henderson 1991; Carey et al. 2013; Wild et al. 2009; Chris McMahon et al. 2004).

Above are identified four core issues for the reuse of latter stage engineering design information and knowledge giving rise to a gap in the research literature and thus form the focus of investigation and development of design engineering knowledge and information support for this research thesis. The research work that has already been conducted to support investigation into this area is addressed in the next section when the nature of engineering design information needs and research are further characterised.

2.3 Characterising Design Engineering: Information Research

Engineering design is known to be rich in information processing, drawing upon cross disciplinary expertise. The large and cross disciplinary of nature of the design engineering project teams places physical distance between information creation driving physical asset containers and experiential knowledge and information growth. For these reasons many of the issues found regarding the growth, pervasiveness and disparity of information are even more significant for Design Engineers.

There is much research that has investigated the information requirements of Design Engineers from both formal and informal sources, and there is a body of experimental knowledge experience to review to aid the design of any future experimental requirements. The purpose of this section is to review the evidence from design engineering research studies to elicit any strength and weaknesses, used in subsequent chapters, in the methods employed, any critical avenues for the direction of this research and to seek what has already been characterised about design engineering information resources and the purpose of its utilisation.

2.3.1 Information in Design Engineering Research

The relevance of information for the design engineering process is indisputable and the nature of the information in design engineering projects has much been researched under many guises. This section seeks to review the significant findings of research into design engineering information to assimilate what has already been identified about its character. Although it is recognised that experience potentiates a source of valuable information it is used here simply to contrast with findings of explicit information forms. As per the summary in section 2.2.5, particular attention is paid to the *explicit* information resources available in engineering design.

Characteristics

Many studies have sought to assimilate the characteristics of engineering design information and it is recognised that the nature of engineering design information is evolutionary (Robinson 2012). The balance of tacit or internalised information emerging as experience versus explicit information is a knowledge balance that is of interest to design engineering due to the high proportion of experts that are involved. (Smith 1988) suggests that 95% of design has been conducted already and is available for re-use. (Wong et al. 2008) also state that 70% of information is taken from previous design. However, this proportion does not represent the amount of information that is recorded in explicit forms and it is not possible to estimate with any accuracy that information that remains tacit. While it is not reasonable to estimate the information content of an expert it is possible to seek clarification of how other utilise them as information resources (Wallace & Ahmed 2003).

(Heisig et al. 2010) cites Corfield (1979), "The life-blood of the designer is the information at his disposal when he creates his designs", suggesting that information is the most important requirement for engineering design tasks. It is also estimated by (Vijaykumar & Chakrabarti 2007) that 70-95% of design work is by reuse of existing knowledge, in agreement with (Smith 1988) and suggestive that information is utilised for a majority of design engineering tasks. However, if this is the case the observation of (Marsh JR 1997) that "only 24% of a design engineer's time is spent in acquiring and disseminating information from personal sources" means that the reuse of valuable information is largely an overlooked activity. This disagreement potentially reflects either a difficulty in comparing design research findings directly due to varied need throughout the product lifecycle or presents an evolution in the requirements of design engineers and information needs.

(Huet et al. 2007) seeks to explore the importance of information exchanges in other design scenarios such as meetings in particular to facilitate documenting it for reuse. The case studies he outlines elicit that 60-70% of the meeting is utilised to "inform" and "clarify" suggesting that information sharing in personalised settings is of more importance to design engineers. This agrees with the studies of (Marsh JR 1997) and also in (Robinson 2012), where they find that 76% and 40.37% of time is spent respectively in work of a social nature. (Hirsh & Dinkelacker 2004) agree with Robinson and identify that less time is spent by asking colleagues for information than previously suggested (40-48%). This could reflect the nature of the design being conducted, the stage of design or simply an evolution in behaviour of designers.

Documents

The importance of design engineering documents are widely recognised, the information studies illustrate relatively low percentages of time being spent upon these resources for design engineering overall. (Heisig et al. 2010) found that 32% of a design engineer's time is spent seeking information and (Lowe et al. 2004) find that 20% is spent upon document resources. These figures appear relatively low

and potentially reflect the difficulty design engineers have in seeking information from documents or their preference for personalised seeking strategies by asking colleagues (Ahmed 2001). This is reflected in the one common cause of engineering failures identified by (Wearne 2008) as failure to use information that was available elsewhere. However, more recent studies by Robinson (2010) report that this figure has jumped to 40-66% reflecting the evolving nature of design engineering and requirement for optimisation and informed knowledge work. Tang et al. (2010) echo this concern that knowledge workers are now expected to be spending up to 60% of their time seeking information. This is a significant amount of a design engineers working capacity upon seeking information alone.

However, Heisig et al. (2010), also finds that 84.2% of information sought relates to the decision making or rationale of design, indicating a significant need for understanding the entire judgement process, finding that 57.5% of the audience are unhappy with their current information provision, and finds gaps not yet provided for are in geometry based information, suggesting that changes in the way information is utilised and presented is required.

Information types

Wild et al. (2010) elaborates on the issue of previous research and the focus upon seeking information types for design engineers as he explains that the myriad of information types can all be sought from documents, thus agreeing that accessing document information is critical for the success of design reuse. Wild et al. (2009) records 250 different types of document from one such corpus, highlighting the difficulty in accessing the right information easily from document collections. The significance of documents is also raised in the studies by Jagtap & Johnson (2011) and Carey et al. (2013)

Court et al. (1998) explored the utilisation of information strategies and information types being utilised for 300 designers, finding that 45-50% of designers captured decisions in informal logbooks, with 18% not recording their decisions. Court et al. (1998) also found that traditional document filing systems were utilised in 80% of cases, this is now significantly different and cannot be relied upon due to the technology changes and drive for digitisation. This is significant when 84.2% of designers in Heisig et al. (2010) suggest they require this information, thus we can assume that design engineers must now assimilate this themselves when viewing information (reflected in the findings of Robinson 2010, in Figure 2.6 below).

Court et al. (1998) relate one of their questions to the format of information for designers. However, it is difficult to determine from this the proportions of information to which it relates. This is due to the overlapping nature of the categories utilised and the time that has lapsed since the study. However, it is possible to suggest that a very broad and in the main visual media are being used to represent and store design information. McAlpine et al. (2006) agrees with this perspective and list similar heterogeneous media compositions that are required to represent design information.

Vianello & Ahmed-Kristensen (2008) elicit that 75% of changes to aero engine designs are requested during the service phase of a products lifecycle but this drops to 50% for construction such as for oil rigs. Although this indicates the heavier information need later in the design engineering stages for modification (seeking information from early stages and later stages of design) it does highlight that this is clearly different for differing design projects and should be considered with caution. This suggests that information needs in the latter stages of design differ from those in the early stages. However, Jagtap & Johnson (2011) find that the information requests of early design stages also require significant information (91% of requests) are about "deterioration mechanisms" from in-service data. The

transition of requirements and purpose for reuse of information throughout the lifecycle appears somewhat unclear and not possible to assume from the literature.

Significance

The relevance of the findings of the design engineering information studies are somewhat reduced due to their generalised exploratory nature and purpose, thus the varied outcomes make it difficult to directly comparing their results. We can surmise the significance of documented information as it arises in many of the studies, even those such as Huet et al. (2007), studying the information needs of engineers during meetings. This is also evident in the number and variety of documents that are illustrated by Wild et al. (2010) and in Jagtap & Johnson (2011). There are a number of needs that arise that are not solved that are potentially solvable by reusing the contents of documents (McAlpine et al. 2006 & McAlpine 2010) such as the need for “design rationale” and “geometric information” found by (Heisig et al. 2010).

However, utilising the findings of Robinson (2010) in the illustration below (Fig 2.11), we find that in using non-human resources, approximately 73% of an engineer’s information seeking activity is spent utilising the information from non-human resources (17% of time spent locating information within a source, 32% locating information within a source, 16% understanding the information, 7% problem solving, 6% making decisions). With the concerns of rising information loads for design engineers this figure in particular the time taken to locate information within a source (32%) and to understand the information (16%), highlights the importance of enabling significantly faster and easier methods for information seeking within resources and knowledge assimilation by understanding information need to be investigated.

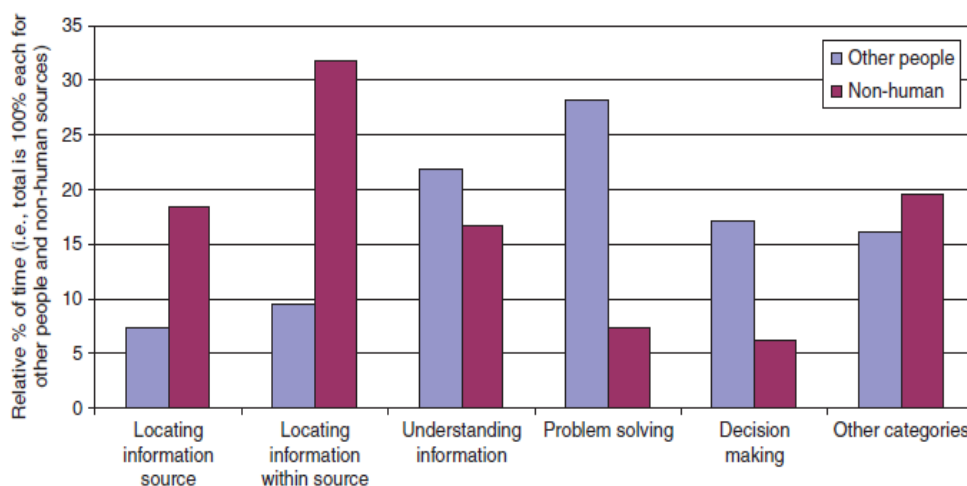


FIG. 4. Relative percentages of time that participants spent engaged in constituent activities while searching for information from other people and non-human sources. Note. See the results sub-section entitled *Hypotheses 6 to 8 – analyses* for an explanation of relative percentages.

Figure 2.6: Robinson (2010) Relative Information Seeking Behaviour

2.3.2 Engineering Information Research Design Methods and Studies

In the last section some of the difficulties in directly comparing the findings of studies conducted in design engineering were discussed. Due to the dispersed nature of design engineering teams and the complex processes it involves, additional difficulty encroaches into the design of scientific research methods. In this section, some of the characteristics of previous design engineering research and their methods are discussed. In the retrospective analysis conducted in this section, unless documented by the researcher in the literature, the full range of

considerations taken into account when carrying out research is not possible. However, a number of features of the design are collected and considered in Table 2.7 that follows.

The table 2.7 collects together some of the characteristics of design engineering research studies to enable a comparison of their features. A number of findings stand out, these are listed here and then the cause and effects of the identified points are further discussed in this section;

- Few evaluation studies are conducted with the design engineers themselves.
- A majority of the studies are analysed using a quantitative approach, evident in 9 studies. Those with mixed approaches (6) also utilised some quantitative analysis.
- Small sample sizes are common and these studies appear more focussed in purpose.
- Broad audience focus, in particular for the higher participant numbers.
- Case study research approach utilised in 8 studies and observations utilised in 4 others.
- Only 2 approaches used content analysis.
- Mixed method analysis approach is common, 6 studies utilised, but purely qualitative is much less frequently utilised 3.
- A majority of studies are still exploratory (15) or investigative in nature.

Citation	Focus of Study	Aim or Type of Study	Participant No's	Research Method	Analysis Approach
(Ahmed & Wallace 2004)	Aerospace Novice Design Engineers	Information Support Method Evaluation	6	Observation	Mixed
(Ahmed-Kristensen & Vianello 2015)	Oil Industry	Information Process Elicitation	1	Case Study	Quantitative
(Auricchio & Bracewell 2013)	Aerospace Industry	Evaluate Information Process Support Approach	1	Participatory Action Research	Quantitative
(Court et al. 1998)	Design Industry	Investigate Information Access	300	Survey	Quantitative
(Fidel & Green 2004b)	Design Engineers	Investigate Information Access	32	Interviews	Quantitative
(Goh & McMahon 2009)	Doesn't State	Investigate In-service Information Requirements	1	Literature Review, Observation & Case Study	Mixed
(Harvey & Holdsworth 2005)	Aerospace Organisation	Knowledge Assessment	1	Self-Case Study	Qualitative
Heisig et al. (2010)	Design Industry	Investigate Knowledge & Information Needs	137	Multi-format Survey	Quantitative
Hirsh & Dinkelacker (2004)	Design Researchers	Investigate Information Utilisation	60	Web-Based Survey	Quantitative
Huet et Al. (2006)	Design Organisation	Exploratory Information Content Analysis	50	Survey & Content Analysis	Mixed
Jagtap & Johnson (2011)	Aerospace Design Engineers	Investigate Information Need	3 10	Survey & Interview Content Analysis	Mixed
Lowe et Al. (2004)	Two Aerospace Organisations	Exploratory Information Characterisation	10	Interview & Audit	Mixed
McKay & Kundu (2014)	Coffee Machine Organisation	Investigate Service Information Elements	1	Literature Review & Case Study	Quantitative
Robinson (2010)	Design Organisation	Investigate Information Behaviour	78	PDA Work Sampling	Quantitative
Vianello & Ahmed (2011)	Two Oil Organisations	Investigate Latter Lifecycle Knowledge Creation	18	Case Study & Interviews	Quantitative
Vijakumar & Chakrabarti (2008)	Designers	Evaluate Knowledge Taxonomy	3 Formal 8 Informal	Literature Review & Observations	Qualitative
Wallace & Ahmed (2003)	Aerospace Teams	Investigation Information Practices	2	Observations	Mixed
Wasiak et Al. (2009)				Literature Review & Case Study	
Xie et Al.	Two	Investigate	2	Case Study	Qualitative

(2011)	Aerospace Teams	Current Information Practice			
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Table 2.7: Design Engineering Research Study Summary

Only a small sample of the design engineering information research studies, with a particular industrial sampling approach were utilised for this summary to make suggestions about the trends and potential causes that may affect the industrial engineering design information focus of this research. To make any causative statements a rigorous quantitative approach should be utilised, hence only comparative figures are used for discussion of any findings. Each finding and suggestion of its meaning for design engineering research is discussed individually below.

A majority of studies (15) are still exploratory or investigative in nature.

The scale of the information operations for design engineers and the comprehensive information work and requirements mean that more focussed investigations into the purpose of such information interactions are required. The immaturity of approaches potentially means that this has limited the maturation of the research area and should thus be addressed to enable progression. This also potentially illustrates the lack of research methods that employ social interaction facilitation. The socialisation effects in the creation of knowledge for design engineering are evident (Yannou 2013) and Nonaka & Takeuchi (1995) discuss the social nature of knowledge processes. Robinson (2012) reports in the findings from his design engineer behavioural study (Robinson 2010) to investigate the importance of the design engineering time spent in social interaction. The utilisation of innovative research methods enabling observation of this social work in practice could prove to elicit any intangible or emergent needs of design engineers, which data could not be collected about by other means.

Few evaluation studies (3) are conducted with the design engineers themselves.

This potentially represents a low number of industrial solutions being presented by researchers that can be implemented in industrial settings. This is impeding current research application for industrial information provision and should be addressed urgently. However, it is likely due to the wide scale technical developments and ICT access limitations this will involve huge industrial based research and developments.

Alternatively this could present an issue in the types of evaluations that are possible to be conducted within industry to present more rigorously tested business cases and potential benefit. This could be solved using approaches such as the participant action research used in (Auriscchio & Bracewell 2013) to progress supporting theory.

A majority of the studies are analysed using a quantitative approach, evident in 9 studies. Those with mixed approaches (6) also utilised some quantitative analysis.

Engineering design is driven by the mathematical principles that underpin the scientific development of rigorously tested products. Thus it is difficult to separate the quantitative results and focus of the domain the types of scientific approach and findings required due to the mind set and behaviour of design engineering researchers. The design engineering perception of the value of quantitative or statistical inference needs to be overcome and more qualitative scientific approaches trusted and employed. This would in some measure enable the findings from the small but focussed sample sizes for design engineering experts to become

more valid approaches and thus research and development to be driven faster upon this scientific basis. This would enable a more human and information interaction studies and findings to advance design engineering research and validate small and qualitative sampling research findings.

Small sample sizes are common and these studies appear more focussed in purpose.

Similar to above the smaller the samples that are required to be studied in engineering design research study are deemed to be of less value than the larger sample sizes. However, it is evident from the table and research analysed that the smaller sampling studies (excluding case studies) are much more focused in their audience and thus relate better to specific purpose. The focus upon specific purpose within information research in particular for reuse is established in section 2.2.3 and poses further potential for development of information support for reuse. It is difficult to overcome this issue within design engineering research hence the triangulation of approaches identified in the mixed method research that is prevalent. An acceptance of this research requirement is needed within design engineering research communities and rigorous application of design research methodologies such as DRM by (Blessing & Chakrabarti 2009) could be applied. More methodologies and accepted approaches are urgently needed to enable design research and small sampling to become more scientifically grounded.

Broad audience focus, in particular for the higher participant numbers.

The nature of the studies that sample much larger participants mean that the results become only broadly applicable (Rosenthal 1966) and for specialist working practice in different stages of the lifecycle becomes much watered down. Research in specialist areas of the product lifecycle are thus required to enable a direct comparison of needs between design engineering stages. In the more recent focus upon in-service stage of engineering (Vianello & Ahmed 2012; Jagtap 2008) and product service information (McKay & Kundu 2014; Goh & McMahon 2009) this in some measure being resolved. However, with the exception of Xie (2013) the current focus of any support is not upon the specific needs of the latter stage design engineers and thus more research is required into the needs of latter stage design engineers.

Case study research approach utilised in 8 studies and observations utilised in 4 others.

Ethnographic methods are clearly valuable for design engineering research due to the prevalence of their utilisation. It is possible that case studies or observations are used to mitigate for the bias that could be introduced by the involvement of the researcher in any ethnographic study, hence the distance imposed by using a case study removes the researcher from the scenario. If we attempt to understand how to mitigate for this better as researchers using other theoretical basis the need for remote observation would be removed. The coding and basis for any findings are frequently subjective for any such studies and frequently is not derived from a theoretical basis. To rigorously understand the meaning of any findings a broader scientific theoretical basis is needed to be sought to enable effective analysis of such research findings. This theoretical basis should be sought from other domains where the application of any such methods are much more mature and can be relied upon to guide the design engineering research process. It is possible that for information research information management or human behavioural approaches may be much more applicable (see wider research and visual requirements in section 2.3.5 and 2.3.6).

Only 2 approaches used content analysis.

Given the focus of the information needs research studies for design engineers, this is a surprising finding for industrial research. This is part could be due to the complexity of the information resources (Carey et al. 2013), the time consuming nature of document audits (Jagtap & Johnson 2011) or the scale upon which any content audits would need to be conducted (Wild et al. 2010, identified 250 different documents in one corpus). It is possible that automating the auditing process might in some measure solve these issues and this is considered in the scoping studies described in section 5.2 – 5.4 of this thesis. However, it is evident in the work by Liu et al. (2007) that automating this for informal resources that are present in engineering design industry that this could present further challenges. There is a body of research that has already sought to facilitate the utilisation of engineering design documents and their contents and the contributions of the research by McMahon et al. (2004): Wild et al. (2009): Giess et al. (2008)& Darlington (2005) are considered further throughout sections 2.3.3 – 2.3.5.

In summary, from the points above it is evident for design engineering research to progress scientific and innovative approaches are required to both conduct and analyse research. There is a perception that quantitative results are more valued than that of qualitative results and this appears to inadvertently drive the quantitative analysis approaches taken by design engineering researchers. Although this type of approach does not always accurately reflect the complexity of influences upon a research study and potentially impedes the progression of design engineering research. The need for the use of qualitative methods is evident in the qualitative methods being used such as interviews, observations and case studies. However, wider human interaction research method is rarely witnessed. Thus the requirement to be rigorous in scientific practice and the need for imaginative social interaction and active participation of small numbers of industrialists is clearly needed.

This is not yet solved. However, Cash (2012) focussed his research in particular upon some of the limitations of design engineering research in practice and much could be learned from application of rigorous research methodology. He identifies in particular one common psychological effect that researchers should be cautioned to mitigate in the form of the Hawthorne effect, when the observer inadvertently increases the productivity of any subject whilst being observed. Caution is required then in the application of such observational studies that are prevalent in design engineering. A method frequently utilised in design engineering research is the triangulation of approaches (Green et al. 2002; Blessing & Chakrabarti 2009).

Eliciting this social aspect of design engineering information interaction will not be possible without intervention of methods from more human focussed research domains. The nature of information investigations also requires the comprehensive audit of information resources, which has had little research focus, other than the work of the KIM project. Only a holistic understanding of the entire information system will enable any emergent properties to become apparent and be fully analysed (Bennett et al. 2010).

Although not highlighted due to the nature if the cases audited, evaluation of methods for supporting design engineers in information provision are frequently conducted by developing and evaluating prototype systems to test with design engineering student cohorts. The need for this type of testing is clearly due to the difficulties both implementing technical solutions within industrial engineering design and the limitations imposed by the tight timescales and costs implicated for industrialists to participate actively in research. However, it remains that for intervention to become industrial application this barrier needs to be broken down to enable the researcher to evaluate methods and approaches effectively and to make inference upon the industrial quality or efficiency of any results.

It must be concluded that the considerations for the design of any studies are complex and thus the issue of research design and the validation of any approaches are detailed in Chapter 3: Research Approach.

2.3.3 Information Need and Design Engineering Dimension

In the previous section a general view of information related design engineering research has been taken. It is evident however, from the design engineering information research, that a variety of information needs and support are required to be met for design engineers. The differences in needs have been introduced in sections 2.1.1 – 2.1.3. A more detailed discussion of the design engineering influences is provided below to focus this research on the current industrial need.

There are a number of areas that emerge from the literature that differentiate the specific information requirements. They appear to dissect the design engineering community into cohorts that correlate multi-dimensionally. Due to the multi-dimensional nature of the issues raised, each issue is considered in turn and a summary of specific concerns for this research are provided at the end. The main differentiating needs for information cohorts with engineering design that emerge from the literature topics are given;

- Information requirements of experts and novices.
- Information requirements throughout the product lifecycle.
- Information requirements from explicit resources.
- Solo information seeking vs social information seeking.
- Human information behavioural traits (see section 2.3.5 & 2.3.7).

Information requirements of experts and novices

Smith & Duffy (2001), in no uncertain terms suggest that without the reuse of formal design costs of design would be 64% higher, this figure would mean that product design organisations would be unsustainable. They also highlight that the reuse of informal knowledge (70%) is higher than that of formal design. This informal reuse could involve the reuse of socially provided knowledge from experts in tacit form. Hence, for the sustainability of design reuse the importance of information interaction between experts and novices cannot be ignored. To overcome some of the knowledge deficits of novice design engineers Ahmed (2001) and Wallace & Ahmed (2003) have sought to investigate their specific need to design effective supporting methods for information provision.

From the work published in Ahmed et al. (2004), they identify that 35% of novices do not know “what” the information is they need to use/seek and devise a list of questions that present their potential information requirements. This is an information provision issue for the entire lifecycle and there is need to create presentations of information in formats that support both novice and expert users.

Information requirements throughout the product lifecycle & Information requirements from explicit resources

The issue of lengthy product lifecycles is significant for engineering design (Carey et al. 2013) and further creates challenges for the management information provision through the lifetime of a product (Goh & McMahon 2009). For the management of future information provision the requirements of product-service system solutions are being researched (McKay & Kundu 2014).

However, specific information support is differentiated as required by design engineers in the early vs late stages of a products life. Jagtap & Johnson (2011) cite from Petkova (2003) that there is “a paucity in in-service literature” and thus little is understood about the needs of design engineers from the latter service stages of design engineering. Jagtap & Johnson (2011), Jagtap (2008), Vijakumar & Chakrabarti (2008), Xie (2013), Xie et al. (2011), Vianello & Ahmed (2012) and

(Ahmed-Kristensen & Vianello 2015) have all sought to understand the information resources that are created in the service stages. In particular as organisational research suggests that it is capitalising upon these knowledge resources that maintains company advantage (Easterby-Smith 2003).

With the exception of Xie et al. (2011) & Xie (2013) the information provisions of the early stages of design have been the focus of such information research. This leaves a gap in the understanding of the provision required for the latter stages of design. In the work by Xie et al. (2011) and Xie (2013) the internal provision of information resources for in-service engineering design is sought to be improved using text based information search and retrieval methods. The focus however, was not upon the content and specific information requirement but to improve the access of information.

Although little is understood about the information requirements of latter stage designers, it is evident that the information resources available in the latter stages have accumulated throughout the life of a product and include early and late documentation. From Wild et al. (2010) we identify that from one corpus there are potentially 250 different document types and (Ahmed & Wallace 2006) we identify that up to 40,000 documents can be produced in the design of aerospace engine. It is evident from this that a multitude of resources that have crossed the expert and lifecycle boundaries for Design Engineers. This presents two significant issues, the first is the scale of the search for information and the second is the ease of understanding of information across those expertise boundaries.

It is evident from more recent literature due to the increases of products expected to be in-service (Boeing 2012; Airbus 2012) that the efforts of semantic or contextually enhanced information search and retrieval alone (Xie 2013) are not going to achieve the level of information support required by latter stage Design Engineers. Reusing information on this scale requires a deeper understanding of its contents to enable ease of use in conjunction with ease of access (Fidel & Green 2004b). It is evident that the information resources are captured from across different product expert boundaries and that common symbolism is required for its representation (Henderson 1991; Carlile 2004), however, Dias et al. (2003) caution that it is crossing the boundaries that risks knowledge not being properly captured.

McAlpine et al. (2006) & McAlpine (2010) identify the need to reuse the contents of informal information resources created often by the design engineers themselves. Markus (2001) also identifies a number of differing captured information resources that are difficult to reuse. She suggests that for them to be efficiently reused significant effort will be required to repurpose these resources. However, there is little evidence in the literature that understanding of what this repurposing may entail for engineering design. Although many efforts shown below describe the contents of information resources they are not easily comparable across studies and product lifecycle stage;

- McAlpine et al. (2006) describe a heterogeneous content including CAD drawings, sketches, notes, graphs.
- Facets represented by text terms (Wild et al. 2009; Liu et al. 2007; Giess et al. 2008)
- McAlpine (2010) identifies the meaning of contents of logbooks for decision making, legal design audit trail, intellectual property documentation, analysis of results, supplier & customer detail & expert discussion outcomes.
- Hicks et al. (2002) identifies type classification of information as textual, pictorial, verbal, memory & expressions.
- Lowe et al. Fig. 2 PP. 415 (2004) suggests that latter stages of design are more visually represented. Designers pass across stage boundaries

- Geometry (CAD models), Numbers (Calculations), Words (written memos, faxes, company reports or technical specifications).
- Wild et al. (2010) finds that documenting and information gathering are the most frequent design engineering activities. Document archives were a significant resource and that often they found no answer from their activity. A majority of the time accessing one document fulfilled the information need, but the document was accessed for up to an hour in each instance.
- Jagtap & Johnson (2011) deconstruct in-service document using the text to classify the product information type such as in-service, design, testing & analysis and cross project. They also present subtopic content meaning such as deterioration information or location information.
- Xie (2013) common text terminology for creating ontologies.
- Darlington (2005) comprehensively breaks down the content of documents in a multiple schemas to represent alternative views of document contents

The list of contents do not suggest comprehensively the repurposing need for the information and thus how to present it for “ease of understanding” or “ease of access” are not able to be synthesised. It is the interactions of design engineers with these resources that may suggest “how” they need to be utilised and thus be presented to reuse them efficiently. Vianello & Ahmed (2012) identify that the subject of information utilisation at a data level is little broached upon in engineering design research and is a gap that needs to be filled.

Solo information seeking vs social information seeking

Knowledge transformation has been referred to as a social process and this is associated with the communication patterns of design engineers. Studies have sought to understand the social or communication needs of Design Engineers by studying their behaviour (Robinson 2012) and their communication traces for example in emails (Wasiak et al. 2009). These studies seek simply to understand more about the working practices and thus information needs. Although, if we compare the findings of Robinson (2010) that 40% of an engineer’s time is communicating and the findings of Marsh (1997) that 76% of an design engineers time is spent in communication activity it appears that potentially with the advent of new technologies this is now being either conducted in less tangible means (less sociable) or more solo work is now prevalent and presents more of a challenge in designing technology to support it. Either way, the interaction of design engineers with information in both social and solo work needs to be understood better.

This section has described how the differences in expertise, stage of a products life cycle, information utilisation and type of role and work being undertaken influence the information requirements for design engineers. It is evident that the contents and utilisation of information resources in the latter stages of design are less well understood and the communicative properties of the information types, the “how” or “why” they are required also require further research. These gaps in the research are required to be filled urgently for design engineers to be able to efficiently “re-use” previous design.

2.3.4 Design Engineering Information Research and Technological Progression

This section seeks to present the main technology contributions relevant from design engineering research.

As Tang et al. (2010) describes, as the capability for technology to store data rises, so too does the scale of the information overload phenomena that “plagues” knowledge workers. The majority of this stored information will never be looked at again, Tang et al. (2010) state that as much as *80% of filed information is never*

utilised again. Facilitating its efficient utilisation is a daunting task; even though technological capability is rising, human capacity to capitalise upon this resource are not advancing at the same rate.

Textual information has proved useful to design engineering researcher to facilitate the supporting technologies already in place. (Shi et al. (2015) have utilised the text from design project reports to apply data mining techniques for recognising patterns and predicting the progression of design projects for management support. Similar approaches are taken in the ontologies that are deduced from the textual corpus to suggest better searching mechanisms or machine learning processing for information search and retrieval enhancement (Xie 2013). Krowne & Halbert (2005) and Greco & Cangelosi (1999) use artificial intelligence methods for language or text from resources to be mined eliciting knowledge or information components to deduce implicit meaning from explicit resource texts. Liu et al. (2007) developed the ECDMS prototype for browsing or viewing engineering projects that built upon the existing work of faceted classification using the text of documents to suggest its content and support its retrieval (Wild et al. 2009: Giess et al. 2008: Darlington 2005).

McKay et al. (2009) describe engineering design informatics as a new research area for engineering design information support systems for through life product support that aims to provide service elements and systems that include the need for models such as CAD. However, other efforts described thus far are based upon the utilisation of textual document components and largely ignore the visual representations that are discussed in other information studies (see section 2.3.3). The work of Liu et al. (2007) suggests the reason for not including visual search is a limitation of the technological and research capability. Hence if these resources are to be efficiently and effectively accessed the additional valuable visual elements and content must be sought to be reused also.

2.3.5 Design Engineering Documents, Information Formats & Visual Content

It is recognised that there are complex information resources and utilisation patterns that need to be understood better (Ahmed 2005; Darlington & Culley 2008; C McMahon et al. 2004; Xie 2013). Xie (2013) refers to patterns in documents for use of information elements but focussed upon the utilisation of the text patterns recognisable and Kremer et al. (2004) identify relevant information objects that suggest implicit meaning for decision support. Other studies seek to explore the information types that are available (Lowe et al. 2004; McAlpine et al. 2006; Court et al. 1998: Darlington 2005). (Jagtap 2008) state that the accessibility of document data is the key issue in enabling reuse and the information is disparate, unstructured and heterogeneous.

In section 2.3.3 a number of the descriptions of the information resource contents are listed. Many of the descriptions are not directly comparable due to either the study participants or differing purpose of the researcher upon reporting the content. In section 2.3.2 it was identified that few study methods sought to audit the content of information resources, likely due to the size and scale of the job. Wild et al. (2010) identify 250 documents in one corpus alone. Automated methods for the auditing of document content in engineering design does not appear to have been utilised or explored other than in the work of Liu et al. (2007) developing document content viewing and searching tools.

It is possible that the benefits of automated content audits for design engineering would be useful but presents a challenge that is scoped in Chapter 5 of this thesis. It is evident from the list in 2.3.3 that there are a multiplicity of information resources available and heterogeneity in their information formats and contents. This further exacerbates the auditing challenges and the information reuse difficulties.

Data as symbols

Stenmark (2002) views data as symbols and describes (Spek & Spijkervet 1997) view of data as being un-interpreted symbols. Hence one of the limitations of text methods in 2.3.4 is the lack of meaning that is possible to be attributed. Wong et al. (2008) developments summarise the contents of documents although it is unclear how this is done but there is common agreement that the content of engineering design documents and information is highly visual (Wild et al. 2010; Henderson 1991).

The importance of this visual representation is widely accepted but less well understood, there is little research into the specific role of visual information contents for Design Engineers and most of that work has been evidence based in the auditing of information contents for design engineers (Wild et al. 2010; Carey et al. 2013).

Visual representations

Henderson (1999) also focuses upon the multiplicity of purposes for which visual representations in information are suggested to be useful for (layered properties) in terms of information provision. Grebici et al. (2009) discuss this in terms of diagrams and the support it provides for Design Engineer's information understanding. Carlile (2004) and Henderson (1991) illustrate the communicative properties of visual media especially in crossing expertise boundaries. Card et al. (1999) devote an entire chapter of their book to focus upon complex documents as they are a source of need for visual methods. Similar approaches present opportunities for the complex information and document resources that form the boundary between Design Engineers from different expertise or stage in a products development. Although the utilisation of visual media appears somewhat neglected in the latter stages of design.

The visual representation research thus far for design engineering has been able to provide evidence of the high proportions of visual information contents and the propensity for this data to be represented in visual forms (such as spatial or diagrammatic arrangements) (Carey et al. 2013; McAlpine et al. 2006; Wild et al. 2010; Darlington 2005; Lowe et al. 2004; Robinson 2010; Aurisicchio & Bracewell 2013)). However, research has yet to investigate the causal role of visual information content upon the understanding of design engineers when reusing information.

Accessibility Strategies

Accessibility an important factor in information utilisation (Fidel & Green 2004a), this refers to both ease of use and to physical access concerns. There are also the concerns raised by Wallace & Ahmed in (2003), who suggest that Design Engineers do not always know the information that they require and thus accessibility becomes an extension of this issue. (Edmondson 1999) also highlights the importance of accessible information for teams' cohesive behaviours and learning. Hicks et al. (2002) suggests that trusting the reliability of information is a critical issue that affects its access. Hence although not the focus of this research accessibility, quality and integrity are aspects that all need considering. Tang et al. (2010) cites that knowledge workers dedicate up to 60% of their time searching for information. Although earlier studies cite lower figures (Marsh 1997 24% and Lowe et al. 2004 20%), Robinson (2010) suggests similar figures of 40-66%. (Vianello & Ahmed 2012) find that little research is being done to investigate knowledge systems at the data level. This suggests design engineering working practice is becoming more reliant upon explicit information resources and that few research studies have investigated the design engineering utilisation of information resource contents at a data level. Kremer et al. (2004) identifies that "relevant

information objects" are critical to supporting design engineering decisions. These present gaps in the research for exploring the value of data objects in information resources for identifying their role in determining the relevance of information.

2.3.6 Wider Research for Design Engineering

Much of the extant research has focussed upon the design engineering corpus itself. However, studies such as Rocca (2012) study the use of knowledge based engineering tools from other domains. McMahon et al. (2004) takes the stance that knowledge based engineering technologies are one of the needs for design engineering. Rocca (2012) refers to the need to utilise a combination of broad and heterogeneous fields such as psychology, philosophy, artificial intelligence, engineering, business management, computer science and web technologies. This illustrates the wider applicability of information management techniques for design engineering such as data mining, ontologies and more. The wider technologies and methods for document content utilisation are reviewed in more detail in Appendix 6.

There are many cross domain issues to be considered due to the multi expertise nature of design projects. However, those of particular interest to this thesis are cognitive studies to understand the thinking that underpins design engineering process (including information processes) such as cognitive work analysis (Fidel & Pejtersen 2004). Human interaction studies include the study of cognitive science but have broader more applicable focus useful applying to the design engineering information interactions research currently seeks to understand. Decision making theory that is applicable to the larger design rationale decisions that is highlighted as a regular concern for design engineers, but also decision making theory applies in the information supported processes of knowledge workers such as design engineers rely upon to discriminate the value of information they view relative to the task they undertake.

Kumpulainen (2014) is an example of wider research studying human information interactions and information environments for eliciting patterns in information seeking behaviour of humans associating it with differing information supported tasks. They identify differences in "berrypicking" trails across heterogeneous information and identify trails that are synonymous with complex biomedical focussed tasks. Similarly studying the complex information supported tasks undertaken by Design Engineers would reveal patterns in their information "berrypicking" trails that are useful to understand their utilisation patterns.

The methods of other researchers are potentially useful to innovatively overcome some of the problems identified earlier such as the Storyboarding approach taken by (Wilkstrom 2013). The value of these is discussed further in Chapter 3.

The applicability of decision making theory is raised in the literature for multiple purposes. Hicks et al. (2002) is one such example referring to the need for decision making. Due to the nature of the information investigations conducted in this these decision making literature and the subject of information processing for relevance and discrimination is critical. Hence an entire section is devoted to its discussion in 2.4.

2.3.7 Human Visual Perception and Design Engineering Information

Design engineers are anecdotally described as visual thinkers and some of the design engineering research has begun to suggest the role of visual media in communication of knowledge and information across expertise and design process boundaries (Carlie 2004; Henderson 1999).

In human visual research the need for visual stimuli to process and understand information is described from a neuropsychological perspective. In the work of Cavanagh (2011) about human visual cognitive processes, he explains that the human propensity for imagery or visual stimuli is in part due to our ability to recognise object outlines before we see the intricate detail. One such example is

our ability to recognise human faces before we can see the features and thus person. Wood (2011) also identifies that our visual working memory is closely associated with our core knowledge systems and thus explains that we see in terms of representations rather than the raw data. This suggests reasons for the design engineer capability for recognising objects and patterns in information or documents by browsing them or skimming them rapidly. The utilisation of such a propensity and investigating the value of visual objects in the reuse of documents or information contents is one that shows immediate potential for more efficient processing.

This hypothesis is further supported by much of the design engineering literature. The suggestion by Rotter (2011) is that "visual elements aid personal synthesis of knowledge" and Stanković et al. (2012) interprets from Card et al. (1999) that visual information methods are for the amplification of cognition for design engineers. Burkhard (2005) compares the synergies and purposes of knowledge visualisations and information visualisations for design engineering, he states suggests we have an innate ability to process visual representations. It is thus surprising that more design engineering information research has not focussed upon the reuse of the existing visual representations of design engineers given the role they purport in amplifying cognition, especially since examples in supporting creativity are already lending themselves to visual representations using visual storyboarding techniques Wilkstrom (2013).

Many in the field of visualisation also echo these sentiments; the book by Card et al. (1999) is aptly named "Using Vision to Think". One of the authors Shneiderman (1996) in his work on visualisation (or advanced graphical interfaces) lists the key purposes of for information seeking visualisations, "overview first, zoom and filter, then details on demand". Comparing this to the Cavanagh (2011), he illustrates that human vision enables us naturally to overview first, then to zoom in on the detail later. Supporting design engineers to be able to utilise document information in a similar manner potentially removes the "overload" syndrome as the detail would not need to be sought before enabling the relevance to be discriminated.

Burkhard (2005) also suggests there are multiple purposes of visual representations and concludes that the humans channel of input is greater when we use our visual abilities as our brains have a perceptual ability to identifying patterns and visual recall is more effective than verbal recall. This suggests that for designing supporting methods to reuse information the value of visual information content is higher, for prompting recall and recognising information patterns. It is thus this value and the patterns recognisable by design engineers when viewing information that could facilitate their more efficient relevance to be determined and thus make reuse more accessible and easier (Fidel & Green 2004).

In summary more needs to be done to enable current information resources to be utilised to their full capacity and their content is valuable visual representation for design engineers to capitalise upon. It thus makes sense that research and developments should focus upon making these elements more visible and easier to access to facilitate more efficient information reuse.

2.3.8 Summary of Implications for Design Engineering Research

This section has sought to characterise the engineering design research from the literature. It has discussed the key findings of research studies, the challenges relating to the research methods that are needed to be employed for design research, the dimensions of design engineering that complicate research into explicit information reuse, the technologies thus far that have been explored to provide support for information needs, the complexity and nature of engineering design information resources, wider domain literature that pose potential for use in design engineering research and a review of the need for visual information content

utilisation. In summary, the findings of this section that are relevant to the focus for this research are:

- The information and data content studies thus far not directly comparable and research into the informative contents of resources is needed.
- The most significant gap in understanding information resources and needs is in latter stages of design and hence must be focussed upon.
- The visual nature of design engineering and human propensity for assimilating knowledge from visual information forms should be capitalised upon for easing access and understanding, making reuse much easier. Understanding the utilisation of role of such information objects will support the design of efficient reuse methods.
- Difficulties in automated solutions for design engineering document content utilisation should be addressed in research studies.
- The need of latter stages of design to utilise already documented or explicit information resources mean that research should seek to support their efficient reuse first. This includes understanding the information relevance discrimination processing that is required.
- The concerns raised for rigour and sampling for design engineering research method require careful consideration (see Chapter 3). The social aspect of information utilisation, small sample sizes, content audit potential and ethnographic study need novel method, triangulation of approaches requires grounding in wider literature and evaluation with the design engineers themselves is critical.

The focus of this research is aimed at supporting design engineers to understand, access and reuse the growing information resources they have available. Of particular interest are the prevalent documents and informative content objects and the value of how they are represented. Design engineers are knowledge and information workers, making many decisions to support the products they engineer and now provide through-life service for. The processing that is required of design engineers for deciding the relevance of information resources for supporting design engineering processes must be understood better to enable it to be researched. Hence the next section outlines the design engineering information processing and the significant decisions that are of concern to fulfil the objectives for this research.

2.4 Information Related Decisions in Design Engineering

Information overload is a concern that has spread much wider than the engineering design domain or knowledge work. It reflects the information society driven by the internet and web 2.0 technologies have made information a pervasive commodity. An informed society could in many ways be deemed positive but also has negative consequences, wading through and considering comprehensive data resources to make even simple decisions. Both at home and in the workplace there is the persistent need to make informed decisions and to determine the relevance of the information used on a regular basis.

This illustrates the impact of an "informed" vs an "overloaded" society. Increasing information resources and making informed decisions is thus a much wider research concern than for just for engineers and solutions from wider domains should be sought to reap the benefits design engineering. This section first overviews the applicability of decision making for Design Engineers and illustrates the synergies between information processing related research, decision making theory and design engineering research concerns.

Design engineering information overload in particular for the latter stages of design engineering has already been established in sections 2.2 & 2.4. The following statements from design engineering literature all suggest that there is a strong

relationship between the information processing of design engineers and their need for making decisions;

- Xie et al. (2011) refers to the high-level *decision making practices* within one such case study of design engineering information studies with a particular focus upon informing best practices from previous projects.
- Giess et al. (2008) states the provision of relevant information for design engineering is a significant demand as access to and *assimilation* of information is required.
- Tang et al. (2010) refer to the need to *evaluate* information.
- Mancilla-Amaya et al. (2012) state that reuse of knowledge and experience to make *decisions* to capitalise on assets of company requires high quality knowledge.
- Eppinger & Ulrich (1995) in stating the challenges for product designs say that "decision making" in an environment of constant change is a formidable task", "requiring thousands of such decisions".
- Liu & Boyle (2009) review the concerns of design engineering research devoting an entire section to decision support needs.
- They cite Coley et al. (2007) to be focussed upon the design engineering support required for the reasoning and problems that they solve.

The prevalence of decision making in engineering research will itself not surprise many but it highlights a need to understand the underpinning cognitive processing that is ongoing in particular for information processing for discriminating its relevance to a design engineering task. Liu & Boyle (2009) also raise the issue of understanding the behaviours and thinking that underpin this design decision making in general terms. However, the subject of this section is the literature and associated theory that enables the better understanding of how design engineers utilise information and make the decision upon its relevance to their current task. There is a need throughout this section to discuss the cognitive processes and research that underpins viewing and assimilating information and the decision making theory that is potentially representative of the types of information supported decisions design engineers face.

2.4.1 Theoretical Studies in Complex Decision Making

The importance of decision making for Design Engineers is well established in literature Eppinger & Ulrich (1995) and illustrated in the examples cited in the previous section. Much of the design engineering research in particular for information need is focussed upon establishing the data and information required to assimilate knowledge. Although not explicitly stated the purpose of such studies is to help the design of effective knowledge management support for engineers, thus for organisations the purpose of knowledge systems is to support organisations to capitalise upon knowledge resources for the purpose of making better informed decisions (M. Easterby-Smith & Lyles 2003; Alavi & Leidner 2001).

Decision making theory has emerged from organisational and management theory to characterise the processes that individuals of organisations are required to take (Bryant 2002). A number of factors are related closely in the literature to decision making theory, such as cognition for understanding the decision and thinking processes that guide the by the human decision maker (Bryant 2002). The nature of the decision process thus involves collective specialism from psychology for human behaviour Lipshitz & Strauss (1997), human information interaction for seeking "why" and "how" information resources support such decisions (Klein 2008) and management expertise to understand the applicability of such methods to organisational concerns (Nilsson et al. 2012).

A number of topics emerge in the decision making literature that are related to the design engineering process and decision concerns. These topics are represented in Figure 2.13, this shows the relative proportion of decision making literature dealing

with complexity, naturalistic field decision making and the cognitive concerns underpinning the decision making theory. These topics all relate to the needs of design engineering studies. The cognitive processes for information work for decision making is highlighted in the work by Payne (1976). The complex characteristics described about design engineering projects mean that the decisions they make are complex in their considerable dimensions. The prevalence of the key word "complex" is implied by research need and hence related literature finding. The term illustrates the complex underpinning process analysed by theorists for decision making and is similar to the engineering design information processing research.

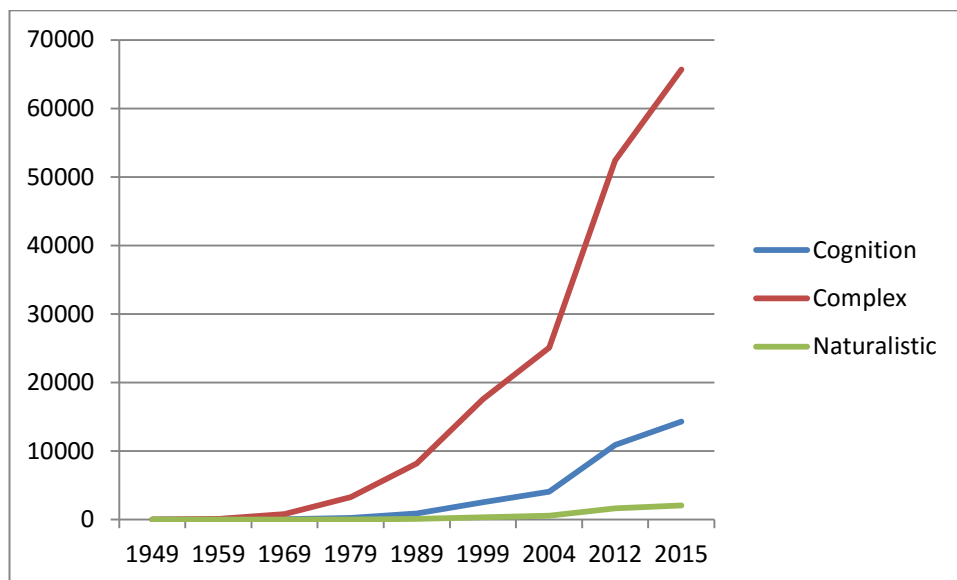


Figure 2.8: Themes in Decision Making Theory

Although relatively little research is published on the subject of naturalistic decision making in the comparison to the complex decision making literature in the Figure 2.8, the commonalities between design engineering information decision work under time and information constraint and focus of naturalistic decision making are evident. Bryant (2002) describes *naturalistic decision making theory as research into the need of humans to make decisions under time and information constraints*, hence the similarities to design engineering. This common purpose suggests the applicability of naturalistic decision making methods to design engineering informed decisions.

Design engineering research has already utilised aspects of naturalistic decisions theory to understand the processing being undertaken by design engineering users. Klein (1993) explains a sequential evaluation approach for decision making in naturalistic domains that is applicable to the types of questions that are required to be answered. He describes an iteration of scenario recognitions that either fulfil the decision makers need or the process is supported by further information seeking practices. This is similar to the approaches described by design engineers when they seek to reuse information and knowledge, first recognising a scenario and then seeking information to support or negate their hypothesis until they recognise a suitable solution (Duffy et al. 1995).

The research of Lipshitz & Strauss (1997) utilised naturalistic decision making processes to analyse 102 reports of decision making in uncertainty that are comparable to the decisions design engineers carry out utilising large cumbersome information collections. They find that three main causes of uncertainty could be identified, these were (1) inadequate understanding, (2) incomplete information, and (3) undifferentiated alternatives. If we compare these limitations to the research being conducted in respect of design engineer similar issues emerge.

Hence, using the theory constructed about how humans make decisions under time and information constraints of naturalistic decision making potentially offers insight into respective entities to analyse and to suggest the best process by which to understand the design engineering concerns.

2.4.2 Information Processing for Making Decisions

In the previous section the significance of naturalistic decision making for characterising “how” design engineers utilise information resources was discussed. Similarity between the Klein's (1993) model for sequential evaluation of information resources potentially mimics the sequential evaluation of document information observed in information search and retrieval for design engineering Xie (2013). Figure 2.9 below is taken from Hicks et al. (2002) and illustrates a relationship between knowledge, information and data in making design engineering decisions. This suggests that for design engineering it is essential to process data and information to either create knowledge or make decisions. Hence a close relationship between decision making process and the need to process information and data resources is visible in particular for design engineering.

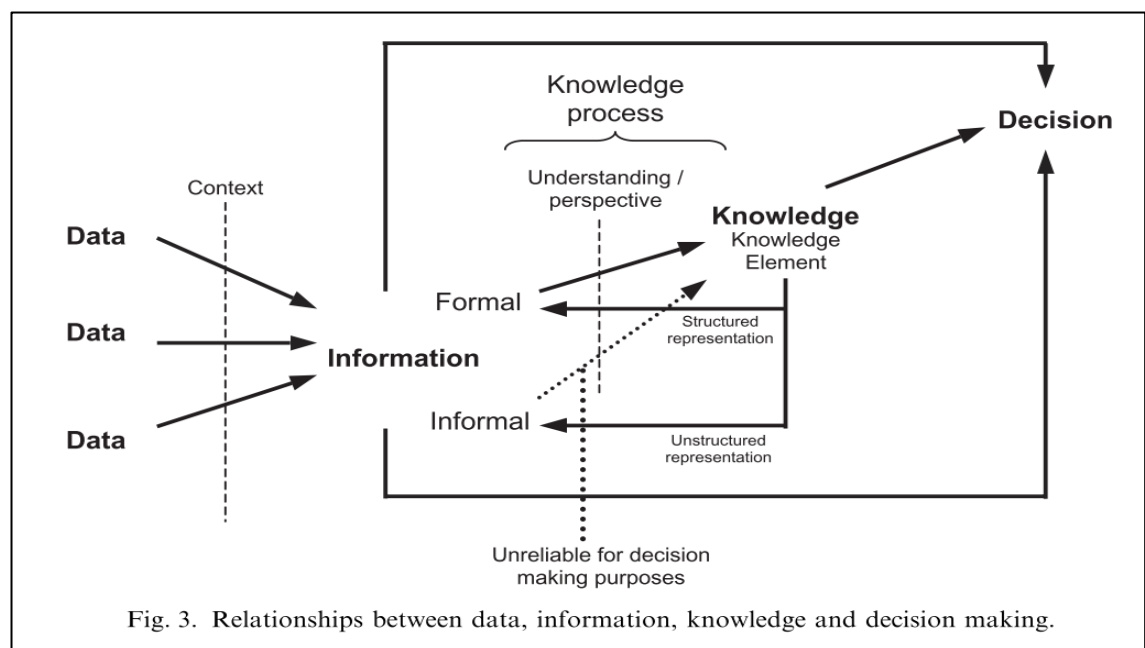


Fig. 3. Relationships between data, information, knowledge and decision making.

Figure 2.9: Hicks et al. (2002) Knowledge, Information and Data

The previous information related study presented in section 2.3 does not seek specifically to investigate the information and cognitive needs of design engineers when utilising information resources. When using the information from these studies in isolation or for comparing general design engineering findings it is valid to assume that they are applicable. *In other words they seek to find the “what” of information need for design engineers but not the “how do they use it?” or the “why is it useful?” questions that need to be answered.* Hence for the dynamic questions related to information processing these studies need to be built upon and deeper understanding of the issue sought.

Knowledge workers are deemed to be complex information supported human decision makers (Tang et al. 2010) this is true of design engineers and is evident in the nature of information rich processing that is elicited from the literature. Design engineers are expected to “assimilate, rationalise, arbitrate and authenticate large amounts of information sources in many formats” (McAlpine et al. 2006). All of these words relate to sub processes within the decision making umbrella and hence information processing must be critical to the overarching decisions being made.

McAlpine et al. (2006) also state that "improved information and communication has a beneficial impact upon business process, decision making and innovation", correlating the need for information processing and decision making again. Tang et al. (2010), Xie et al. (2011), Giess et al. (2008), Mancilla-Amaya et al. (2012), Eppinger & Ulrich (1995) and Liu & Boyle (2009) all associate the information need or process with the decision making process, signifying their relationship.

2.4.3 Information Processing and Relevance Decisions

Determining the relevance of information resources is critical if engineering information is to be reused. Discriminating the relevance of a specific piece of content or data is a human process due to the nature of human vision and the ability to assimilate information quickly. Supporting this information discrimination process for design engineers thus contributes to making successful decisions and the re-use of information and data..

It is recognised that as experts find it sufficiently difficult to explain their thinking or tacit processes, this must be ever more difficult in more intangible principles such as the utilisation of information and knowledge. Utilisation of information resources and document contents require assimilation of the object meanings (Kremer et al. 2004) and represent cognitive or thinking process, thus studying knowledge workers to some extent involves studying cognitive workers. The thinking demands placed upon design engineers are significantly increased as the number of resources they use for assimilation purposes increases and hence understanding this information processing in particular "how" the relevance of the information being utilised is determined is critical for this research.

Design engineering is described by Smith (1988) as a "cognitive apprenticeship". With information being at the heart of the organisations (M. Easterby-Smith & Lyles 2003) this apprenticeship extends to the information processes involved. Employing methods or conducting research that seeks to clarify the cognitive processes must thus describe some of the information processing it is associated with and provide richer meaning to "why" design engineers use such information elements in their process. These information elements if elicited in conjunction with the thinking that is undertaken can suggest "how" information content is most efficiently used.

To research this information processing methods from wider domains such as cognitive research fields are thus necessary to be employed. One example is Cognitive Task Analysis, although this is often a lengthy ethnographic research method it is useful research method for studying the underlying cognitive work being undertaken for highly specific tasks that is difficult for users to effectively describe and Fidel & Pejtersen (2004) have researched its utilisation for design engineering purpose. Although the benefits of a utilising this method are recognised, it is underutilised due to its ethnographic approaches and lengthy timescales for conducting research. This method is thus further discussed in Chapter 3 and Chapter 6.

2.4.4 Summary of Concerns for Informed Design Engineers

Decision making theory, information processing and information relevance decisions have much common ground for cross domain applicability. This common ground is embedded in the cognitive process that underpins them. The tacit nature of cognition suggests it is sufficiently difficult to be captured and this needs rigorous evaluation of approaches to ensure a valid research outcome. This is discussed further as part of a wider discussion on research method in Chapter 3.

The utilisation of decision making theories (and in particular naturalistic decision making) are likely to be critical for providing rich detail and thus the applicability of decision making is further summarised in the next section and in Chapter 6. In

particular the relevance of naturalistic approaches to understanding the construction of informed theories for reusing design engineering artefacts arises.

2.5 Research into Decision Making Theory

It is widely accepted that design engineering process requires complex judgements and decisions to enable products to be developed (Eppinger & Ulrich 1995), although research into how design engineers make these decisions is sparse in particular for the latter stages of design. There is one example of engineering design and decision making in the work conducted by Lipshitz et al. (2001). Lipshitz et al. (2001) conduct research studies with multiple audiences to understand how expert decisions are made in naturalistic settings, design engineers are identified as complex decision makers and included in the participants. However, this study is focussed upon eliciting the complex decision making process and originate from decision making theoreticians; hence there is a gap in the design engineering literature to specifically focus upon design engineering decision making processes. However, it is still possible to relate this much decision making theory to the complex remit of design engineering processes.

Much literature within the design engineering domain highlights the significance of the complex information requirements, the strict time and cost constraints, and so on. Substantial similarity can be drawn between facets of design engineering and other complex judgement scenarios studied within decision making theory in particular to other time constrained information supported decision examples. One example is the clinical judgements made by medical staff in accident and emergency departments, where time critical decisions save lives (Lipshitz et al. 2001) utilising complex information such as disparate medical records (Sittig et al. 2010). Therefore the methods researched for example in naturalistic decision making theory in the next section to enable support for other complex domains also applies also to the scenarios faced by design engineers (Lipshitz et al. 2001). The next section describes the research from naturalistic decision making and highlights the overlap with design engineering decision making.

2.5.1 Naturalistic Decision Making

Oppenheimer & Kelso (2015) review early decision making theory, explaining that its origins come from the human need to rationalise options for economic benefit. He goes on to describe fundamental holes that have appeared in this theory as a result of the number of anomalies that have appeared in the literature. This is likely due to "fundamental misconstrual of what scientists think they are investigating", later relating this to the missed opportunities of scientists to understand the information processing that has been undertaken by humans when making decisions. (Turpin & Marais 2004) also notice that decision support software is often not utilised by managers as was intended, suggesting they do not support the practical decision process. Differences in decision making approaches are also observed in the thesis study of (Diaz 2010), highlighting that as time pressures and information constraints take over the decision maker there is more risk introduced and humans tend to begin to satisfice with information resources rather than to optimise. Understanding this decision making process in depth and its supporting information processing means that information support could reduce this satisficing need and potentially reduce the risk of decision makers overlooking optimal solutions.

Research in the field of naturalistic decision making (NDM) has attempted to mitigate this by observing expert decision-makers in situ, to observe the decision making practice under uncertainty and the informational influences sought in conjunction with one another (Lipshitz & Strauss 1997). However Lipshitz et al. (2001) and (Bryant 2002) thus far limit the applicability of such measures to expert and complex decisions. The complex, expert focussed and information supported nature of naturalistic decision making is suggestive that the decision process it describes is similar in nature to that of design engineers, similarly working under

the constraints of information need, limited time and complexity (Bracewell & Wallace 2003). Naturalistic Decision Making theory is thus a basis for understanding the underpinning decision process that is undertaken by design engineers.

Two features of NDM that make it an applicable framework for understanding the decisions of design engineers are its holistic evaluation of an entire situations or scenarios (Bryant 2002) and its situation-action based rules that are followed (Lipshitz & Strauss 1997). This compares to the design engineering decisions in that they utilise holistic scenarios to base their creation of experience and learning (Smith 1988). The need for utilising holistic design rationale is evident in the design engineering literature in the supporting tools that are being developed such as the DRED diagrammatic approaches to presenting design rationale for design engineers. It has long since been recognised that design engineers “do not reinvent the wheel” but seek similar scenarios that they can base their experience upon to reuse previous knowledge or design scenarios (Smith & Duffy 2001). Similar approaches are discussed in the design engineering information needs literature such as the need for “holistic” case based information retrieval (Xie 2013).

There are a number of generalised models from NDM literature that have emerged for suggesting how decision processes can be understood (Lipshitz et al. 2001). Bryant (2002) suggest they are very loosely defined approaches that are consistent with expert decision making covering broad cognitive aspects such as recognition, mental simulation and pattern matching. In the next section we describe a detailed NDM process first described by (Klein 1993) useful for applying information supported decisions of design engineers.

2.5.2 Recognition Primed Decision Making

Recognition Primed Decision (RPD) models were first reported in the literature in Klein (1993) belonging to the family of NDM theory. (Klein 1999) describes the RPD model as a fusion of two processes: the first is the way decision makers size up a situation to recognise the best course of action to take and secondly the imaginary way in they evaluate any such course of action. He suggests that making decisions in this way applies to highly expert and difficult decisions. This is simplified by Turpin & Marais (2004) in their review of NDM as decisions where the decision maker has the ability to recognise a situation from past experience, identify goals and cues for courses of action, evaluate any course of action by mentally simulating or visualising that action mentally and either seek more information if the situation is not recognised or until the course of action is favourable. The information seeking practices of Design Engineers are very similar and one of the original participant groups from Klein’s original study in (1993) was in fact Design Engineers.

Other perspectives and examples of the use of RPD are shown below. The application of the principles of RPD include Diaz’s (2010) presentation of a simplified view for understanding how to apply RPD for novel environments such as naval security operations:

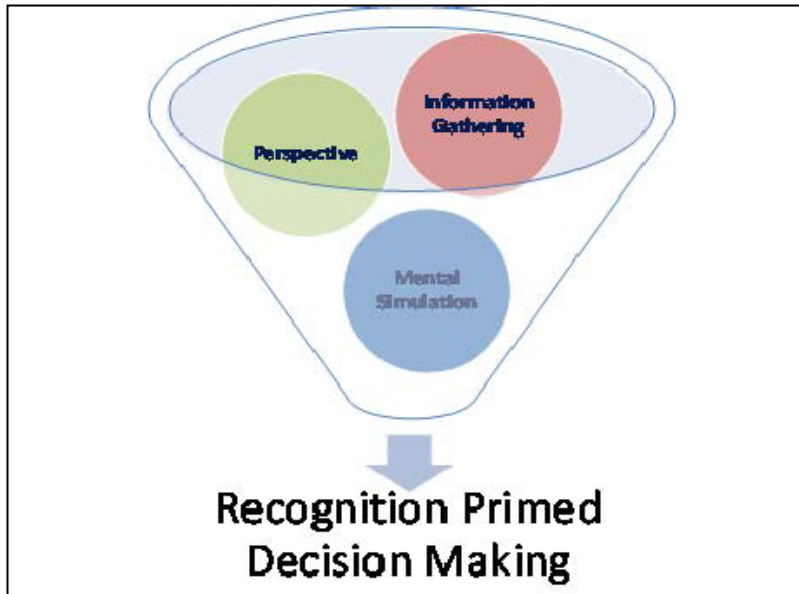


Figure 2.10: Diaz (2010): Simplified RPD

Diaz (2010) recognises the only three key aspects of RPD for encoding the decision information, and to make sense of decisions in the analysis. Diaz (2010) loosely applies selective principles of RPD and combines them with other decision making strategies. The codes she elicits as important are as illustrated the information gathering, perspective (recognition) and mental simulation stages. This example demonstrates that highly selective and limited features of the RPD process are useful in understanding complex decisions.

Another example below (Figure 2.11) illustrates a differing perspective upon the wider usefulness of the RPD process in the patent application of Yen et al. (2013). Yen et al. (2013) use a more comprehensive RPD process in a cognitive-aware software system to support agent based simulation to support homeland security teams to make more informed decisions and to reduce their information overload in decision making:

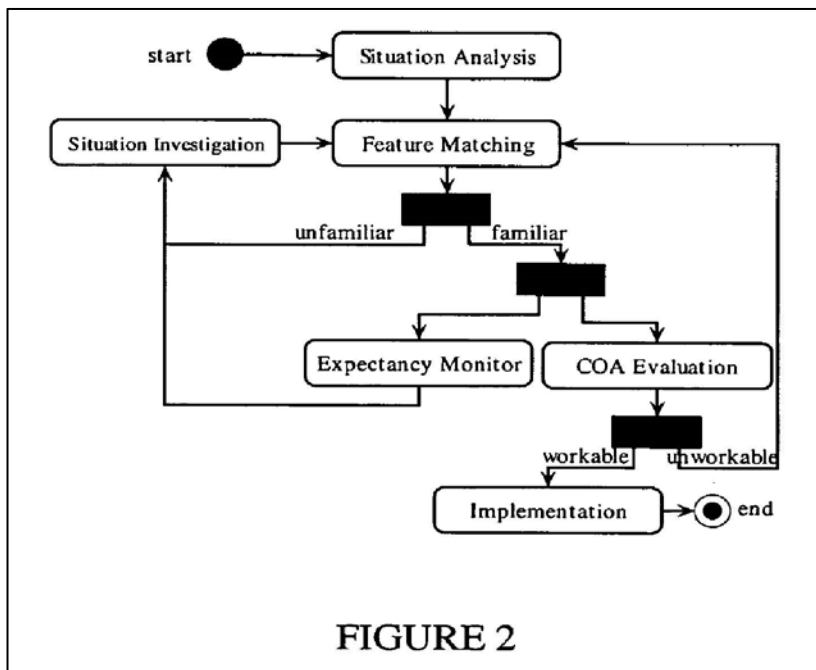


Figure 2.11: Yen et al. (2013) Patent Application RPD Process

2.6 Summary of Literature Contributions

In the early sections of this Chapter, the history of design engineering research and the precursor issues facing engineering design research have been described. This is to outline the current concerns for engineering design research and some from industry. The later sections have then concentrated on the areas of more specific concern for the current challenges. The literature examined for this purpose has been in:

- Knowledge management to highlight the concerns for the knowledge reuse,
- Design engineering research to characterise the nature and evolution of information related studies,
- The theoretical basis for decision making theory and its applicability to the relevance of design engineering information and the wider concerns of Information Technology, Human Information Interaction and Cognition and the purpose of Visual Representation and its relevance to design engineering.

It is clear that the drivers for design engineering research are as broad and complex as the processes it involves. However, the concerns identified below have not yet been solved by design engineering research:

- The heavier reliance upon information in later stage design engineering (Vijaykumar & Chakrabarti 2008), exponentially increasing service information (Jagtap & Johnson 2011), trend to capture prolific knowledge for sharing and limitations of IT solutions exacerbate information overload challenges.
- The focus for knowledge management methods upon capture, transfer and sharing in design engineering leading to the overlooking of the purpose of any reuse and those explicit resources that are most useful.
- Difficulties in conducting empirical industrial research with small number expert participants (Rosenthal 1966) due to research pressures for quantitative results and the under valuing of existing qualitative research methods due to the underestimation of reliability of any findings in research direction.
- In particular there is the recognition of the high number, high value of visual representations (Lowe et al. 2004) in engineering design and their propensity for collating and communicating design engineering information (Henderson 1991) but difficulties in re-using them (Duffy et al. 1995) leads to their underutilisation and inefficient reuse.
- The need for application of decision making theory in particular from naturalistic decision making theory is established (Klein 2008; Lipshitz et al. 2001).

Investigating the relevance, purpose and value of information collection contents and the formats required for design engineers to effectively and efficiently "reuse" them, in the latter stages of design is vital as performing under the increasing information burdens they face is unsustainable. This includes characterising "how" and "why" the informative contents of documents are utilised and for "what" purpose they are being "reused".

It is expected that the development of a theory for the importance of such contents within informed decisions to reuse specific explicit asset resources in turn will provide insight into the information utilisation patterns for in-service Design Engineers and suggest how to present information to them to better support them to discriminate their relevance much faster.

In Chapter 3, the aims and objectives for this research are outlined in more detail and the research methods to achieve them are established, especially due to the concerns raised in this chapter regarding the methods and constraints required to conduct industrial research. In Chapter 4 the industrial case is outlined adding further detail to the industrial concerns influences the research methods choices and inherent limitations for industrial studies. This chapter also highlights the importance of the objectives for this research within an industrial case.

3. Research Approach and Methods

In Chapter 1 the overarching aim for this thesis was introduced and in Chapter 2 the scope of the research was outlined. In this chapter, the research that has been designed and then conducted to assist in fulfilling the aim for this thesis is described. This includes describing the objectives that seek to achieve the overarching aim. There is a discussion of the research approach taken for achieving this and the methods employed to complete each of the objectives are described with justification for the approach.

It is necessary to relate to some of the judgements made for research approaches and objectives to the compelling industrial constraints and technological limitations elicited in Chapter 4 and Appendix 6. Hence a particular need for the research methods is to prepare experiments that allow for the use of theoretical principles of information processing facilitating the capture of what can be thought of as design engineer "thinking" approaches. This needs appropriate research methods and studies to accomplish each objective and facilitate the reuse of explicit document resources.

The focus of this research is upon explicit knowledge or document information resources and an investigation into the human information behavioural traits of design engineers. The research expertise can come from different domains than traditional design engineering s and as such have differing approaches for methodologies and approaches. While there is significant overlap in some of the objectives for these research areas their approaches can be quite different (Rocca 2012). As examples, technology developments for information and knowledge management lend themselves to creation of information support prototypes that require structured research methodologies (Bennett et al. 2010; Venkatesh et al. 2013) to elicit lists of requirements for developing technologies for latter functionally and usability evaluation (Christel & Kang 1992). For cognitive studies a human focussed approach is required to understand the underpinning thoughts of participants and research design is guided by psychology or social approaches (Shneiderman & Plaisant 2004), this requires more qualitative approaches for richer more detailed studies such as the examples in (McNeese 2004) that seeks video capture and analysis of participants. Liu & Boyle (2009) highlight in their recent review of challenges for design engineering research that the benefits of such cognitive studies are clearly valid and needed but that the methods for conducting them in design engineering research are limited to "protocol analysis" or the capture of design engineer thinking using "speaking aloud" studies and thus subject to considerable bias (Coley et al. 2007; Liu & Boyle 2009). These references are from the design engineering and information systems domains.

There has been debate in design engineering literature about the tensions and validity of quantitative and qualitative approaches (Green et al. 2002). In design research, a much more pragmatic approach (Green et al. 2002; Blessing & Chakrabarti 2009) is often more suitable to enable development of highly numerical technologies (quantitative) to support (qualitative) human design engineering users and the (quantitative) underpinning information resources (Hayes & Krippendorff 2007). Approaches that are cross applicable to wider domains could all be argued to be appropriate for this research. However, given the strengths of both qualitative and quantitative approaches (Dawson 2009; Bergman 2008) and the objectives being mixed between human focussed needs and technological information systems support the research in this thesis seeks aspects from multiple approaches for triangulation using a series of industrial and academic related studies. This triangulation means the findings and outcomes reflect real world or applied research in technological information systems for industry and more human focussed understanding for meeting the individualised needs of Design Engineers (Green et al. 2002; Coley et al. 2007; Venkatesh et al. 2013). This triangulation between quantitative and qualitative approaches studies sequentially and their respective findings to be integrated, corroborated and built upon for rich detailed

and reliable triangulated findings. It enables the joint outcomes of quantitative and qualitative studies to be combined to prepare reliable industrial evaluation.

In the next two sections, typical research paradigms and methods for information science, design engineering and psychology are discussed. The benefits to be appreciated from each in respect of this research are further developed with discussion of the potential for individual research methods. This is followed by affirmation of the original aims for this research from Chapter 1 and the objectives that are to be met to achieve this aim are fully defined. The final part of this chapter elucidates further the sequential design of the studies and the methods that are utilised to achieve the objectives.

3.1 Domain Tensions and Research Paradigms

There is significant overlap in the research aims for engineering design science, psychology and the information management sciences, where both seek to improve technologies and products for human users. Two distinct areas of focus identified are product or support functionality and the practical needs of the human users that utilise them. The cross applicability of knowledge management research is evident in the literature for managing information and data resources to optimise their organisational capitalisation (see 2.2 & 2.3). In information management, the capitalisation is upon utilisation of data and in knowledge management it is the facilitation of the capture and reuse of knowledge (Stenmark 2002; Markus 2001; Culley et al. 2002). However, the overarching methodologies and approaches of each of these domains differ significantly.

Historically in science subjects positivist approaches to research have been typical and quantitative (large participant sample) methods are thus employed to test specific hypothesis, with objective theorists deducing or converging upon causal or statistical findings (Bryman 1988; Bergmann 2008). This is historically true for engineering that lends itself to highly numerical methods and psychologists that have sought to be scientific in their approach to human research (Balnaves & Caputi 2001; Green et al. 2002; Todd 2004). Todd (2004) cites that psychologists have sought to be considered a science (rather than a social science) and have thus been driven into scientific or objective approaches using quantitative methods. This does not necessarily mean they have been more appropriate for such research but that constructivist approaches or qualitative data collection has historically been reserved for more subjective smaller participant samples of social research (Bergman 2008; Dawson 2009). The intent of qualitative research method is to seek to capture rich and broad data to infer and interpret any meanings.

In the latter constructivist approach it is accepted that the researcher is deeply involved in the interpretation of any results and thus highly influential upon findings and in the former the researcher is expected to be distant from any findings and thus not influential upon any interpretations. Arguably the objectivity and distance of the researcher in positivist approaches do not result in much more reliable findings than subjective constructivist approaches (Bergman 2008; Dawson 2009; Todd 2004; Ventkatesh et al. 2013). Summed up by (Bryman 1988) "few quantitative researchers subscribe to the view that research can be completely value-free" and hence repeatability of research is considered a measure of its validity. Upon balance the distance between the scientific values of subjective or objective approaches are thus not as far from each other as has previously been cited (Todd 2004; Balnaves & Caputi 2001) and for the purpose of this research are considered to be equally valid. This research is in agreement with Balnaves & Caputi (2001) whom have suggested that the culture of the researcher is the driver for perception of validity.

Clarke & Dawson (1999) write that evaluation studies are associated with qualitative approaches and (Bergman 2008) writes that mixed methods research utilises the benefits of opposing research approaches to mitigate for the biases of

each other. Hence for modern post-positivist purpose reliable research it is not surprising that multi –method or mixed method research approaches are becoming much more accepted and popular with researchers than single method approaches (Rossman & Rallis 2011). Hence the intention of this thesis is to combine the benefit of quantitative approaches to test the initial hypothesis of the informative content of documents and its accessibility required to support its effective reuse in design engineering resources. The outcomes from this research approach are then combined with qualitative research approaches to find deeper richer detail about the purpose of such informative content and to elicit the human needs that are satisfied by its utilisation to drive document content reuse for design engineers.

However, given the purpose of triangulated studies in the mitigation of research bias, it is still considered necessary to explore the strengths and weaknesses of any study methods that are to be employed. This is to ensure that upon triangulation any outcomes are indeed validated and reliable upon balance between the weaknesses of any data collection. The next section deals with discussing the quantitative study data collection and the qualitative data capture employed to explore their specific strengths and weaknesses and suggest precaution necessary for such research design to avoid any bias in interpretation of results.

3.2 Mixed and Multi Method Approaches

(Sternberg 1999) states that “The field of human intelligence is on the border between science and quasi-science”, leaving much debate about the methods that are appropriate for its investigation. The focus of this research is upon the knowledge and cognition of design engineers when reusing information and hence the applicability of research methods is also subject to similar fields, borders and thus debate. This section deals with the appropriateness and similarity of overarching research methodologies. Examples from design research, cognitive psychology and information sciences are used to derive the mixed method or triangulated approach that is becoming more appropriate for design engineering information research. Further attention is then paid to the actual methods employed to conduct and analyse the resulting data collected.

3.2.1 Design Research Methodology

Design Research Methodology (DRM) created by Blessing & Chakrabarti (2009) is a multidisciplinary framework born out of the lack of scientific rigour and difficulties that design engineering researchers experienced in their studies. The aim of this approach is to enable iterative cycles of descriptive and prescriptive research studies to be employed to investigate and latter application of solution. Initial stages of this methodology are used to explicitly derive measurable success criteria for the result of any research that is thus available or latter reflection, this also forms the basis for defining any research aims or objectives. The actual research methods are not defined and thus restricted by this framework but left to the researcher to decide upon those methods that are appropriate for achieving the aims of the research offering significant broad applicability and flexibility. The method flexibility and iterative sequence of the DRM framework mean that this approach is highly applicable for the investigative and prescriptive research needed to fulfil the aim for this thesis.

3.2.2 Cognitive Work Analysis

Another approach is the Cognitive Work Analysis (CWA) research framework that has been focussed upon more recently and created as a result of the need for scientific rigour in fairly new field of cognitive science (Vicente 1999) that combines the efforts of psychologists with organisational science to understand human focussed support or needs. (Fidel & Pejtersen 2004) describe CWA as a holistic approach from information science research that seeks to understand human information interaction and not to understand an individual’s mental model but to deduce models of behaviour independent from the content of their mental model. CWA does not define concrete research methods but an overarching framework to

guide the research process for rigour and reliability. Similarly Cognitive Task Analysis (CTA) has a narrower focus upon task processing and is described as an extension of traditional task analysis seeking to understand the knowledge, thought processes and goals structures for observable task performance (Schraagen et al. 2000). In CTA much focus is placed upon the skills of the researcher to enable more than just a description the experts' naive personal psychological theory being elicited (Schraagen et al. 2000). (Vicente 1999) defines steps in CTA but (Crandall et al. 2006) simply use the title to explicate the purpose of any studies leaving the methods broad. In summary Crandall et al. (2006) define CTA as studies that "try to capture what people are thinking about, what they are paying attention to, the strategies they are using to make decisions or detect problems, what they are trying to accomplish, and what they know about the way a process works." This summarises one of the key investigation needs for this research project in seeking to understand the thinking of design engineers in information processing tasks for determining its relevance for reuse and hence this approach is highly applicable to the aim for this research.

3.2.3 Classical Approaches

It is also possible that the objectives for this research could be achieved by synthesising from the explicit assets hypothesis of utilisation and importance of informative contents and thus this approach would require the comprehensive content audit of design engineering document contents (Hayes & Krippendorff 2007). Given the document collections described in Chapter 4 in the industrial context any manual document content audits would require significant time for the huge repositories (10% of the 90,000+ documents to be reliable under the metrics defined by Hayes & Krippendorff (2007) or the development and understanding of automated document content methods. Hence, this should form part of the scoping for this research prior to enabling any document content utilisation and understanding to be fully achieved.

3.2.4 Discussion

The approaches described thus far in this section could all arguably be appropriate to achieve the aims of this research and to employ multiple methods for collecting data. However, there is a need to study the design engineers information processing and need in a naturalistic setting to ensure that their current working practices are not influenced by the research process. The recreation of out of the workplace studies could potentially not be representative in the ways of working for eliciting cognitive process and thus be biased to the artificial working environment and could potentially consume significant amounts of industrialists time that they cannot afford (see section 3.3). Arguably the CWA approach is incredibly time consuming due to the nature of the ethnographic stages required to fully situate the research studies within the working environment that is being understood (Vicente 1999), meaning that conducting research on this scale might not be appropriate for industrial research into current design engineering practice. However, Crandall et al. (2006) and (Zachary, Crandall, et al. 2012) describe a "rapidised" method conducting CTA that may be more appropriate. It is also evident that extensive additional scoping studies are required to understand fully the possibilities for the utilisation of document content. For these reasons a combined mixed methods research approach is likely to be more appropriate with aspects of CWA and DRM being combined to triangulate and findings and rigorously conduct the research studies described in section 3.5.

3.2.5 Proposed Approaches

Hence, this research utilises aspects from a number of approaches to enable a triangulation of the benefits from each, using qualitative and quantitative methods to hypothesise, theorise and build upon to support and corroborate any findings. Similar difficulties in the needs for rigorous mixed method approaches are described in the information science literature due to the mixed domain purposes and focus of much research (Venkatesh et al. 2013). In Venkatesh et al. (2013) the mixed

method approach is described and referred to as the third research methodology and is seen as the strength of information science due to the “dearth” of methods and approaches. He suggests that the triangulation approach is valid providing an evaluation is conducted to support any findings.

Other design engineering literature suggests that mixed method research approaches are significant requirement for design engineering research (Green et al. 2012). Similarly, the multi-method purpose of the DRM framework created by Chakrabarti & Blessing (2009) supports the use of combined qualitative and quantitative studies in one research framework specifically for design engineering research. Hence this pragmatic approach is also taken in the research in this thesis using quantitative and qualitative research methods and combining their results with a final evaluation to validate any findings (Ventkatesh et al. 2013).

A number of scoping studies are also needed to capitalising on both primary and secondary research resources to understand the industrial background and prepare a hypothesis regarding the important content of design engineering document for reuse. A sequence of studies is then essential to test the initial hypothesis first by surveying the working practices of design engineers in reusing document information resources. Richer detail is then needed to be elicited from the design engineers in qualitative study to understand the thoughts and processing that they undertake when viewing document information contents to discriminate its relevance for reusing in their current task. The combined results from these studies are then needed to be corroborated and any evolving hypothesis evaluated in the industrial setting. To encourage any industrial uptake and design engineering engagement the evaluation methods will need to be designed to ensure that any hypothesis is tested and demonstration of the current value of any results for current design engineering practice (Carey et al. 2012). Any evaluation study will be required to test specific information utilisation principles and describe the behaviour or opinions of design engineers in utilising any demonstrations. This will require further quantitative and qualitative approaches.

As previously surmised by (Bryman 1988) researchers should not approach research without expecting or considering some bias or influence from their own participation, even for objective or quantitative methods. Venkatesh et al. (2013) also suggests that mixed method approaches are popular with researchers due to the balance of bias and mitigation that occurs naturally in combining approaches. However, the consideration of primary and secondary research resources and mitigation of researcher bias is still clearly a concern for conducting any research and thus this is considered in more detail in section 3.5 the description of the methods utilised after the objectives for this research are clarified in section 3.4. Prior to this it is necessary to be aware of the limitations of the industrial setting and the context for this research and any practical influences this exerts upon the scope of this industrial research are hence discussed in the next section.

3.3 Practical Considerations for Industrial Research

In Chapter 4 a comprehensive description of the industrial case is outlined. A number of constraints of conducting research within industry emerge that need considering in the design of any research studies. The constraints of working within industry potentially limit the possibilities for working closely with the design engineers, in part due to the cost for industrial partners in what is considered to be unproductive time with researchers (Carey et al. 2012). (Hall et al. 1995) highlight the difficulty in identifying and isolating expertise; this is a highly influential factor in industrial settings due to limited accessibility to experts, scope for conducting research methods and the small number of true expertise. It is also evident due to the complexities of design engineering process, tasks and cognition involved in this research that considerable prior understanding is needed (Schraagen et al. 2000) and thus further scoping investigations and experiments will be required to be able to create hypothesis upon the reuse of informative document contents prior to

experimentation. Hence the scoping studies for this research need to be comprehensive and utilise where possible secondary research sources to minimise the design engineering time involvement. The appropriate research methods are first outlined in section 3.5 for conducting these empirical studies and further considered in the respective chapters.

Caution needs to be exercised when considering the contextual scoping and industrial understanding for the researcher, the participant numbers available, the expertise and industrial audience and any timescales that may be required within which to conduct experiments effectively. It should also be noted that an industrial audience to engage fully, a rapport with the researcher needs to be built, and in sensitive information environments such as the aerospace case, trust and confidence in the researcher is paramount for industrial partners and personal design engineer involvement. Although these things are acknowledged within the literature (Bennett et al. 2010; Burke & Kirk 2001; Fidel & Green 2004a) the impact of these upon the scope and timescales of a project need considering in advance and reasonable limitations expected for the research project. However, it is expected that empirical and theoretical studies are still a significant requirement for achieving the objectives and overall aim and thus appropriate research methods for each will need to be considered in turn and hence the significant role of scoping experimentation to ensure the design of empirical study is thorough.

Thus far in this chapter the theoretical considerations for this research and the industrial limitations have been outlined. In the next section the aims and objectives from Chapter 1 are reaffirmed with description of how the methods used in this research thesis seek to achieve them.

3.4 Aim and Objectives of the Research

The overall guiding aim for the research in this thesis is to understand the role of visual information in documents for making information based decisions. This investigation requires an understanding of current design engineering information challenges from a number of areas.

To inform development of theory of what the informative visual elements in design engineering documents are, and why they support design engineers to both understand document content and to make a decision upon the relevance of such documents to their current task, several things need to be understood: i) the visual informative elements of documents, ii) the information supported decisions and processing undertaken by design engineers when reusing document resources and iii) the relative importance of document content elements. Secondly, novel methods are needed to study design engineers in their naturalistic setting to elicit difficult to explicate cognitive processes and supporting information content utilisation.

A number of objectives emerge to describe current and necessary utilisation of legacy and recent heterogeneous media during design engineering information processing and to suggest optimal formats for design engineer support to improve the reuse of document contents. One of the main visions for the future of this research is the provision of better engineering information systems to support the cognitive processing required of Design Engineers thus expediting crucial design and information decision making. In particular this is the nature and form of engineering design data and the sub-processes that are rich in information utilisation. It seeks to begin to describe some of the cognitive process that underpin engineering design information flow and map them to information format support requirements for design engineers. In the future this could provide a solid grounding for provision of better knowledge supported decision systems.

It is the understanding of the value of document textual and image content for discriminating the relevance of such information resources that supports the development of document representations to better portray their informative

contents and thus ease design engineering information reuse. If design engineers better present their information resources the task of information processing should become less onerous hence reducing cognitive overload (Busby 1999) and becomes much faster. Thus the design engineering need for accessible and easy to use information is much improved (Fidel & Green 2004a; Carlile 2004). This expedites the reuse of captured design engineering knowledge from explicit forms and facilitates faster reuse and synthesis of new knowledge. In turn this more rapidly inculcates previous engineering experience and reuses and implied knowledge that emerges.

3.4.1 Research Objectives

To be able to understand the role of design engineering information for its reuse it is necessary to identify what is currently making them difficult for design engineers to utilise it and what is their valuable content that drives the need to reuse them. A number of additional questions or objectives contributing to understanding the patterns of information reuse arise that need to be answered to fulfil this aim;

- i) Identify current theoretical and industrial challenges for design engineering information reuse.
- ii) Define an industrial case study that includes a typical large heterogeneous collection of data and information resource for design engineering.
- iii) Characterise the current difficulties facing design engineering practitioners in the case study.
- iv) Identify key document content (information elements) and, in particular, the role of visual representations in design engineering decisions.
- v) Describe information strategies, patterns of use and thinking processes used by design engineers in the case study.
- vi) Recommend and evaluate approaches for improving practice.

In table 3.1 the research objectives listed above are mapped to research method for addressing the objective and the relevant chapters.

Objective	Method	Chapter
OB1: Identify current theoretical and industrial challenges for design engineering information reuse.	i) Literature Review ii) Industrial Case Study	2 & 4
OB2: Define an industrial case study that includes a typical large heterogeneous collection of data and information resource for design engineering.	i) Industrial Case Study	4
OB3: Characterise the current difficulties facing design engineering practitioners in the case study.	i) Industrial Case Study ii) Survey of in-service Design Engineers	4 & 5

<p>OB4: Identify key document content (information elements) and, in particular, the role of visual representations in design engineering decisions.</p>	<p>i) Survey of in-service Design Engineers ii) Storyboard Design Engineering Workshops</p>	<p>5, 6 & 7</p>
<p>OB5: Describe information strategies, patterns of use and thinking processes used by design engineers in the case study.</p>	<p>i) Survey of in-service Design Engineers ii) Storyboard Design Engineering Workshops</p>	<p>5 & 6</p>
<p>OB6: Recommend and evaluate approaches for improving practice.</p>	<p>i) Design Engineer Evaluation Interviews ii) Decision Making Analysis Framework</p>	<p>7 & 8</p>

Table 3.1: Objectives, Data Collection Methods and Thesis Outline

3.5 Research Methods Design and Empirical Studies

In this chapter thus far, the overarching aims and the objectives have been established. The approaches needed to be taken for the studies contained in this research have been considered and outlined with some consideration for the industrial factors that have influenced those choices. The next sections use the objectives Table 3.1 to discuss further the data collection methods suitable and considerations that may be needed to ensure the rigour of its conduct. Figure 3.2 below shows an outline of the research studies to be conducted in this thesis, independent of the objectives being fulfilled illustrating how the multiple methods and results are developed and corroborated from one study to the next.

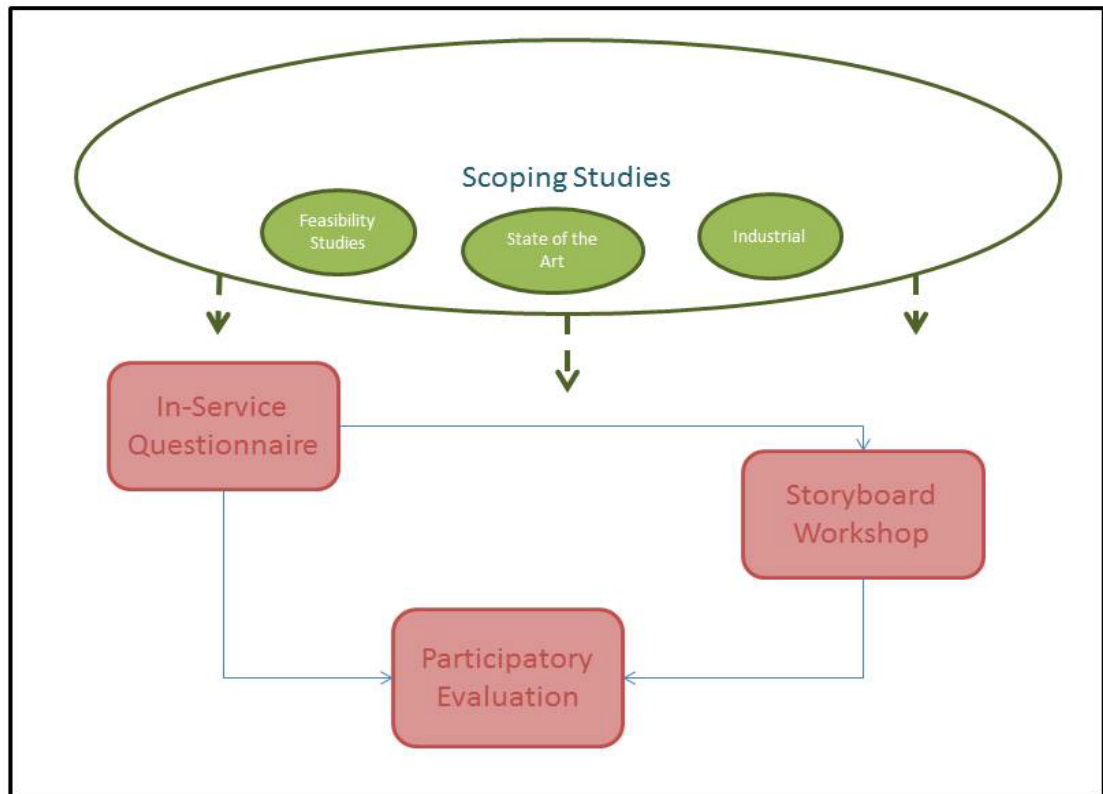


Figure 3.2: Research Findings and Data Collection Development

(Klein 1993) suggests that studying expertise in its naturalistic setting is important for observing the cognitive process underpinning that expertise. The focus of this research is upon capturing the design engineering cognitive expertise for reusing document information elements. Hence the significance of industrial studies for this research is high to capture the design engineers in their natural setting. It also highlights any potential strengths and weaknesses of such data collection method from literature resources and how the mixed method research approach chosen best mitigates for any potential industrial research reliability issues. As a reminder from section 3.2 the approach described is to utilise *a mixed methods approach* that is guided by the iterative design research framework of Chakrabarti & Blessing (2009) and the cognitive work analysis approaches described in (Zachary, Crandall, et al. 2012) and Schraagen et al. (2004 PP.4).

In Table 3.1 the objectives for this research are outlined and mapped to the methods used and chapters.. The objectives generate a need to understand theory originating from a number of domains including organisational and knowledge management, information systems, design engineering, organisational decision making theory and cognitive sciences, dealt with in Chapter 2 and extended subsequently.

Chapter 4 describes the observations, information resource audit and document content audits needed to study the case of an aerospace design engineering in-service team to understand and characterise the information resources typically available, the tasks undertaken and the current provision of support for design engineers focussing on objectives 1, 4 & 6.

The need to pay attention in particular to document information content is confirmed in the work of (Li & Ramani 2007) where they conclude that a majority of historic information is stored in document formats. As highlighted above and in Chapter 2, section 2.3, engineering documents are highlighted as a significant information resource in much of the design engineering research; as in the work by

Wild et al. (2010), Jagtap & Johnson (2011) & Xie (2013). It should be noted that utilisation of the documents themselves as the primary source of information would be preferable purely due to the minimal industrial participation cost incurred and reliance upon the researchers time and efforts (Jagtap & Johnson 2011). However these documents would be considered secondary research resources and the audit of very large samples of data would be required to conclude any results reliably (Dawson 2009). Hence there is a balance to be traded between industrial involvement and researchers' time to decide upon a suitable course of action. Hence these types of audit are considered as scoping research activities and resources in this thesis.

However, document content audits are largely manual and time consuming and for research validity Hayes & Krippendorff (2007) suggest around 10% sampling are required; hence the scale of the audit that would be required tends to limit the usefulness of this approach. Chakrabarti & Blessing (2009) suggest that small document sampling introduces bias by misrepresentation of the content and Xie (2013) suggest that the textual descriptions are unreliable due to the prolific acronyms prevalent and the ambiguity of text semantics. Hence the intention for this research is thus to audit smaller representative samples of documents to be able to make hypotheses about their usefulness to guide further empirical testing.

A number of further scoping studies have been required to build upon the findings of the literature and industrial observations to begin to elicit and describe some of the pressing technical issues limiting current industrial practice. It is worth pointing out that the technology testing utilised in Chapter 5, further extends the work and uses information science principles for software application testing such as functionality and performance to suggest the suitability of tools and technologies (Bennett et al. 2010).

3.5.1 Survey Approach

Using the hypothesis formulated from the literature studies and scoping studies about the need to reuse document information content, its current challenges and limitations for industrialists and the potential for valuable types of information and strategies for utilisation a survey has been necessary to empirically collate data to confirm our findings thus far and to rank the most pressing current challenges to focus the development of support. It is important to enable this research to be reliable that a large representative number of participants be sampled when seeking to confirm and further characterise any information utilisation challenges for design engineers. Hence a survey is an appropriate method to enable a large number of respondents to take part. This also enables sampling from participants that are in internationally based teams that are typical of design engineering teams. The empirically collected findings are thus required to be able to reliably create hypothesis about document content reuse using significant amounts of data collected. Hence the most suitable method for this data collection was survey that could be both distributed remotely and to a large number of participants (without the need for external internet access).

In using a survey method for data collection from design engineers, a number of considerations arise. Although this method of data capture is quantitative and thus objective with limited involvement of the researcher (limiting researcher bias) (Dawson 2009; Balnaves & Caputi 2001) the wording and style of any questions needs careful consideration, ensuring that the questions are suitable for depth of response and they can be interpreted as intended to enable speedy participation and accurate results to be captured. The findings of the survey and the scoping studies are broadly focussed and thus much more detailed data capture method is still required to elicit the thoughts of experts during information processing, hence the focus upon an ethnographic method to facilitate cognitive task analysis.

3.5.2 Participatory Approach

The literature findings for previous design engineering research suggest that participatory approaches are useful for the capture of difficult to encode (Jastroch & Marlowe 2010; Christel & Kang 1992) but rich cognitive data (Auriscchio et al. 2013; Coley et al. 2007). Robinson (2010) and Marsh (1997) both suggest that the nature of design engineering tasks are social and Nonaka & Takeuchi (1995) describe knowledge and information processing as a socialisation transformation from explicit to tacit forms. Limitations of previous research design engineering research for cognitive process elicitation such as participatory or action research method for suggests that significant bias is introduced by utilising "speak aloud" protocols and thus less intrusive methods are needed (Coley et al. 2007). It makes sense thus that any research method truly wishing to capture design engineering cognition needs to enable capture of data that is in its natural and socially created undertaking. Methods to enable this type of data collection are not yet evident in the methods of design engineering literature and thus novel data collection and creation methods are required that are rich and qualitative to enable the capture of intangible cognitive process.

Any deeper investigation using typical ethnographic approaches (Venkatesh et al. 2013) could take any considerable time of design engineers and thus the needs and limitations of industrial research needs careful consideration. It is evident that the qualitative research needed for the capture of rich information would likely have to adapt to small sample sizes of highly expert participants, limited time for participation and be highly responsive to the needs of design engineers for trust and data sensitivity. Pareto's law suggests that small audience samples are appropriate for information research as 20% of the entire audience can effectively elicit 80% of the issues.

3.5.3 Alternative Approach

(Sternberg et al. 2012) highlight some of the methods used in cognitive science research such as naturalistic observation, self-reports, case studies and computer simulation. Industrial focussed research for design engineering is inadvertently using some of these approaches to observing design engineers in a naturalistic setting (Baird et al. 2000) self-reports have been utilised in diary studies (Wild et al. 2010 & Robinson 2010) and in protocol analysis (Auriscchio et al. 2013) These methods suffer from similar bias due to the reluctance of design engineers to speak aloud or influences such as the Hawthorne effect that affects design engineer performance when being observed (Cash 2012; Blessing & Chakrabarti 2009).

Cognitive systems engineering are trying interesting alternative methods for observing and collecting qualitative data for latter analysis to avoid such researcher influence, such as video recordings (Schraagen et al. 2000; McNeese 2004). This is an interesting approach that enables any analysis to be conducted without the need for additional participant time, useful for naturalistic settings such as in industry. Burke & Kirk (2001) in an alternative take upon the audit of document content also describe the content of documents as highly subjective and thus requiring highly qualitative measures of content and (Hicks et al. 2006) are one example from the literature that characterise design engineering data as multi-format. The features of storyboarding are capability for capturing multi stream data without identifying an individual thus encouraging participation and allowing social construction of information process. As referred to by McNeese (2004) this could be "multi-modal data" or multi-format information object manipulation, "remote presence" of video capture of the storyboard to capture "what is in their head" at the same time as viewing their action to make correlation easy. It is thus possible to design a workshop to study for highly expert participants (primary resources of information processing) and to facilitate their working on a task in a social or naturalistic manner and capture unobtrusively incredibly rich stories of information utilisation would be incredibly useful for understanding the intricate cognitive stories created by design engineers in using them. There are very few examples of the use of

storyboards for design engineering data capture although not directly for the capture of information processing (Andersson & Eriksson 2011) and the design of the workshop is discussed further in Chapter 8.

It is difficult for experts to describe their thoughts (Jastroch 2010) and as complex to encode them (Christel & Kang 1992) hence Hayes & Krippendorff (2007) discuss the need for standardisation in encoding of content for analysis. It is important then to define appropriate measures for the encoding and further interpretation of any findings qualitatively sampled. The framework for analysing the results of the storyboarding workshop is supported by the use of a decision making literature and framework for naturalistic decision making and is outlined in Chapter 6 (Lipshitz et al. 2001).

3.5.4 The Chosen Mixed Method Approach

In Venkatesh et al. (2013) they suggest that any mixed method research is valid providing sufficient evaluation of any findings is conducted and Green et al. (2012) also suggest that mixed method design engineering research requires thorough corroboration. Hence the final research study conducted in this thesis combines the findings of the quantitative survey and the qualitative storyboarding workshop to test the hypothesised value of informative elements of design engineering documents and the value of some cognitive support. The individual evaluation opportunity is also used to demonstrate to design engineering participants the benefits of utilising different information presentations and to elicit their preference for two presentation approaches suggesting representation preference for future support.

The evaluation study findings can then be compared to the results of the previous studies to rigorously corroborate any findings. In the next section, the outcomes from this chapter are summarised and related back to the literature gap identified for this research from Chapter 2.

3.6 Research Methods Summary

This chapter has discussed the overall approach being taken to conduct this research projects and has described the considerations that have needed to be accounted for in the method construction. This need to incorporate "real world" or industrial research and scientific rigour is experienced not only in Design Engineering Research but also in other complex domains such as undertaking medical research (Venkatesh et al. 2013).

An issue that has also been raised considerably with design research is the lack of wider theoretical grounding from related areas, such as using tried and tested research methodologies from information sciences. This research has taken as a key consideration both of these needs and has integrated the practicalities of conducting "industrial" research together with the triangulation of research methodologies from information sciences and the overarching design research paradigm. This triangulation has resulted in the series of studies employing quantitative and qualitative approaches and findings that are described in the subsequent chapters of this thesis. The main contributions expected for these studies for understanding knowledge asset reuse for design engineering is highlighted in Figure 3.3 below, the four blue bubbles are the key questions that need to be considered. These research studies are the fusion of "real world" research conducted within an industrial setting with practical approaches to develop the underlying theoretical basis

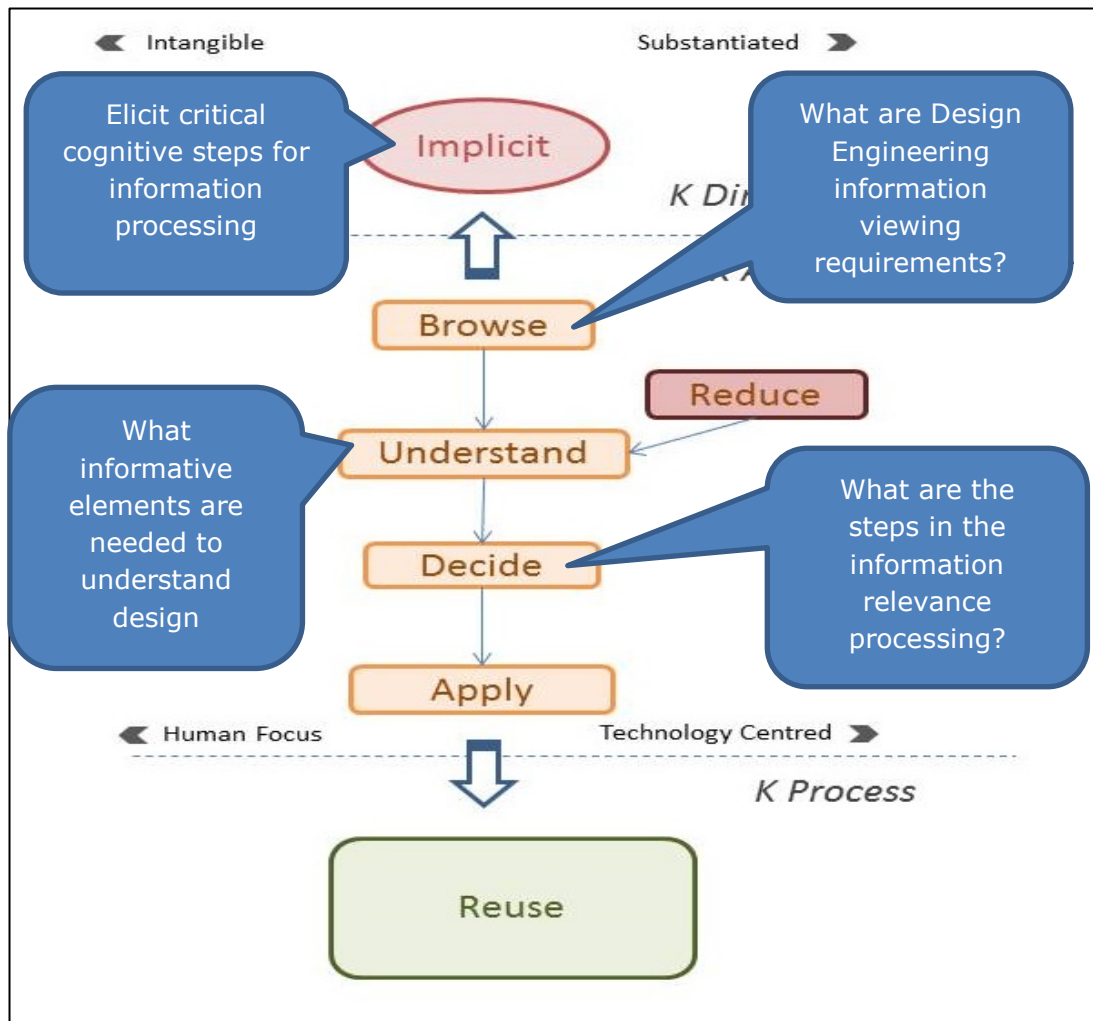


Figure 3.3: Summary of Research Approach for Filling Literature Gap

Chapter 4 now describes the context within which this research has been conducted. Some key industrial challenges are highlighted, within which the bounds of the studies have been set. Detail is provided to consider both the broader knowledge management for engineering concerns and the individual practicalities of tasks and information resources within in-service design.

4. Industrial Case Observations and Practical Influences

In Chapters 1 and 2 the key areas of literature have been discussed and in Chapter 3 an overall aim, objectives and methodology for the research has been detailed. As already discussed, the collaborating team for this research is the In-Service repair design engineering team in a large UK aerospace organisation. For practical reasons it has thus been necessary to be aware of the particular needs and capabilities of this activity, hence this chapter describes the characterisation studies conducted in industry illustrating the key concerns for in-service design engineers.

4.1 Industrial Research Context

As derived from the literature in Chapter 2, there is a key requirement for knowledge and information to support a wide variety of design processes, including the repair design process. Hence, this chapter describes the higher level knowledge and information support provision for industry based Design Engineers and the current information resources and information supported working practices of in-service design engineering teams. The approach taken is to study the case of the industrial knowledge management function with a focus upon the facilitation of explicit knowledge reuse and later the In-Service repair design team design processes and resources.

Further attention is paid to characterising the explicit knowledge and information resources available for reuse by In-Service Design Engineers. The findings of this Chapter conclude with comparison of the synthesised industrial challenges with those found in the literature from the theoretical information reuse model (see Chapter 2, Figure 2.2) and summarises the key practical constraints that influence the conduct of industrial research.

The following subsections also highlight other related work undertaken by the parent organisation, including by the wider internationally based and UK Knowledge Management and Competence team and the In-Service Wing Customer Service team. The descriptions are the result of direct observation and discussion with individual team members in management, expert and administrative roles.

4.2 International Knowledge Management Operations

The industrial case studied is a large transnational company that deals with the design, production and maintenance of aircraft. These products involve highly complex engineering projects and require vast amounts of expertise and knowledge. The lifecycle of these product families span many decades and therefore amass huge collections of design and in-service data. Managing information and knowledge resources on this scale requires expertise and considerable effort; therefore the company has dedicated teams and resources to manage knowledge concerns. This subsection deals with describing the role, function and purpose of this team.

4.2.1 Knowledge Management Strategy

The knowledge management team are effectively an internal consultancy team that both offer additional support services to internal teams and project management of company scale knowledge management development projects. Internal departmental budgets are expected to fund individualised consultancy and services, while the larger company funds range of tool and application developments for companywide utilisation. It is the responsibility of each management team to take ownership for their own knowledge management requirements, seek support and to negotiate any required service costs. This is conducted on an individual basis by the knowledge management project managers.

There are internal and external teams: the internal team consists of knowledge management project managers or consultants and the external contractors in the main deal with the implementation of work packages or specific technological development work packages. The company centrally recognises the importance and benefit of knowledge services but due to a slow service uptake and dissemination, have taken the decision to centralise some funding, thus encouraging the use of knowledge service provision.

The next section describes the consultancy and services provided by the knowledge management team and the role each service performs within the knowledge system spectrum (see chapter 2 for more detail about the relevance of a system in knowledge provision).

4.2.2 Knowledge Management (KM) Services

The knowledge management service offerings are hosted on internal intranet web page designed by the KM team. These are accessible by internal customers and detail the fundamentals of the industrial KM services and their associated solutions. The purpose of the intranet is to inform internal customers and encourage uptake of the KM solutions. There is a spectrum of standard services that can be requested upon consultation or alternatively an initial team assessment and analysis can be requested at cost with direction to appropriate services. It is possible for a custom made KM service; however the cost would be the responsibility of the recipient department. Figure 4.1 below is taken from the intranet web page for KM and illustrates the spectrum of services offered internally and the potential knowledge benefit.

In a majority of circumstances the internal customer is unaware of the facets of their teams knowledge needs and a consultation to evaluate and prioritise these knowledge needs is the first steps to knowledge service provision. In the illustration this service is the KMOD. This initial assessment maps out the key knowledge points and risks, and highlights appropriate solutions to be negotiated as further services.

The Table 4.2 below each KM service is summarised together with details of any supporting technologies. The purpose for each service is included and demonstrates the current industrial state of the art provision of KM services for design engineering teams. Later in this chapter, this provision is mapped to the key knowledge reuse system components described from the literature in Chapter 2, to synthesise any gaps in the current provision.



Figure 4.1: The Wheel of Knowledge Management Services

KM Service Title	Industrial Purpose	Knowledge Management Purpose
Knowledge Map of Department (KMOD)	Meetings and analysis of departmental knowledge system to manually create map identifying, evaluating and prioritising knowledge concerns.	Practical ethnographic knowledge system analysis technique to identify critical knowledge facets and prioritise risks.
Expertise Transfer (ExTra)	Systematic support for the transfer of knowledge from experts (e.g. before retirement).	Support for transfer of social and domain knowledge sources upon expertise loss.
Yellow Pages	Key words search engine to identify people, departments and expertise.	Corporate platform for implementation of communities of practice.
Professional Networks	To identify and connect professionals and experts. (See technological solution above.)	Raising the profile of Informal knowledge networks to encourage development of communities of practice.
Innovation Management	Workshops to facilitate innovation process.	Supported knowledge creation process to encourage product innovation.
Reuse, Improve and Share (RISE)	Corporate process for facilitating regular meetings post hoc to capture lessons learned.	Support for the capture of knowledge into explicit form for reuse (post hoc).
Knowledge Capture Project (KCP)	Extended in project capture of product and process knowledge.	Support for the capture of implied knowledge during product development into explicit form for reuse.
Business Search	Enterprise level search tool development project.	Enterprise level Information Search and Retrieval platform development.

Table 4.2: Knowledge Management Service Purpose

The spectrum of tools and processes offered in respect of knowledge management support appear extensive. These are also outlined in Weber et al. (2007). However, only a limited number of solutions have companywide scope such as Business Search and many solution implementations are designed to be locally integrated such as the RISE tool thus limiting the accessibility and recipients for such

knowledge creation. There is considerable overlap in the purpose for each service, the maturity of their implementations differ considerably (Business Search in particular) as does the respective internal audience. There is still a substantial need for human intervention in support provision suggesting that automated technological support within industry remains a large challenge. This need for human intervention and technological limitations limit the reach and usefulness of current knowledge support systems in industry and makes it difficult to compare any successes directly. Thus, the impact of any service is highly reliant upon the specific purpose for which knowledge is created or captured, the technological capacity of any tools and the individual budgetary constraints that influences departmental uptake of services.

The nature of localised knowledge capture restricts the influential knowledge audience, in particular for any documented knowledge assets, control of asset accessibility and updating remains the responsibility of the knowledge owner. This is in part due to challenges providing automated accessibility of information assets and the control of any knowledge captured being influenced by the focus and budget of the owning team. The take up and effectiveness of such costly services is difficult to encourage when few and unstructured measures of knowledge management uptake and successes can be demonstrated industrially to make a business case. The next two subsections discuss in more detail in the industrial services related to accessibility of information assets and the facilitation of knowledge reuse.

4.2.3 Business Information Search and Retrieval Strategy (IS&R)

This subsection focusses upon the industrial business search capabilities as the aim of this research is to investigate the reuse of such explicit information and knowledge sources.

It is not possible to publish an estimate of the current number of knowledge and information assets that it is necessary to implement search, however in Weber et al. (2007) surmises that the business search provision serviced 57,000 employees over 16 international sites, this number is subject to rapid growth. It is also noted in (Jones et al. 2015) that 108 of 574 business search queries specifically seek documents, this is the second highest search term. The sheer size and scale of operations within industry suggest that connecting all of the resources within each individual department is not currently technologically possible using one interface. It is also not possible to encode information on this scale and facilitate its retrieval specific to each and every potential uses purpose, meaning that often information assets contain prolific redundant information that is difficult for users to comprehend (or understand).

Huge challenges arise in the development of business information search and retrieval including those listed below, especially with the scale of the operation described above;

- Huge number of sources to be made accessible.
- Cost of implementing information source accessibility.
- Existing meta-data and structure of the resources.
- Motivation of the data owner for keeping resources up to date.
- Security and user access limitations for resources even within each team.
- Integrity of data assets and the need for access permissions.
- Heterogeneous format and nature of the data being accessed and viewed.
- Limitations and reliability of the network and access implications.
- Understanding limitations of multipurpose data and multi user systems.
- Additional data controls to maintain airworthiness regulation.

The cost of implementing search on this scale within industry means that although the value of a single interface to aggregate business search is recognised by the organisation the actual applications are limited to those resources financially viable to support and thus each department needs to support their own isolated information search and retrieval tools and strategies. Similar challenges are faced by individual departments with large asset repositories of heterogeneous data to manage and it is evident that there has been much requirement for developing unsupported lower level knowledge intervention.

The successes of these interventions are reported as high; this is likely due to the high level of understanding for the local user purpose and requirements as the developer is often the user development, thus encouraging utilisation. However, due to their unsupported nature these developments remain subject to multiple risks, including lack of development funds and resources to keep information sources up to date. This in turn means that interventions frequently become redundant as technologies and programmes rapidly move forward.

4.2.4 RISE & KCP, & Extra Services and Industrial Knowledge Reuse

(Huet et al. 2007), suggests that to enable design knowledge to be reusable there are four facets that need to be captured within the information. These are the design *rationale, decisions, actions and lessons learned*. A number of the knowledge services listed in table 4.2 deal support part of that capture and facilitate the reuse of the knowledge content. These are namely RISE (Reuse, Improve and Share) that facilitates the capture of post project lessons learned, KCP (Knowledge Capture and Publishing) that supports the capture of knowledge and ExTra (Expertise Transfer) that facilitates the transfer of expertise from one person to another (Weber et al. 2007). Each of these services operates as an individual entity and focus upon human facilitated knowledge processes. The necessity for human intervention in each of these services illustrates the industrial limitations of technological solutions for capturing and transferring knowledge. The independent standing of each service also demonstrates the practical limitations and complexity of human knowledge processing limiting the ability for holistic capture of knowledge for a specific purpose or audience. This results in the capture of large amounts of potentially redundant data and information that is not designed with *efficient or effective* user "understanding" and "utilisation" in mind. In practice this means the industrial focus is upon capturing knowledge from the front end of the design lifecycle and results in large repositories of poorly coded data and information for utilisation by the latter service design teams. Some of the difficulties of the capturing process also relate to the nature of design engineering process being at the forefront of cutting edge technologies, where little is yet understood about new technologies, materials and methods, exacerbating the difficulties determining what "knowledge" is important to be coded for reuse. This issue and the nature of technology and application advancements is contributing significantly to the information "overload" and the incompatibility of supporting tools for knowledge reuse in the latter stages of design engineered projects such as service provision.

4.2.5 Knowledge Management Summary

Support services within industry for knowledge management appear to cover the spectrum of knowledge requirements for industry. However, the variable take up of support suggest some real challenges in this KM area. This has been reported elsewhere in the work of (Jagtap 2008) and (Auricchio 2005) with Rolls Royce. The constraints of multi customer focus and the lack of tailoring to specific knowledge purpose limit the actual user impact and thus the effectiveness of any solution. For example what is needed to be understood by one audience capturing knowledge to produce an innovative design is considerably different than another audiences needs in understanding the rationale behind design decisions.

The knowledge users' purpose and thus requirements play a large part in the dynamics of their knowledge needs. The structure or proximity of working teams in practice also influences the needs of a user, for example those teams working remotely or internationally may be forced to rely heavily upon explicit knowledge assets due to limited communication or sharing opportunities for knowledge. In particular as a design project progresses the nature of the design teams changes and thus these issues become amplified. As a project progresses more and more design knowledge is accumulated and potentially becomes available as a resource. This increase in design knowledge is also exacerbated in the latter stages of design by the increasing data and information available, the widening expertise, increasing size of project teams, and disparity of the team members internationally.

The list below summarises the *challenges* discussed throughout this Chapter thus far specific to industrial knowledge reuse;

- No measures for effectiveness of solution or each departmental knowledge support process instantiations. (Possibly flaw in research or in industrial process).
- The gaps in provision highlighted in the diagram below in particular for knowledge reuse.
- Tailoring of specific needs or tools may not be possible as the service spectrum is high level, this may limit their usefulness at a departmental level.
- The differentiation in instantiation requirements, it is not evident how this is captured, measured or met.
- Industrial team perception is that the solutions are high level and thus not applicable at a departmental level, thus engagement in knowledge management is poor industry wide.
- Analysis and comparison of take up difficulties for different product lifecycle stages is not possible due to the lack of measurement in current take up and localised provision (work around technologies or departmental level processes).
- Cost of consultancy and service provision together with departmental budgetary constraints mean that knowledge management often do not become local priority. This is a more significant issue for service focussed teams where cost cutting reduction and lean process are important key process indicators.
- Implementation of many of the supporting Knowledge service tools are limited by the local data management resources.

Assisting technological intervention could remove the scope burden upon these services and provide service to a wider audience while improvements to individual applications could also increase the impact benefit to users by automating and removing the difficulties in information search. However, as is the case with the Business Search the challenge lies in addressing specific departmental user need and engaging the users at a much more individual level. To integrate each of the heterogeneous knowledge assets requires huge finance, lengthy exploration and individual support development for individual teams. This then does not address ongoing maintenance of any support or consider the differences in how each utilises the retrieved information.

The next sub-sections characterise the knowledge needs and systems in place industrially for the latter stages of a design project. There is a particular focus upon the explicit knowledge assets collated and "reused" by the In-Service operations for aircraft during the product lifecycle to improve and maintain.

4.3 In-Service Operations

The current In-Service team's workload and activities continue to increase significantly, supporting new and increasing product numbers, whilst continuing to be constrained by the time demands of a customer service department. This section reviews their information supported processes and thus their increasing knowledge management requirement with any associated activities to describe the information needs of In-Service design engineers.

Of particular relevance to this project is the increasing accumulation of stored information and in particular documents (or explicit knowledge) that is utilised for the design of each repair, and the need to have a complete and robust archival record which is fully accessible. Thus this section considers the in-service requirement to reuse knowledge and mine explicit historic case data for speeding up repair solution generation and activity. The current market outlook for (Airbus 2012) and (Boeing 2012) illustrates the rising aircraft numbers in service and those predicted to continue to increase in the next 20-30 years. It is expected that the number of aircraft in-service is likely to double in the next 15 years with no further personnel capability into in-service design engineering. An overview of repair In-Service activity and the records administration process is provided in the sections below.

4.3.1 In-Service Activities and Workflow Management

The In-Service team conduct tasks responding to both the requirement to repair in-service aircraft and design repairs for newer aircraft programmes as they enter in to service. The purpose of the team is to react in response to customer repair requests and to proactively seek to define repair best practice for new materials and products.

When responding to customer service requests, due to the associated customer costs, minimising aircraft repair and ground time is of paramount importance. The reuse of historic repair information is a key part of developing a proposed repair, thus of particular relevance to this report is the creation, reuse and information search strategy for documented and archived repair data.

There are multiple In-Service teams within the customer service function, each responsible for a different location on the aircraft for example the wing is dealt with by the UK in-service teams and the pylon repair is the responsibility of teams located abroad. However, the tools and working practices differ for each department but it is important that there is facilitated communication between departments as repairs on one region of an aircraft could impact another. The large nature of the aircraft product being repaired also means that within an in-service team it is possible that there is further sub-division of teams to distribute the responsibilities. In practice this means that one in-service function could have teams that reside transnationally, for example some of the "wing" in-service team are based in the UK and some are based in the US.

The focus of this research is the aircraft "Wing" In-Service customer service team. This team resides in the UK but also has contracted teams located in the US and in nearby UK offices. This heightened the teams need for communication, transnational information accessibility and effective workflow management support that is discussed in latter sub-sections. The UK design engineering teams may be distributed with workloads evenly from proactive or reactive repair tasks and the team is subdivided accordingly. The design engineering resources for the teams are fluid in nature and thus engineers are frequently seconded across the department to respond to dynamic workload. More detail is provided in the following subsection regarding the types of tasks undertaken by the subdivided teams, their information management resources and workflow management strategies.

4.3.2 In-Service Teams and Responsibilities

As introduced above, there are two main types of subdivided team within the in-service operation and these are described below. It is important to note that this does not relate to an engineer's expertise such as design or stress, this expertise facet adds further dimension to the engineering resource and workflow management and is thus discussed later on in this thesis;

The *reactive teams* deal with tasks that all have stringent customer response time expectations. The response targets are not agreed by the In-Service teams but by Customer Service interfacing teams in Toulouse that deal directly with the airlines and support them to keep the aircraft off the ground. Hence the In-Service team has limited control of the expected response timescales to which they adhere. It is important to note that the response times may vary per individual repair case (due to the customers own schedules) and often there is little comparative consistency between agreed timescale. The information created during this design repair process has previously been scanned and stored in a historic case PDF file. Currently administrative tools allow for the information to be collated by part electronic data capture and part scanned files. The result remains a PDF document collection for each repair conducted.

The *proactive teams* continue to design and develop new aircraft programmes when they enter into service, including the design of standard repairs and review of current design materials and methods. It has been suggested that the proactive type work is similar to project managed work packages. This is significantly less time pressured as the timescales are negotiated with customers as larger packages of work. Therefore time exists to plan thoroughly the organisation of any information outputs. In this instance the information created is not likely to relate to individual repair case data and is not stored as a historic PDF case file but in its current digitised file format within an intranet repository. It is possible that the data range could still consist of traditional text or image based file formats and CAD file data but also potentially includes video recordings.

However for *proactive teams*, there are specific repairs designed for aircraft recently entering into service (aircraft programmes within approximately two years of entering In-Service remain under the remit of proactive repair) and conducted by the proactive teams. The nature of these repairs could be somewhat different as newer materials and parts are introduced to aircraft programmes. In this instance the paper information packs are created and scanned as historic case files similar to a reactive repair case.

To summarise an overview of the "wing" in-service teams, tasks and overall workflow management is shown below in figure 4.3. It is evident from the additional activities undertaken by the department shown at the top of the illustration and from the information sources that a vast majority of input and output from in-service process relates to information in a document format. The documentation produced from each repair has a dual purpose, under EASA regulations there are legal requirements for the capture and retention of repair records for traceability and certification purposes. It is cited from Allen, B (2012) the legally required information was the original purpose for the formal collation of repair case records that are still retained in a company supported image database (historically a microfiche collection). However, in tandem more detailed repair case records have been amassed in PDF format, this document collection forms the repository that is regularly utilised by the in-service engineers to seek historic information.

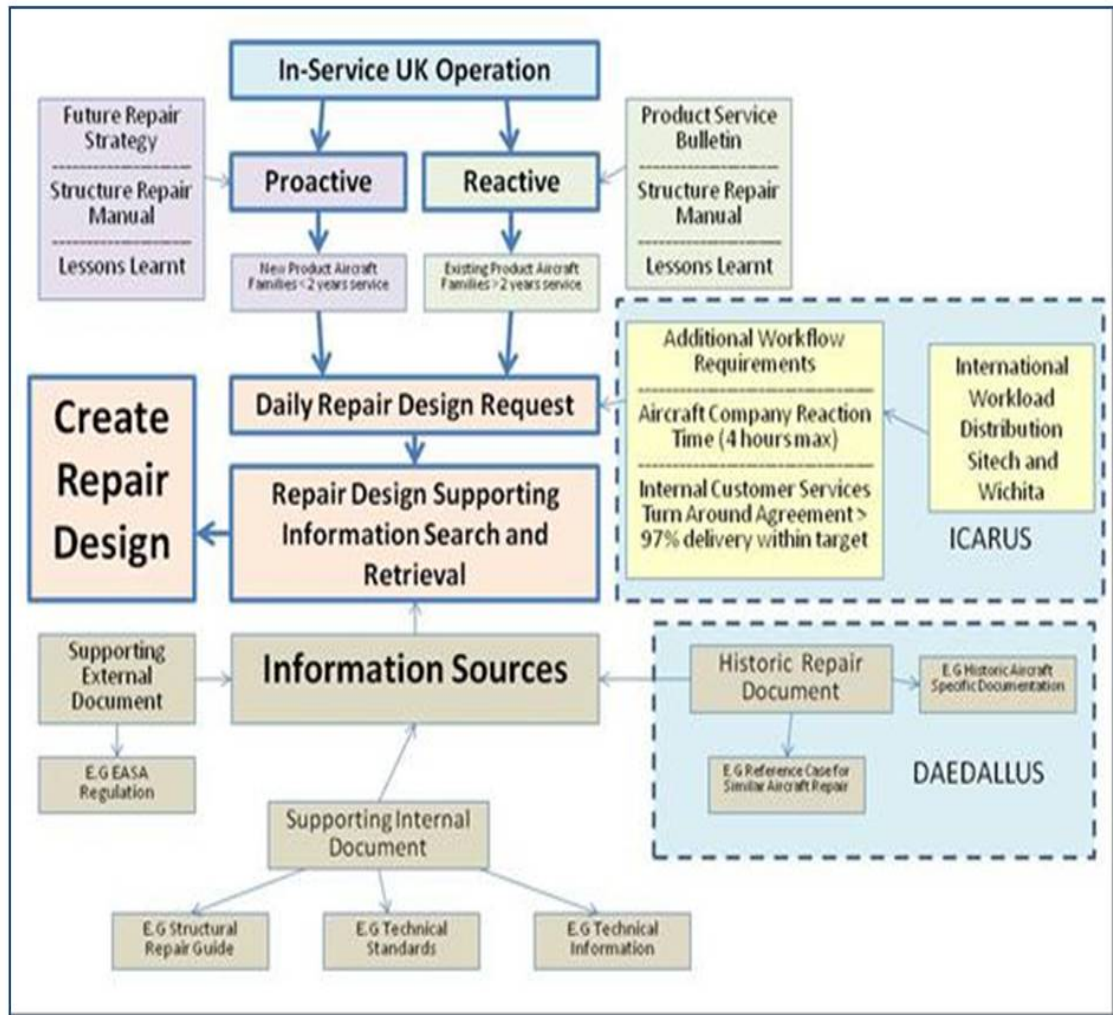


Figure 4.3: Overview of In-Service UK Teams, Tasks and Workflow.

4.3.3 In-Service Repair Process and Workload Management

The in-service team are currently responsible as detailed above for tasks and projects related to both the current and future needs of aircraft programmes, this involves designing repairs for ongoing maintenance and projects to improve the aircraft family design (described in the proactive elements of repair tasks in subsection 4.3.2). The maintenance repair workload hosts the tightest timeframes as it includes responding to daily requests for repair designs and the provision of standardised technical repair manuals for airlines. Each design engineer in the reactive in-service team is currently conducting on average 20 repair requests per week. It also influences the necessity for larger proactive projects when it is evident that there is a wider aircraft family need. The focus of this thesis is upon the latter more time constrained repair design scenario due to the imposing constraints that industry are required to overcome. However, the findings are applicable to both proactive and reactive aspects of in-service workload.

The illustration below (Figure 4.4) shows the in-service reactive repair process followed by in-service engineers to complete each repair request. The initial stages are when an airline contacts the customer service team (SEER) and the repair request is then passed to the respective in-service teams. The "ICARUS" workflow management tool is then utilised to capture the incoming repair details (via email and XML tags), this is then allocated for repair to a design engineer within the workflow management tool.

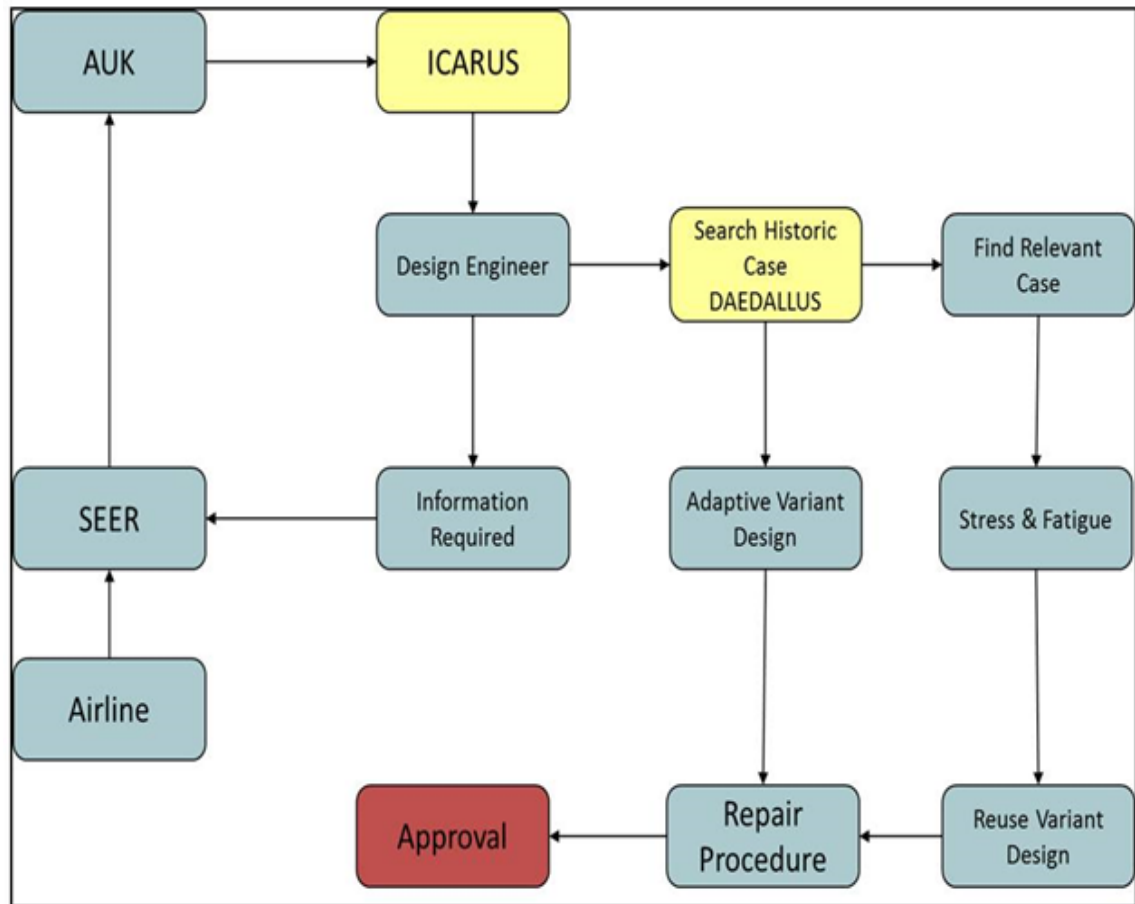


Figure 4.4: In-Service Operation and Workflow Management

ICARUS is an Oracle SQL database developed to become the in-house workflow management tool; it is developed to collate partial repair case data. ICARUS is used for workflow and case distribution to subcontracted teams, in house engineers and internationally based teams and all of these teams have access to this system. It records and offers a view of the pipeline work for each engineer, diaries future fatigue repair cases and collates information from customer service emails of repair documents and document reference numbers. Once a design engineer is allocated a case it is at this stage that the repair processing begins and in the initial stages information is then sought in the first instance from the historic repair collections or further clarification from the airline about the repair is sought. This search for a supporting historic repair case is typical of the in-service repair process and a tool named DAEDALLUS (see Figure 4.4) has been created from excel and scripting programmes enable textual information search and retrieval of suitable historic repair case information. The work undertaken to create the contextual search functionality of this tool is described in Xie (2013). The information seeking practices and the knowledge that is required to be reused is discussed in more detail in the following subsections.

The average number of cases that a reactive repair engineer is dealing with in an average week is currently approximately 20 repair cases. Each of these repair cases both utilises document information and creates the next generation of reference documents and collections. This currently represents the creation of 10,400 new repair case collections each year and the focus for information being captured is multipurpose for EASA regulation, management, administrative and for purpose of service repair, resulting in comprehensive collation of information within each document.

There were approximately 17,354 aircraft in-service at the beginning of 2015, this number is expected to more than double in the next 15 years to 35,749. This is

expected to generate at least a double in the numbers of repair requests that the engineers are creating, potentially this could result in 20,800 new documents to be added to the repair case collection each year. It is also noted that cost streamlining for airlines has forced them to deskill somewhat and thus further reliance is being felt upon the in-service teams for repair requests. Facilitating the effective storage, searching and updating and thus reuse of document collections of this magnitude under current pressures would be unsustainable for in-service teams.

4.3.4 Historic Repair Case Information Management

The in-service team archive each and every historic repair case, as discussed above this archiving complies with legal standards for retaining aircraft repair information and retrieval of supporting repair case information. In the past the collection of documents pertaining to a specific repair, have been archived in methods such as the use of paper files in cabinets or copies of paper files on a microfiche film. These repair cases are currently part digitally created PDF's and part scanned images. It is anecdotally cited that the current purpose for in-service teams to refer back to this historic document collection is for seeking historic details about an aircraft, confirmation of best practice, to find and utilise supporting calculations for EASA regulation and as a resource for experiential learning.

Administration of file archival had previously been outsourced to an externally contracted team. At this time historic information was scanned using flatbed scanners into a digital image pack for storage (scanned PDF images at 200 dpi). Accessing this information previously was time consuming and cumbersome as it was stored on microfiche copies that were requested from a central library or in locally retained paper copies. This left the in-service team with little control over the quality of the information repository as there was no engineering expertise in the administrative teams influencing the information retained. This delegation of control has led to issues such as duplication and poor quality image documents. In more recent years the information resources have been improved in quality by administration being taken over by a local in-service engineer. The recent trend to digitise all paperwork has in some ways supported the retention of comprehensive information resources; however it has added complexity and difficulty in the searching for relevant information.

This has shifted the burden of both information integrity and retrieval from the archive department, to the in-Service team, raising the teams' awareness of information management challenges. The quality of the data and supporting mechanisms for information retrieval are some of the issues that have been identified by the In-Service management team. These are exacerbated by the stringent response deadlines imposed within customer service (see right hand side of Figure 4.3), in particular for the daily repair queries. The current document management process for daily repair design request is described in subsection 4.3.5.

4.3.5 Document Management

The historic cases repair cases collection represents a significant proportion of the document information resources available to the in-service team. They also represent information spanning the entirety of the repair design process, such as the originating repair request together with any design repair documents in one collective document. When designing a repair the information from previous repair cases, current design standards, standard repair information and the newly created documents are all reused from a document format. As previously highlighted each historic repair case is stored either as a scanned bitmap images in PDF and TIFF formats or they are more recently they are made up of a combination of part image and part digital files. Each of historic repair case file is one master document containing multiple

sub-documents and each aircraft potentially has multiple historic repair cases associated with it.

The image documents that record previous repair cases were archived using a scanner to convert a paper file to a PDF bitmap for digital filing. These files were scanned and stored at 200 to 300 dpi. However, in approximately April 2014 technology support enabled part of the files to be deposited in digital form, however, the remaining paperwork is still required to be scanned as an image file, hence part image PDF's are now typically the file storage format. The nature of image documents or part image makes it particularly difficult to automate the extraction and thus reuse of information digitally, thus issues with facilitating document reuse is looked at in more detail in Chapter 5 in the preliminary studies.

The illustration in Figure 4.5 is a graphical representation of the growth of the repair case document collection (recorded by the administrator) since January 2005 when a repository was formed to support repair case history reuse. The growth of this repository is immense and reflects the impact of the digital era upon industrial information collections. The repository has expanded in September 2011 from 59,632 files in total (data storage of 72.5GB) over 95,705 files (201GB of data storage) in April 2015. Although the digitisation project to eliminate paper filing reflected some increase (2011-2012) it is evident that rapid increases in numbers of aircraft in-service (see section 4.3.3) and deskilling of airlines is resulting in rising repair requests. This data is stored locally on the in-service network and management remains the responsibility of the in-service team.

Each individual repair case ranges in size from approximately 8 pages to 600 pages and contains a wide diversity of document types for example faxes, emails, copied pages from standard sources such as repair manuals, a variety of technical document such as issue of repair instructions or drawing documents such as CAD drawings. The document contents is made up of information in an expanse of formats such as photos, sketches, references, handwritten text, symbols (signatures or annotation), typed text, calculations, data tables, formal CAD drawings, emails and more. Thus auditing of a representative sample of the documents has been necessary to ascertain more detail about facilitating their effective contents reuse and is detailed in Appendix 6. However, it is evident by the importance of this resource and the efforts placed upon facilitating their search for reuse that the historic cases contain an important source of previous practice; aircraft repair history, lessons learned and exemplar calculations.

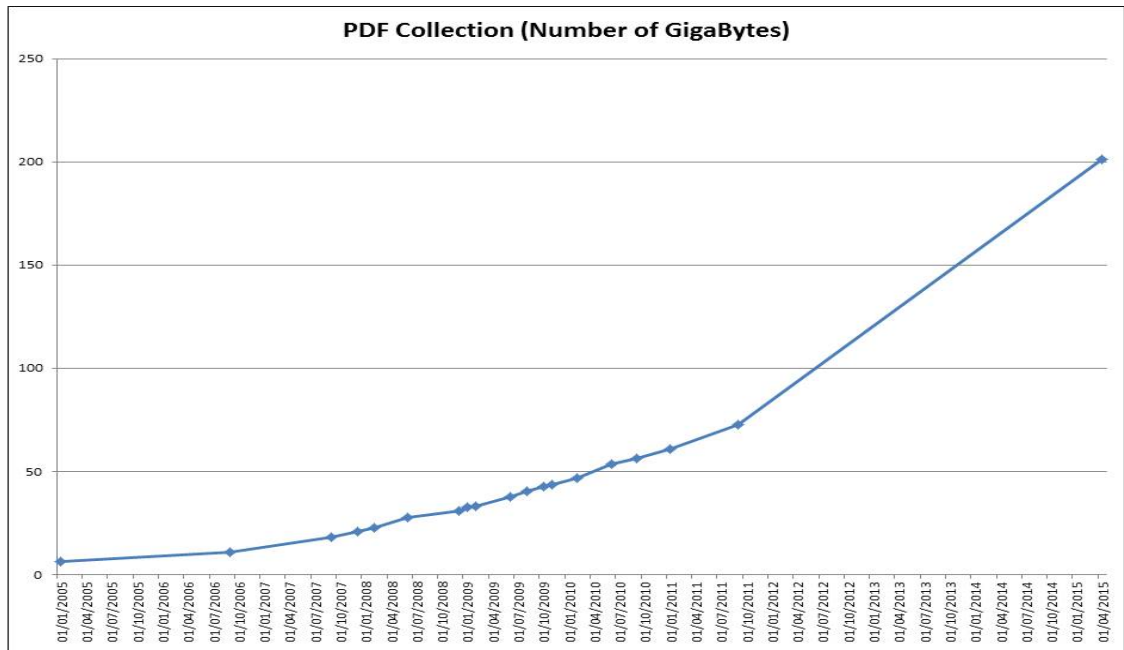


Figure 4.5: Historic PDF case file growth 2005-2015

It is important to overstate that each PDF file represented above is an individual historic repair case document and each case consists of a number of related repair information documents for the aircraft concerned. Each customer may have more than one aircraft and each aircraft may have more than one historic repair case.

As a result of the need to re-use the document information, many attempts have been made to classify and annotate the historic documents to aid information search and retrieval methods. This includes the addition of metadata such as page bookmarks to demark sub-documents and increasing speed of navigation to sub-documents within a historic case file. These bookmarks have also served the purpose of search parameter tags (adding contextual search terms) facilitating development of more sophisticated software intervention by knowledge management teams (see Carey et al. 2012, Xie et al. 2011 & Wild et al. 2006).

Given the rapid growth of the document the increasing requirement to retrieve information from these historic cases to creating new repair designs, if this department is to survive, there is a clear need for further knowledge and information systems support. A number of departmental interventions specific to the existing systems to support knowledge and information management are described in the next section.

4.3.6 In-Service Knowledge and Information Intervention

The nature of the local ownership for creation and administration of in-service data creates a need for locally managed and developed information interventions. It is evident broadly across the in-service department that a “do it yourself” approach to developing interventions exists, this is more prevalent in the reactive repair departments and may relate to the ownership of the information resources. It is also possibly influenced by the necessity for duty engineers that operate in the week and at weekends to provide round the clock in-service customer support and thus become even more reliant upon the explicit information resources available at unsociable hours to enable them to generate repair solutions.

A number of strategies and interventions have been observed that the in-service teams utilise and are described below. A majority of the observed interventions

are developed by guerrilla developers that are in-service engineers in the main. Some of these interventions are further developed and responsibility taken on by the central IT service such as AIRDOCS, DAEDALUS and ICARUS (see below), however in the main they remain the responsibility of the in-service team and thus remain localised tools.

AIRDOCS is the name of a document management tool utilised by the in-services departments for creating and annotating their repair case PDF documents. Each design engineer is responsible for adding sufficient labelling and detail to each repair case to facilitate its retrieval when searching. It assigns a case number and populates fields in a cover sheet document such as a title and date descriptive. Although this tool was developed by an international (Bremen) in-service team control is now central by the companies IT department. Due to this centralised IT control updates to this tool are not possible and thus this system does not provide comprehensive search and retrieval function for the historic repair cases but is linked to the local search tool for retrieval of summary text data only.

Historically a spreadsheet of summarised information from AIRDOCS facilitated the search of key terms for retrieving the case numbers for potentially relevant historic repair information packs. The poor performance and increasing numbers of aircraft programmes and documents has necessitated the development of enhanced functionality and additional scripts to create a contextual search tool known locally as the DAEDALUS system. DAEDALUS utilised the summarised text for each historic repair and has added semantic libraries of text and integrated scripting within excel to provide advanced search and retrieval via local document link. It is possible to update the semantic libraries to achieve more accurate information retrieval using extended semantic search propagation. Thus the aim is to reduce the retrieved list of potentially matching repair cases for an engineer to view. This intervention is locally administrated although similar contextual search facilities are now rolled out to additional in-service repair teams internationally.

Each of the individual historic repair cases contains multiple subdocuments and frequently the motivation for information search could be for example the engineering expertise such as stress. It is acknowledged that browsing documents of this size is time consuming and thus to further accelerate the information retrieval process the documents are manually annotated with bookmarks by an administrator using the Adobe PDF application. This facilitates faster traversal through an open document to specified pages or sub-documents. The bookmarking administration process is time consuming but the business benefit for accelerating information seeking are deemed sufficient to out-weigh this cost. There is little information captured about the consistency or level of bookmarking in current historic repair cases. It is clearly a manual task undertaken by few administrators and is not an audited process.

A number of other interventions to support the management of personal or team access to information resources have been observed, these include both personal strategies and group developed information navigation and accessibility interventions. Examples observed and the purpose include;

- Excel spreadsheets embedded with 3D XML models to provide location links to information.
- Scripts to interlink personal spreadsheets to local file systems for speed of accessibility.
- Personal copies made of reference documentation such as standard repair manuals to avoid accessing information in other formats and systems.
- Company "lean" processing projects to streamline information resources in particular visual management information.

- Task specific data mining and summary spreadsheets reflect management information, thus supporting business case development for proactive projects.
- Other internal departmental access of task specific summaries to support feedback of in-service learnings to early stages of design for newer programmes.
- Development of tools and technologies to provide customer access to standardised product service information.
- Location maps in spreadsheets to enable mapping of illustrations or photographs to original product models.
- Local desktop organisation of information resources (for inexperienced engineers).
- Embedded product models within Adobe PDF to map extended resources.
- Expert summaries of informative files and their locations.

There is evidence of prolific engagement in developments to improve information accessibility for reuse of explicit assets which illustrates the shortfall in current information and knowledge provision and the Chief of Design persistently seeks to engage in developing new supporting tools and technologies.

4.3.7 Summary of Key Issues for In-Service Departments

This section has characterised the working practices and support currently in place for in-service repair teams (The plural is used, as although the key participant is based in the UK, consideration and input has come from sub contract teams and teams in the USA and Germany. It is apparent that although there are central knowledge management services available to the department, there is little evidence of uptake of these services, likely due to the overarching need for document collection management and the difficulties in centralised business search technologies. Thus, the responsibility for managing the reuse of documented knowledge and information remains within the remit of the department itself, hence the number of departmental specific interventions apparent. Documented knowledge resources are clearly a prevalent information resource for in-service teams and the historic repair documents are a comprehensive collection of subdocuments containing information spanning the entire repair design process from customer inception. The multiple collections of document resources available to the entire in-service terms contain product design information from both the early and latter design stages and clearly amass as the product lifespan progresses. This begins to illustrate the differences in information reuse required between the early and latter stages of the design process. Where the in the latter stages there is additional pressure for knowledge reuse from captured explicit forms (from earlier design stages) in comparison to the tacit knowledge intensive stages of early design.

The list below summarises the current difficulties that the in-service repair teams face, each of these issues in some measure will affect the in-service team ability to effectively reuse design repair knowledge and thus impact the service provided in the future by the in-service departments;

- Expectation of product in-service numbers to double in next 15 years and current information resources likely to also double.
- Prolific information resources in the main in document format.
- Trend to capture information for storing knowledge increases information resource but not quality.
- Focus upon searching for documents with less focus upon how or what is required from each document.
- Technical difficulties in automating utilisation of documented information, in particular poor quality image document collections prevalent in in-service

create reliance upon time consuming and manual human understanding of information that is subject to multi interpretation.

- Stringent customer response expectations and little control over timescales.
- Internationally distributed in-service teams increase reliance upon explicit knowledge assets and increase network sharing issues such as data security and bandwidth for information accessibility.
- Necessity for learning from reactive repair to increase proactivity and thus competitive edge increases reliance upon reuse of product learnings from history that are in cumbersome document collections to access and summarise.
- Multipurpose nature of information capture to support legislative needs under EASA regulation, manager, administrative and in-service repair needs mean that large amounts of data are stored within same repository exacerbating search difficulties and information understanding overhead.
- Lengthy aircraft product lifecycles mean that amassed data collections cross technological eras and legacy data becomes inaccessible using current methods.
- The scale of local data growth and local responsibility for data increases prevalence of guerrilla developers for knowledge interventions; this is risky and burdensome due to lack of expertise, data quality maintenance and its time intensive nature.
- Content complexity of the historic document collections and the poor quality of storage methods make human endeavours for understanding information time consuming and unreliable.
- Increasing knowledge assets and poor quality of the information create additional challenges for search methods and tools to enable effective knowledge provision.

In Chapter 2 the idea of a tipping point for the latter stages of design was raised and the teams reliance upon effective "reuse" of knowledge to support product design teams to perform competitively (Jagtap & Johnson 2011) and it is evident that the reuse requirement for explicit knowledge and information resources within in-service design is ever more present. Hence the biggest challenge that the in-service department will face over the next 15 years is likely due to the increasing information and knowledge that overload (Boeing 2012) and effective support for utilising information from documents will be crucial to the sustainability of services for the design repair in-service teams.

As summarised above, a particular focus that has not yet been addressed within the in-service knowledge industry is the requirements for human understanding of explicit knowledge resources and the range of resources available, thus this is one focus for this research. The next section describes preliminary studies conducted to characterise and describe both the types of resources available and the format or informative contents. The aim of these preliminary studies is to provide a more detailed description of the contents of the design repair case documents to understand their contents and to begin describing the human engineering understanding requirements for in-service engineers.

4.4 In-Service Characterisation Studies

It is apparent that in-service engineers carry out complex tasks in a pressured working environment. Information seeking practices and support provision appears tailored by personal experience, expertise and the current task an engineer is undertaking. It is thus necessary to understand in detail the explicit resources and the information types available to in-service engineers to exploit in the reuse of knowledge. It is also important to understand the intended purpose and information types sought when an engineer is seeking to reuse information assets. To aid in this understanding and to support the design of appropriate research investigations an audit of the explicit information resources, the tasks undertaken and engineering expertise utilising such

information is conducted. This is to further characterise the information seeking practices of in-service engineers and includes an in depth audit of the contents of historic repair cases and an overview of the information resources available. This audit has been published in Carey et al. (2013) and is appended to this thesis.

4.5 In-Service Information Resources and Task Audit

The aim of the audit of in-service tasks and information resources is to characterise both the requirement for information seeking and the services already being provided to serve in-service engineers when seeking information from local resources. The audit was conducted informally over three, two hour lunch periods within the in-service department on an open invitation or drop-in basis. This was to encourage engineer participation and to canvass the perspectives of a broad sample of design engineering expertise. This participative research approach (Dawson 2009) this was very successful as it encouraged active participation, without impacting on the highly time constrained working environment of the engineers.

There are some interesting and varied examples of methods in the search habits of some engineers that is demonstrated in the results below.

4.5.1 Purpose of Audit

The design of this audit was to broadly investigate the points listed below and to offer further insight into the potential needs of Design Engineers that may need further investigation, thus an informal approach was considered appropriate;

- Who are the engineers and colleagues both conducting and influencing the information search requirement for in-service?
- What is the information that is being sought and what format is it currently provided in (media/visual/textual)?
- Where does this information or knowledge reside (explicitly as information on a local server or tacit knowledge of experts)?
- Why is the information being sought and how might it be utilised?
- When within in-service processes (purpose/task) is the information required?

The key findings of this audit are summarised in section 4.3.5 and further utilised to influence the creation of investigative studies conducted in this thesis in Chapters 5, 6 & 7.

4.5.2 Conducting the Audit

The audit was conducted informally over three two hour lunch time periods using informal drop-in sessions to invite In-Service engineers to participate. The audit was intentionally informal to encourage participation and to collate a perspective from a broad sample of engineer discipline expertise. This is effectively a scoping research activity as discussed in Chapter 3 shown in Figure 3.2.

At the drop-in sessions there were three flip charts available for the addition of annotated post-it notes. The post-it notes were added anonymously although where instigated the researcher was available to offer instruction. Each participant was encouraged to add as many post-it notes as they felt possible and additional resources such as "screen copies" illustrating personal information organisation or "large tabulated listed of references for informative resources" were provided by some individuals.

Each of the post-it notes was marked by the engineers themselves and contained either an information type that may be sought by the engineer, the source of information being used or the possible tasks that the engineer might be conducting. The back of the post-it note was used to denote the number of years' experience the

recording engineer had attained in in-service. Although the focus of the audit was to capture from multiple expertise the results purposely did not differentiate their requirements as defining the expertise of an engineer at this stage was deemed complex to ascertain.

4.5.3 Results and Key Highlights of the Audit

The audits were well attended and a number of 172 post-it notes reflecting information sources, 32 post-it notes reflecting the information types, 10 additional contact personnel for certain information types and two additional information seeking strategies were collected. A number of these information sources were posted multiple times thus the results were collated and analysed in some detail and the tables below reflect the collated results. A full tabulated list of the post-it notes are appended to this thesis in Appendix 1 and the summarised results have also been published in Carey et al. (2013) paper also appended to this thesis. These findings are discussed further in the discussion in section 4.5.4.

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

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 4.6: Information Supported Task and Information Source Format

Number of Audited Occurrences per Information Source Format Identified					
	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 4.7: Classified Information Resources

The following additional information provision resources and strategies were collected. These are not included in the results tables as they are outside of the scope of the audit. However they are valuable to illustrate the complexity of information seeking practices for in-service tasks and the diversity of strategies that are employed personally.

Figure 4.8 is an example from an in-service engineer with only 4 weeks experience and illustrates the vast number of resources and number of purposes each in-service engineer has to refer to information for, even in the first instances of processing in-service tasks.

Figure 4.9 below is an example checklist created by one in-service engineer of all of the important sources of information that they may be required to refer to complete in-service tasks. The large number and range of sources illustrates both the complexity of information resources and need for understanding a multitude of information formats and the importance of each potential source. It is very interesting to reflect that these very useful activities (Fig 4.8 and 4.9 are personal to the engineers own working practices).



Figure 4.8: Desktop Resources Organisation for Novice Engineer

Airbus World/AOLS	S80 Procedures Scamp	Airbus
Technical Manuals - IPC/SRM/DRM/PMS	SAP Worklist	CARS
Air Nav	Casting and Forgings	A320 DG System
Copedoc	Aircraft Information	A340 DG System
ICC	Spreadsheet	A380 DG System
ZAMIZ/Windchill drawings	Pre Defined Solutions	A400M DG System
A350 Primes	SAP(Sari etc)	A350 DG System
A400M Primes	DQN & approval	Design Product Handbooks
A380 Primes	Welding	Standards Department
IXOS Archive	Madame	M & P materials and processes
Catia/CADDS 5	Production Procurement Work	A380 DMU
ICY codes/Trevor Pierpont ICY info	Packages	A400M DMU
MODS System	Reading Drawings	PEGS via SAP
Composites (inc FPQ & 20 A1)	Tooling Engineer (see separate matrix)	Pegs (B&F)
Fasteners Inc Alts	S80 stores nationwide	CCLE
Plastic Injection Moulding AP2020	STS System	TRS
SAP/PEGS Raw Matl Catalogue	Material Masters	Data Exchange
Docmaster & Standards Department	S80 SAP planning	Loft Scanning
Alternative Materials	Quality Inc Class Parts	Suffixs
ConcessionsPMS System	Supplier Instructions ASI	Repair Planning
Aircraft MSN numbers	DPDS	Supe@airworld
S80 SAP BOMs	Harmonisation	DMS
A300/A310 eWQN System/Tracker	Suppliers Visits (see separate matrix)	SAP A400M process plannings
Toulouse Visit	Titanium Forming	Training courses attended (see separate matrix)
Hamburg Visit	Broughton Visit	
GKN Filton		

Figure 4.9: In-Service Engineers Personal Checklist

4.5.4 Discussion of Audit and Summary of Findings

The audit has been essential and very useful to character the in-service information resources and to begin suggesting their purpose for in-service tasks; however it is by no means an exhaustive study. There was little control over the engineers that participated or the value of their respective contribution to the overall audit. The level of experience of the contributor was attempted to be measured, however, this was as not successful as intended as not all participants volunteered this information.

The number of information sources was the most successfully audited result (total 172 different sources of information) and it is evident that the sources for seeking In-Service information are immense. From observation of in-service practices and the audit results it is also apparent that a majority of these sources relate to information in a traditional documented format (approximately 64% of all 172 sources reported). The two most sought after resources relate to **historic repair case information** and **standard design repair information** (combined entries for these total almost 50% of all information requirements). Other important resources were **spatial representations of information**, design request documentation and reference text.

A large variety and difference in the working practices of different engineers was highlighted, even when processing similar repair tasks. This requires careful consideration when attempting to draw similarity in working process or practices and care is needed to design solutions that may be suitable for a broad set of use cases. Alternatively each identifiable "reuse" case of knowledge will be required to be studied individually to ascertain the information requirements and outputs. The influence of differing levels of experience is also apparent in the types of information resources favoured or the range that may be utilised for similar purposes. In these circumstances it may be necessary to design research studies

that elicit further detail and thus offer deeper understanding of the information processing undertaken by in-service design engineers.

A number of additional visual interventions developed by in-Service engineers were also identified throughout the course of the information capture. The strong reference to the importance of spatial information representations means these interventions should be assessed to elicit their potential for informing engineers (by identifying the task and purpose for their construction).

The results of this study are useful to add richer detail and understanding of the in-service department and engineering requirements, this is to inform future research studies and to aid in the effective design of the necessary engineer experiments for this thesis. 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 one difficulty a person might have in explicitly describing the practices they might automatically undertake and influences the results of industrial research studies. This is one such concern that needs to be considered when designing further research studies.

The importance of the historic repair case collections and documentation is highlighted from the above audit results and thus the following section describes an audit conducted to characterise further the nature of the historic in-service repair case document collection. This contributes to the work based scenarios used in the research methods for Chapter 7, 8 & 9 and forms part of the preliminary research to guide the media extraction technologies reviewed in Chapter 5. Please see the scoping studies in Figure 3.3 of Chapter 3.

4.6 Case Study of Engineering Repair Design Documents

In section 4.3, the in-Service operation has been described in detail, including a brief view of the historic repair case document collections and the document formats that are prevalent for information storage. The repair process illustrated in figure 4.3 shows the necessity for seeking a previous repair case to support the design of each and every new repair, thus highlighting the value of storing and repeatedly reuse these explicit information assets. The purpose of this study is to analyse the content of these files to understand better their potential informative content and to assess the requirements for future information asset storage methods to facilitate better information utilisation.

4.6.1 In-Service Historic Document Collection

Many historic documents are amassed during in-service repair processes as for each repair conducted a repair case document is required to be produced. This aircraft information has been created over a period of decades for each aircraft family. When comparing the scale of the in-service repository it is useful to note that a similar collection from the front end of the design process contained a total of 2083 lessons learned documents (Jones et al. 2015). This compared to the much larger in-service collection over 90,000+ documents illustrates the larger information asset collections that amass in the latter stages of the design process and thus suggests a higher reliance upon explicit knowledge assets within in-service process. These repair case documents are utilised to capture the information throughout the entire in-service repair process (also for EASA regulation purposes) and thus for the purposes of this study the historic repair case files are a representative sample of the entire design process. As stated above this document collection numbers over a huge 90,000+ files for sampling purposes and thus are a substantial document collection available for review. It is also evident in the description that follows that the historic case files consist of a number of sub-documents that and are representative collection of media contents being utilised by design engineers.

Historic document collections can pose administrative challenges due to their non-digitised formats and this historic collection is no exception. All of the previously paper cases were being digitised in December 2012 (due to internal target for paperless working). The result of the digitisation process is a scanned document copy into individual PDF images for each repair case. This process was described in section 4.3.4 & 4.3.5, however, the resulting document collection are not easily processed digitally due to the image contents of the documents. The format of the file collections resulted in the requirement for a manual audit of their contents.

4.6.2 Audited Sample Description

A small number but representative sample of previous cases from the digital data repository have been audited to investigate the main content that the data comprises. The historic data is stored as scanned images (not using OCR – optical character recognition) and converted to PDF format. 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, to maintain the relevance of the information audited a sample was taken from more recently processed cases from 2008 onwards.

4.6.3 Visual Information Media Features

The document contents were audited for a number of items as is detailed in the section below. It is evident from the audit the historic cases consist of a number of *visual* informative elements (referred to as media features). The following is a list of the easily identifiable media objects 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 represents the sample audited and an illustration of the visual audited objects is provided below in Figure 4.10. It is remarkable to notice the diversity and extent just in this simple illustration

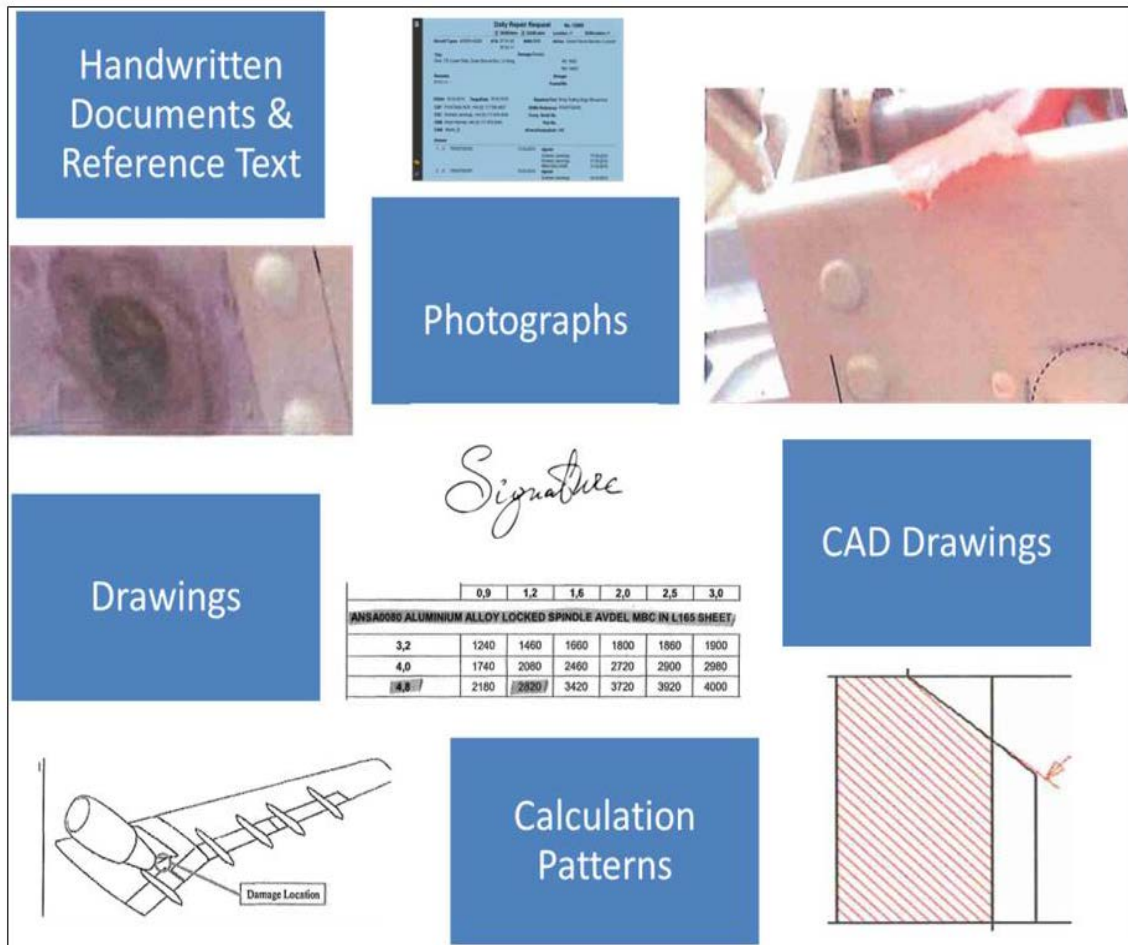


Figure 4.10 Example of visual audited information features

4.6.4 Historic Case Document Collection Analysis

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. This turnaround time includes the time taken until the final communication but does not represent additional administrative time required to file and complete each repair case. The number of individual sub-documents within each case averaged 27, however, the range found varied from a minimum of 4 sub-documents to a maximum of 50 sub-documents. Overall a number of 37 individual document types were identified, with an average of 2 A4 pages per document.

Summary	HISTORIC CASE ANALYSIS	Historic Case 1	Historic Case 2	Historic Case 3	Historic Case 4	Historic Case 5	Historic Case 6	Historic Case 7	Historic Case 8	Historic Case 9	Historic Case 10	Historic Case 11
292	Total No of Documents	18	22	4	17	15	14	17	41	50	27	8
27	Average No of Documents Per Case											
37	No of Documents Identified	9	13	5	8	8	10	10	11	23	6	7
665	Total No of Pages	84	50	8	38	42	36	64	99	133	80	31
60	Average No of Pages Per Case											
2	Average No Pages Per Document	4.7	2.3	2.0	2.2	2.8	2.6	3.8	2.4	2.7	3.0	3.9
	No of Days to Process Case	10	17	7	13	21	3	12	266	15	411	155
85	Average Processing Turnaround											
6	No of Outgoing Correspondence	9	7	1	5	5	3	3	16	12	5	1
8	No of Incoming Correspondence	7	6	1	8	5	4	5	15	13	16	3
5	No of Pages Containing Photograph	3	2	0	0	1	8	12	0	18	13	3
21	No of Pages Containing Text	18	22	4	17	15	14	17	41	48	27	8
14	No of Pages with Drawings/Annotations	31	10	1	2	13	9	19	14	36	10	12
5	No of Pages with Supporting Calculations	5	6	0	4	6	1	17	6	12	0	0
16	No of Pages with Measurements/Testing Results	19	18	1	5	8	9	21	26	58	7	9
2	No of Pages not identified by Aircraft or Case No	1	6	0	0	1	0	0	0	16	3	0
18	No of Pages identifiable by Aircraft No	17	16	4	17	14	13	17	41	34	20	8
9	No of Pages for Internal Use Only	8	13	3	5	6	7	9	11	27	6	4
15	No of Pages for External Use Only	14	13	2	13	12	9	12	33	28	26	5
5	No of Correspondence Pages using Email	7	5	1	7	3	3	1	9	0	14	3
12	No of Correspondence Pages using Fax	12	10	1	13	9	7	8	29	25	12	4

Table 4.11: Illustration of Document Complexity and Differences in Cases

Table 4.11 above illustrates a wide variety of data recorded about the historic cases. Highlighted are findings that illustrate the complexity and varied nature of the repair data being stored. 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 pages, consisting of a large number of annotated drawings, testing measurements and results. However, Historic Case 1 also contained a larger number of drawings and measurements.

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%). It must be noted however that the files did not indicate how much corresponding takes place via telephone but its regular use was evident from the recorded text.

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 does not appear to increase as may have been expected if this represented a complex repair case. Hence measuring the difficulty of the design repair must be a complex assessment that would be incredibly difficult to encode for automatic processing.

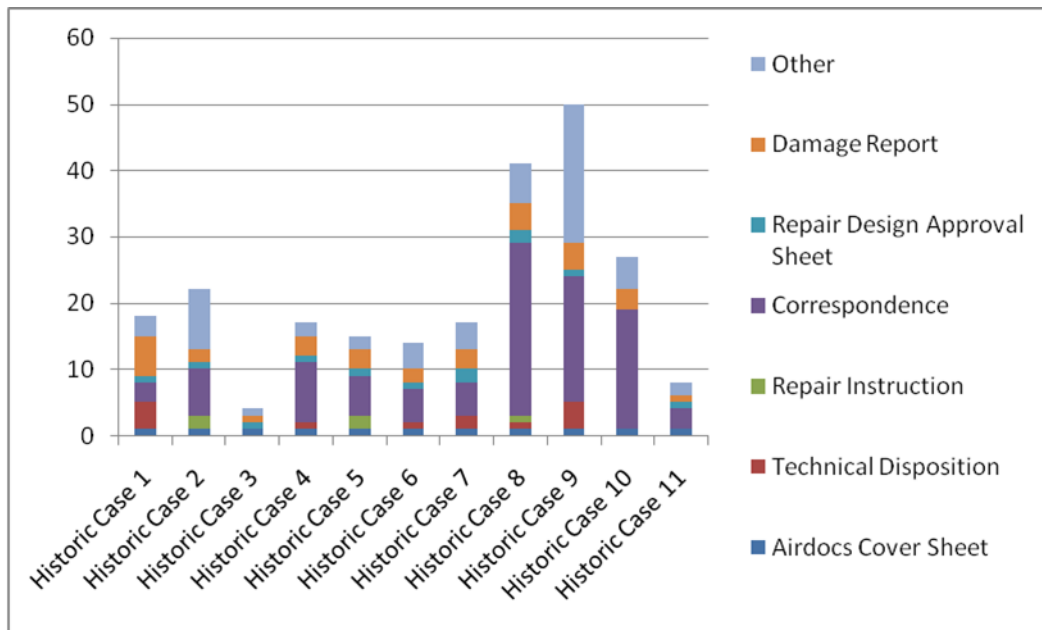


Figure 4.12: Historic Case Document Type Count

There were a large number of sub-documents types identified (37 total) see Figure 4.12 above, the main categories identified are as shown in the legend included. There were a number of sub-documents (29 sub-document types) collated together into the *Other* category as they were individual cases and low in occurrence. It should be noted that these *Other* sub-documents were deemed to be highly significant and appear to increase as the complexity of the repair case increases. For example Historic Case 2, contained 22 sub-documents, a large proportion of those were in the *Other* category. This illustrates that although overall the case was smaller, the complexity of design consideration is not reduced.

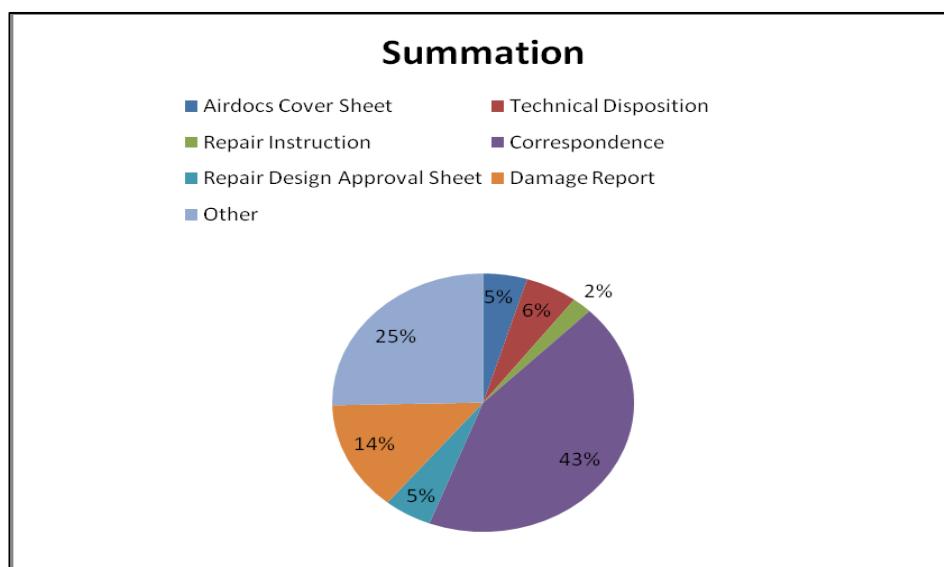


Figure 4.13: Summated Document Type Proportions

The stacked histogram shown above in Figure 4.12 also illustrates (Figure 4.12) the composition of each Historic Repair Case. The illustration shows the increase in correspondence and other documents recorded in each file as the size of the Historic Case increases. An increase in correspondence sub-documents is

considered to represent the need for additional information from an airline before completing a design. However the sub-documents recorded for any other types remains proportional for each historic repair case. This could illustrate the similarities between historic repair cases.

The proportion of document types found is illustrated (Figure 4.13) in the pie chart above. A significant proportion of the file consists of Correspondence (43%) which is further analysed below. 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.

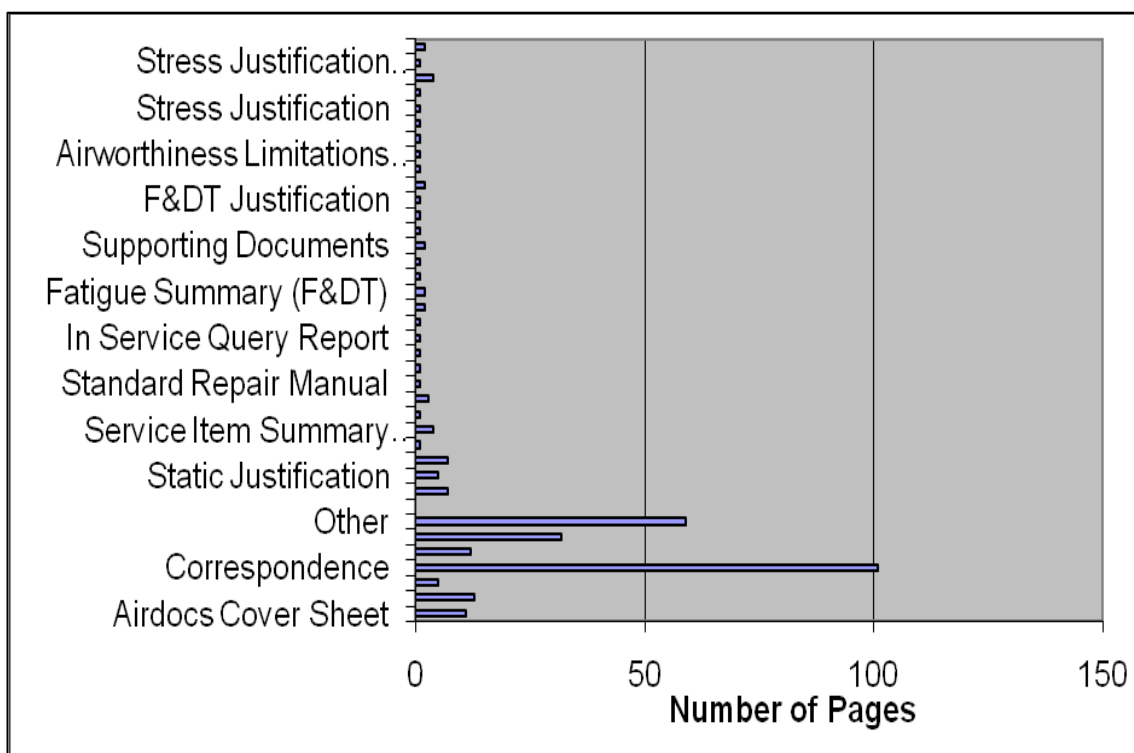


Figure 4.14: Total Number of Pages by Document Type

The bar chart in Figure 4.14 indicates the low number of pages allocated to a set of very varied but individual document classifications. The document classification names indicate the specialist nature of the content of these pages.

4.6.5 Individual Sub-Document Analysis

Each sub-document type has been analysed separately to that of the entire Historic Case file and this has been collated together. The summary in table 4.15 below represents some of the results and table 4.11 above has additional summaries. Analysing the sub-documents individually has provided more detail of the content composition for individual sub-document types in an effort to begin to rank the importance of such sub-document information for the design process.

Similarly to the Case summaries a majority of the sub-documents contain more faxed information than email information. (It appears from the documents that information is first faxed to the co-ordinating call centre in Toulouse and then scanned and emailed on to the Repair Design teams). It is evident that a proportion of corresponding occurs via telephone and these conversations are not comprehensively recorded. Thus the results of this audit may not be accurate for analysing the communication information flows for Design Engineers.

Although a majority of the Documents are indicated to be traceable by either Aircraft MSN or RMT record number (94% of cases were recorded with the Aircraft unique

identifier or repair database record number). There is still 6% of the sub-documents that would not be traceable had they not been contained within a single historic repair case document as they do not record and aircraft or historic case reference. A lesser number of sub-documents recorded the repair database record number (89%). This is significant when assessing if the file content is largely traceable using automated text recognition methods.

Percentage of Total Pages	Content Name
0.87	Faxed Correspondence
0.31	Emailed Correspondence (50% in/out)
94.1	Pages containing Aircraft MSN ID
89.1	Pages containing Repair Case ID

Table 4.15: Document Percentage Contents

The graph (Figure 4.16) shown below illustrates the sub-document decomposition into types of media. The media is recorded by instance on each A4 page and subsequently collated for each document type. It shows the differences between each document and the types of media utilised to represent informative content. All of the sub-documents contain text media, although the proportion of text varies. The Airdocs Cover Sheet content is very little text, however it is clearly a summary and the value of such text cannot be assumed. The damage reports consist as expected mainly of measurements, images and drawings. The document "Other" appears to be rich in differing media type including a proportion of calculations, drawings (formal and informal) and measurements. Further mining and investigation would be required to ascertain the useful nature of each sub-document and respective media contents.

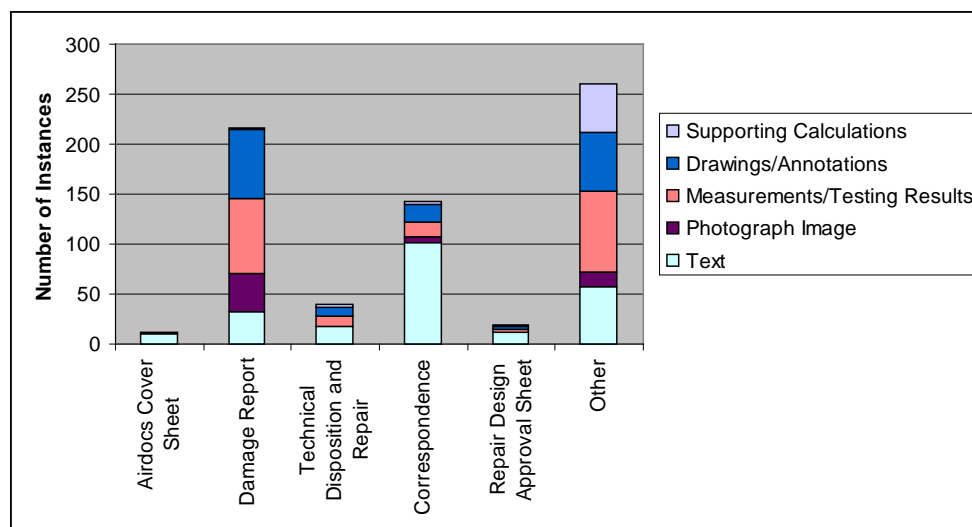


Figure 4.16: Sub-Document Media Composition

A significant proportion of the historic repair case files contain correspondence documents. The breakdown in Figure 4.17 below illustrates the media decomposition of the correspondence sub-document, which is mainly text (71%). This text clearly forms a discussion between the airline and the repair designer, potentially seeking additional information. There are a varied media content within all of the documents, which could be deemed visual in nature. The addition of this content and the high proportion found in most sub-documents, suggests that it is important in the representation of the historic repair design. This suggests that there is a significant need for illustration or visual elements to aid an engineer in the understanding of a historic repair case or sub-document. The Chief of Design is cited to state that the text contains all of the key technical information and all other information adds context and applicability.

However, it is clear that further investigation into the value of respective media communication forms is required to understand the information processing and requirements of Design Engineers.

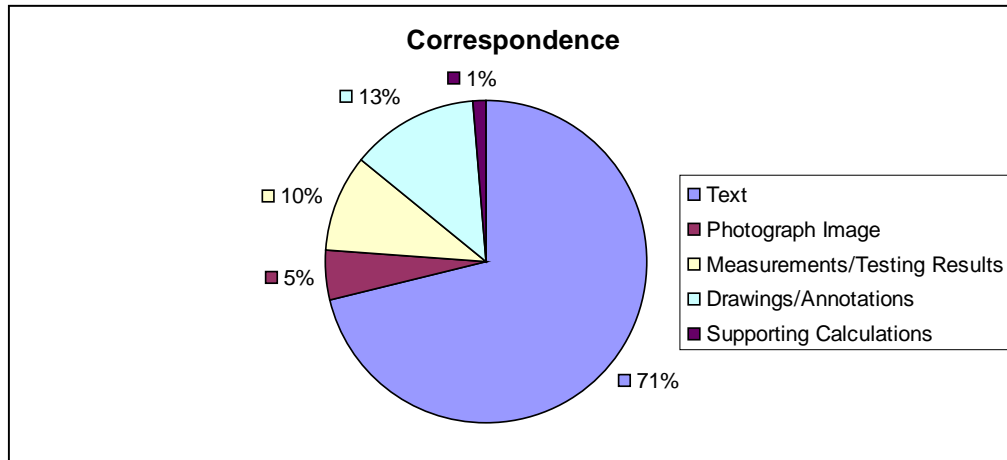


Figure 4.17: Correspondence Informative Composition

4.6.6 Audit Reliability Considerations

The sample of documents audited was small due to the comprehensive and manual requirement for this study, thus the results represent a descriptive or qualitative analysis of their content. As a representative set of data they illustrate the highly visual content of the design engineering repair cases. Also illustrated is the wide range of information media types that are available for Design Engineers to reuse. This also supports an initial definition of repair design engineering knowledge asset facets.

If this study were to be extended to enable a comprehensive data sample to be analysed a predefined coding schema for classifying their content could be constructed utilising these findings and the previous work by Darlington (2005). However statistically significant sampling rates (10% of the entire sample is suggested by Hayes & Krippendorff 2007) would be required to ensure the reliability of any findings. Considering the size of the document sample reliable evaluation of this coding schema could involve considerable time and manual auditing of huge document collections (at least 900 documents would need to be sampled). This means this approach would be appropriate for the purposes of evaluating the value of the visual media contents. Thus this document content audit is utilised therefore for descriptive analysis to guide further work requirements.

It is possible to comprehensive sample using an automated system for extracting and measuring elements for of document contents (Blessing & Chakrabarti 2009). This type of automated document manipulation system would also be required should the document content be required to be repurposed, reused or visualised. The next chapter 5 discusses in more detail the technologies that would be required and feasibility creating such a media extraction system in terms of workload, highlighting any current challenges.

4.6.7 Repair Case Content Audit Discussion and Summary of Findings

The manual requirement for the initial content analysis of the historic repair cases and sub-documents demonstrates the complexity in interpreting their informative elements. A number of clarifications have been referred back to the design engineering team and due to the complex contents of these documents there could be considerable understanding issues for inexperienced personnel. It is also possible that the contents could be subject to bias in judgements, hence the decision to audit based upon agreed classifications such as "drawings" or

standardised company document names such as "Airdocs cover sheet". Thus as discussed previously the findings of this study are best utilised to guide further investigations.

The results illustrate a large variety in the type of media used to represent information, although only five categories were utilised to produce consistent results, other than the text media four of these relate to visual media. For comparable results classifications were also utilised for the sub-document names due to immense variability. The "other" classification contained 29 additional sub-documents, this represents a large diversity of contents that suggests the complexity of the resources. This category made up a significant 25% of the entire sub-documents that would require considerable further investigation. These classifications may require review or breaking down further depending upon the level of content understanding that may be required.

Aside from this it is evident that the historic repair cases are rich in media and visual elements, this is likely to aid in repair case understanding or to effectively represent complex knowledge and ideas. For example, from Figure 4.16 it is evident that a vast majority of the sub-documents consist of mainly visual information media types. This is particularly true of the more complex "other" category and the "damage reporting" sub-documents. With the only exception being the correspondence sub-documents, this suggests that the complex ideas being portrayed are required to be represented visually to be understood and that their informative value must be high.

Analysis of the correspondence documents suggests that approximately 71% of the content is textual media. This does not suggest however that the text is useful for understanding the repair case technicalities but that in communication and clarification tasks that text serves a vital purpose. The "damage report" and the "other" documents do contain a significant majority of visual information elements (Approx. 84% and 78% respectively). It could be that analysis of the purpose and utilisation of these sub-documents may suggest the value of the visual media type.

Each of the pages is in the main identifiable by the main aircraft ID (MSN number 94% of the time) or the historic repair ID (RMT number 89% of the time). This does however mean that up to 11% of the pages of these documents would be lost if automatic text recognition were utilised to associate and annotate pages for retrieval, without further understanding this could represent a significant information loss. It is also evident that the communication mediums also included telephone conversations; however, it is not possible to include this medium within the analysis as they are not recorded within the historic documents and raises issues in reliability of the findings of content audits.

4.6.8 Repair Case Content Audit Summary of Findings

It is not possible from this analysis to suggest with any certainty what purpose the document contents may serve in how the design engineers process repair cases. However, it is possible to utilise the findings to design and conduct investigations to elicit the purpose and value of the visual document information for design engineering process.

4.7 Document Information Technical Reuse Considerations

Appendix 6 describes a number of scoping studies that have been conducted to ascertain the current technical capability of tools, technologies and techniques for supporting the reuse of document content information. The first of these scoping studies has focussed upon the current technical capability and availability of tools and technologies for supporting document content media extraction and reuse. The second part of these studies have focussed upon the typical document information

resources that are utilised and amassed by Design Engineering communities as an example of the potential and limitations of current technical developments. Below is a summary of the findings of these studies that have contributed to the focus of this thesis.

- Heterogeneous document information media reuse requires the image and text extraction and thus the available OCR software implementations available and thus software implementations are not yet suitable to support reuse of design engineering document collections.
- Performance of current combined text and image extraction software applications such as Adobe for extracting media from documents is not yet possible without considerable additional specialist low level document encoding knowledge and software development and thus is not suitable for this research.
- Automated extraction of heterogeneous media and images from design engineering documents such as described in Chapter 4.6 is not yet possible with the required level of accuracy and thus methods for this research will require manual preparation of any required resources and document representation solutions. However, this manual preparation could be supported by the design engineering document schemas (Darlington 2005a) and content audits of Chapter 4, section 4.6.
- Developmental costs, integrity and security issues highlighted in Appendix 6 suggest that it is likely to be costly to develop technical solutions and thus the grounding for any technical developments need to be well established requiring research into those document information contents most useful to design engineers. Hence the focus of this thesis is first upon the respective value of document information contents before embarking upon any technical solution implementation.
- Eliciting critical but reduced key document features (or reduced document features vector from utilisation patterns) for design engineering document contents is the required first step for this research to support the development of efficient to reuse document information representations.
- Traditional visualisation methods are not the most suitable for the design engineering document information collections (Humphrey 2013), this would support how information should be encoded for reuse and minimises document storage overheads, thus speed and accuracy of information retrieval methods could potentially improve significantly.
- The automated extraction and utilisation of text from documents is possible and useful to some extent (Hunter 2010). This alone however does not facilitate exploration of the contents of visual media in documents and thus must be employed with other research methods (McMullen 2011).

Given the findings above and the current limitations of technologies the research in this thesis first must focus on eliciting the specific utilisation patterns of design engineers to focus the future development of technologies to be specific for the reuse of information elements most useful to design engineering communities.

4.8 Summary of Industrial Challenges

This chapter has characterised the industrial concerns for design engineering with a particular focus upon the latter stages of the design process or in-service design engineering. The initial subsections have described the overarching knowledge management support resources and the in-service working practices that influence the requirement for and actual industrial “reuse” of knowledge and knowledge assets. The latter subsections have dealt with providing more detail about the information resources and their contents that are available to design engineers in industrial settings. Numerous challenges arise for industry; these shortfalls are collated and listed in the table 4.18 below. Where possible these

challenges have related the instigating problem and associated cause, then industrial impact is also shown.

Cause	Problem	Impact
High Level, Multi-customer, multi-purpose strategies and tools for wide scale knowledge management service provision. No tailoring capability for services to customers and no performance data capture to differentiate for example needs early in design vs latter stages of design.	Poor KM service uptake and unable to analyse differences in customer needs (early vs late design stages). Data stored is not kept up to date as local budget does not stretch.	Knowledge services remain high level, with little understanding of the end user needs. Leads to low user confidence and encourages guerrilla development. This in turn means knowledge responsibility remains with data owner with less knowledge management experience and data quality reduces.
Difficulties retrieving information and documents using high level services. Local need to address knowledge and information provision requirements.	Local KM Interventions and personal solutions.	Long development times and little impact from intervention, difficulties in keeping the quality of knowledge provision as resources are limited. Information kept on personal drives quickly outdates so information integrity suffers.
Knowledge capture focussed on as the most important part of a knowledge reuse service provision in particular as technical capacity has increased.	No specific knowledge "reuse" service provision (focus is upon capture of knowledge). Knowledge capture service multi-audiences and often the capturer is not the "reuser".	The specific "reuse" or user requirements are not addressed meaning the purpose for reusing knowledge is not considered before capture, results in large, multipurpose and unmaintainable (quality and integrity) information collections. Understanding of complex knowledge captured becomes increasingly difficult and time consuming.
International nature of product design and service teams. Growth of product manufacture and thus international support required.	Disparate and remote teams in latter engineering design stages.	Knowledge disparity and reliance upon physical and local knowledge assets.
Lengthy projects and complex products.	Large historic data collections and experienced engineers amass in latter design stages.	Increased pressure upon teams to search and retrieve relevant information and knowledge.
Immaturity of	No measure of service	Difficult to compare

knowledge services.	efficiency.	tools, technologies and methods for knowledge impact.
Cost and difficulties of studying information utilisation mean little work is done to understand utilisation.	Information and knowledge utilisation is not well understood to be able to inform knowledge service provision. "Information processing" needs are overlooked.	Knowledge provision does not meet those that are required. This in turn encourages large data capture to fit any utilisation purpose.
Need for cost saving and streamlining in latter stage of projects (design engineering) mean that budgets do not stretch to knowledge services.	Planning for information and knowledge needs is not priority and limited take up of services in latter design stages when explicit or physical knowledge assets peak.	Large explicit knowledge asset collections are not utilised efficiently and information and knowledge provision becomes more time consuming and costly.
Lengthy product lifecycles grow historic data collections that span technological advancements. Historic data formats are prolific containing complex design engineering stories and need legacy integration.	Multiple and cumbersome historic document formats relied on as the main information resource for design engineering knowledge (64% overall) as they are useful platforms for information stories. Poor understanding of the actual knowledge facets within documents but prevalence for reuse of specific sub-documents is evident (Damage Report and Other from historic and standard design).	Information and knowledge in document format is difficult to interpret and time consuming to "reuse". Technical difficulties in retrieving useful knowledge from documents as Business Search tools rely upon the headers and titles rather than the actual knowledge contents.
Increasing product numbers and Natural expertise attrition. Stringent customer response times for high value products.	Increasing workload of in-service design engineering teams. Exponential growth of recorded experience and knowledge and limited time to utilise.	The cost and time burden of "reusing" and understanding information and knowledge grows unsustainably.
Competitive markets require innovative products and repair solutions.	Continuous product and design learning essential in the latter stages of design engineering process, this requires knowledge and information reuse.	Trend to capture as much information as possible to refer back to and facilitate learning without consideration of the need to reuse.
Design engineers find it difficult to explicate their tacit processes and misunderstand terminology. Information resources	Design engineering tasks and processes difficult to capture and thus audit. Huge variability in human processing and	Research findings are difficult to interpret and potentially misleading due to the lack of consistency in information captured or

available do not capture complete communication trails.	practices.	recorded (telephone conversations not captured in historic repair case documents).
Complex resources that are time consuming for design engineering users to seek understand and utilise. Preference and prevalence of spatial and visual media (84% of damage report and 78% of other) to support human information cognition.	Multi format information resources. Highly technical and difficult to integrate information formats that rapidly outdate. Highly visual information required for understanding.	Automated systems for manipulating data are complex and costly (if technologically mature enough and 6-11% of data potentially lost due to mark-up). Understanding and retrieving from these resources largely remains a manual and human task. Broad and visual needs difficult to design technological support and measure effectiveness.
Tacit knowledge and the purpose for seeking information and knowledge determine what support is needed and what is to be understood by a user.	Highly variable experience and expertise influences the information and knowledge resources required and the understanding overheads required.	Separating concerns to researching individual design engineer requirements is difficult especially if the use case of information is broad.
Complex products and design engineering expertise create complex multimedia and format information resources.	Document contents highly variable and difficult to interpret. Value of individual media potentially variable.	Manual methods required for researching and appropriate media classifications difficult to apply. Standard categorisations of information difficult for variability found (other category contains 29 sub-documents). Cannot assume the value of media and information from design engineer information audits and document contents analysis.

Table 4.18: Summary of Industrial Concerns

These challenges influence the possibilities for reusing knowledge within industry. A closer look at the impact these issues place upon the knowledge reuse process can be found in 4.8.1 below.

These challenges highlight the need to understand the value of specific documented information for Design Engineers to enable further development of solutions to support knowledge “reuse”. This requires a deeper understanding of the processes, tasks and information flows for engineering design experts. It is evident that a number of measures will need to be taken to ensure that any studies are realistic for working within the constraints of industry. Industrial and practical considerations for the design of research studies include the following;

- The perspective of international teams and audiences will need considering.
- The actual information being utilised and its respective value.
- The careful classification of document contents due to its variability.
- The differentiation between expertise and experience for Design Engineers.
- The current technological capacity for manipulating document data.
- The cost and capacity of engaging Design Engineers in research.
- The human information processing overhead and associated research.
- The overarching need for efficient knowledge "reuse" (see Chapter 2).
- The current technical difficulties that limit the usefulness of the current document resource collections for the reuse of knowledge and information.

4.8.1 Summary of Challenges for Operational Industrial Knowledge Reuse

The practical and industrial concerns for investigating the needs for reusing knowledge have been highlighted in previous sections. The illustration below is taken from Chapter 2 as it represents a view of knowledge reuse as synthesised by concerns raised in the literature. The illustration below highlights the current industrial shortfalls that relate to the knowledge reuse process depicted in Figure 4.19. These concerns are from those summarised in subsection 4.7 above.

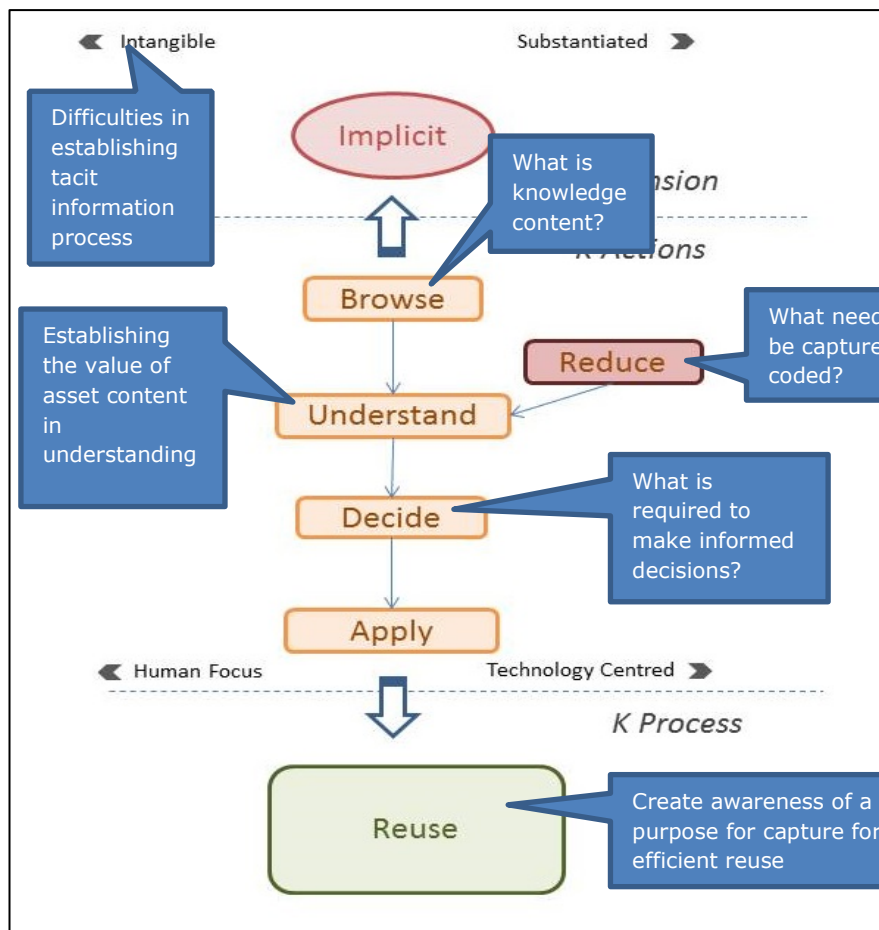


Figure 4.19: Summary of Industrial Knowledge Reuse Challenges

While it is not possible to address all of the challenges raised the primary focus of this thesis is upon the following;

- Ascertaining the information and knowledge being reused by Design Engineers with particular focus upon the growing document collections.
- Understanding the value of respective information presentations, media formats and document contents in supporting Design Engineers to reuse information.
- Understanding the most important knowledge and information content and resources and their utilisation for Design Engineers.
- Investigating the engineering design need to capture and reuse document information.
- Gaining insight about the trade-off between information processing automation and human need to understand resources to reuse them.

These aspects will be used to inform the design of future knowledge reuse interventions and provide evidence of the purpose and specific information needs of Design Engineers in the latter stages of product design.

This chapter has considered the industrial concerns and constraints for the research in this thesis. Appendix 6 provides the background for the state of the art and the current technological capacity influencing the focus of the research approach. The next chapter describes the first of three consecutive empirical research studies conducted within industry to fulfil the objectives for this thesis. The first of these research studies is a questionnaire survey conducted with an international in-service audience.

5. Design Engineering Information: Seeking, Understanding and Utilisation

In Chapter 2 the literature and theory relating to decision making has been discussed, in particular how that relates to the reuse of knowledge and information assets that design engineers rely upon to make informed judgements. Chapter 4 has described an industrial case forming the basis for conducting this empirical research study in this chapter. To enable the creation of qualitative studies that elicit the rich detail involved in tacit design engineering decisions it is necessary to first understand better the character of the information and knowledge assets involved and timeframes required for design engineers when processing these document information resources. It is possible that reference to literature studies described in section 2.3.1 could have been made in an attempt to characterise the information needs of design engineers. However, these studies are drawn from broad audiences that utilise information resources for a variety of design tasks. The specific purpose for which information has been accessed has not yet been characterised or the human cognitive traits or steps that may be required to be supported throughout this processing.

It is thus necessary to conduct a survey investigation directly with the latter stage design engineers regarding the highly specialist tasks that they undertake. It is only then that we can begin to understand information processing concerns for design engineers. The results of this questionnaire also form the background needed to be able to create simulated work scenarios for the design of second experiments to elicit more specific detail about the information relevance process and decisions made by design engineers. It is thus the intention of this questionnaire study to characterise details that we do not already understand about the about the processing of explicit information with a view to enable their content to be efficiently reused. Figure 5.0 the expected outcomes from this study in respect of the knowledge reuse process.

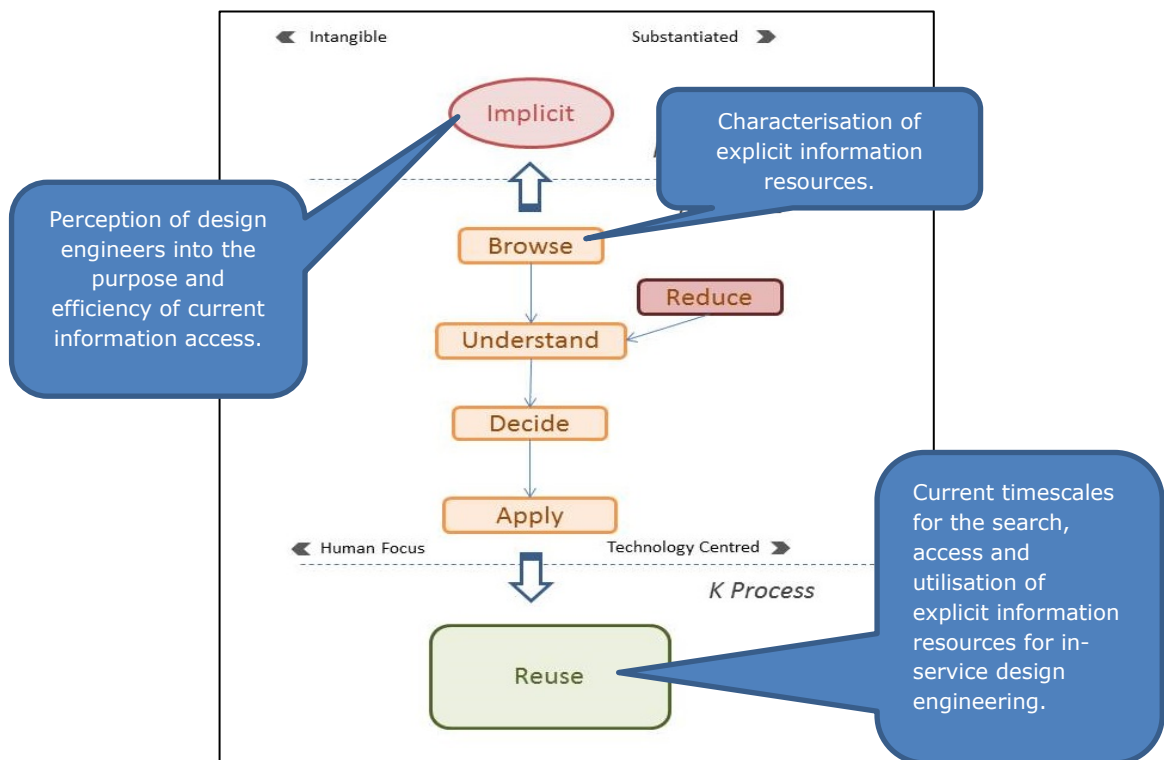


Figure 5.0: Expected Outcomes for the Knowledge Utilisation

Literature observations for design engineering related studies show that while data to characterise both the types of information that are recorded and utilised there is

little to suggest *the purpose* for which the information is recorded. It is evident that previous empirical research has focussed on a broad audience, broad range of engineering design tasks and heavily focussed upon the information needs of design engineers in the early stages of design (see Section 2.3 and 4.1). For example, one study in the work of Jagtap (2008) audited a sample of in-service design engineering documents for the purposes of eliciting the information required in the *early* stages of design. There is no evidence that a survey has been conducted specifically with design engineers working in the in-service period of a products lifecycle or a survey that has characterised specific purpose for information reuse or utilisation during engineering design processing. It is also evident that previous studies both in the in-service remit and for the design lifecycle focus in particular in the needs of a broad spectrum of engineering workers and in particular focus upon the needs of Design Engineers conducting early design tasks. For this reason, it is considered that this questionnaire is the first that has purposely sought to answer the following questions in with respect to the latter stages of the product design lifecycle:

Q1: Within In-Service Engineering Design what is the distribution of expertise and specific roles involved in the design activity?

Q2: What is the main purpose of information resources for In-Service Engineering Design?

Q3: How much time is spent in the seeking, browsing and utilisation of information resources for In-Service Engineering Design?

Q4: Where is the information sought from? (This is questioned at a higher level and a lower level)

The work described in Chapter 4 that seeks to characterise the In-Service information resources and related process have been utilised to direct the subject of the questionnaire to build upon areas where there is ambiguity between the purpose and utilisation of information for the latter design stages. The intention is to be able to utilise the findings to compare to previous research findings (in particular across differing design stages) and find details to create work simulation for further investigation, thus highlighting any differences in the information resources required within the latter stages in a products design lifecycle.

Thus far it is assumed that the design case histories are being recorded for European Aviation Safety Agency (EASA) regulation and for knowledge capture purposes, the intention is to compare how this differs from the need to record knowledge to facilitate its reuse. This has been shown to be one of the shortfalls of current knowledge "reuse" industrial methods and processes (Markus 2001). Therefore to answer this question and to correctly elicit the purpose of utilisation of information within in-service design engineering a questionnaire study was devised as described in the subsequent sections.

5.1 Constructing the Questionnaire

In Chapter 3, the mixed methods approach for this research is described as a triangulation using aspects of cognitive work, task analysis and design research methodology. In respect of the overall research approach this survey is intended to be a quantitative study seeking to characterise further the initial observations made in Chapter 4 and to enable further studies to be designed using details for work simulation purposes. In this respect this study fulfils the enables better understanding of the purpose and utilisation of information to drive the design of scenarios that can later be studied in much richer detail. In respect of the design research methodology approach this study is an empirical study that seeks to quantitatively build better understanding of the timeframes for information access

and utilisation, thus pin pointing the most pressing engineering design support requirements for information reuse.

In practical terms it has been necessary to consider the constraints of the structure of the industrial in-service department and thus questionnaire audience. This includes the remoteness of international teams, distribution of subject expertise and how their role influences the purpose for which they may access information resources. These aspects could subtly influence any response differences for the questionnaire and hence interpretation ambiguity for any results. A large number of participants and response rate is needed to enable efficient quantitative analysis; hence important considerations are the influence of managerial support for encouraging responses and engagement of design engineers in this research study. Thus the time constraints of the design engineers and length of the survey or number of questions are of particular significance. Communication and practical aspects will be ever more pressing due to the remoteness of international participants and the offsite nature of a large part of the in-service team.

Hence in respect of the above a number of design approaches were considered, the final resolution of which is listed below;

- The discussion and engagement of managerial staff to encourage uptake participation of the survey was critical to its success, this was driven by meeting and discussing expected outcomes with managers first, remaining onsite for the duration of the survey to canvass support and the length of time invested for pre study observations and relationship building being of considerable length (2 years prior).
- Strategies for accepting responses had to be in the main by email due to international teams, although paper responses were also accepted. This required additional security measures to be taken with regard to results being encoded using software before return.
- A three section design of the questionnaire supported clarity of expected responses from participants, first relating purely to collecting expertise and respondent characterisation, secondly assessing the timeframe for information search process, retrieval and latter utilisation of document information assets, the final being devoted to collating data regarding the importance of information formats types, information access strategies and further details influencing purposeful information reuse.
- An initial review and assessment of the questionnaire by both academic audiences and industrial management audience was undertaken to cyclically make improvements. A further preliminary questionnaire study was conducted to elicit any practical issues affecting responses and ambiguity of wording or misinterpretations that could cloud interpretation of any results. The result of the preliminary questionnaire changed the structure of the response rankings to enable it to be much clearer to respond.
- The wording of questions used scenarios to enable participants to understand the purpose of the questions to be able to answer as accurately as possible and to ensure that questions were answered as expected.
- The utilisation of Adobe PDF to design the questionnaire as this is standard software utilised by the industry concerned and this also enabled a copy of encrypted responses to be returned than could then not be interpreted without the researchers original question file. This secured the anonymity of any responses that was also advertised to prospective respondents to encourage participation (Dawson 2009).
- A mixture of closed and open ended questions have been utilised within each of the three question categories. The purpose of this is while ensuring the results are directly comparable it enables opportunity for survey respondents to add further detail and thus answer appropriately (Dawson 2009).

A sample of the questionnaire is attached in the Appendix 2 and any responses are digitally held on a secure drive to enable their utilisation in the future if required. Before conducting the questionnaire it was also necessary to consider an effective data collection strategy and timescales before closing the study. These aspects are considered in the next section below.

5.2 Data Collection Strategy

The collection of data for the survey was a key consideration for the success of the study. This was a significant factor in the design of the questions and for the response technologies utilised. The Adobe software forms application was used to create the questionnaire, due to its ability to encode any results sent by email for security advantages. This meant that holding the researcher with the master questionnaire document was the only person able to decode the questionnaire results. This was advertised by email to the respondents with confirmation how the results were to be treated in strict confidence and any results would be reported without identification of respondents (see Appendix 2 for example survey).

It was necessary for a large number of questions to be present to ensure the entire scope of information utilisation for in-service design engineering information aspects to be covered. To make it easier for the design engineers to understand the focus of a question the use of three sections in the questionnaire was used entitled "general", "current practice" and "PDF Files & Contents". These titles guided the content of the questions posed for each section to make it easier for respondents to know how to respond. In the main due to the number of questions they were highly structured and used check box responses to enable speedy response that are suitable for direct comparison between participants. However, the utilisation of open ended questions at the end of each question cluster was intentional to enable opportunity for full and open responses to be provided for clarification as deemed appropriate by participants.

5.3 Conducting the Questionnaire

As previously identified encouraging responses from the questionnaire was an important feature, in particular for international teams. Due to the nature and structure of team communication within the industrial partner it was necessary to route the initial survey via the respective management teams. Hence the questionnaire was distributed via the departmental head and any follow up emails were also distributed by senior management channels, encouraging design engineer participation as management direction was to respond (Nokes & Kelly 2007; Boddy et al. 2008; Carey et al. 2012).

As previously outlined both an iterative approach to developing the survey questions was utilised with an academic audience and management to ensure the data captured was both suitable for making inference about information utilisation and appropriate terminology was utilised for ease of understanding. A preliminary questionnaire was also conducted with a small number of participants to identify any problems with ambiguous questions or terminology and ease of understanding for the participants.

The questionnaire was distributed to 98 potential respondents and followed up by email on three occasions to encourage participation. The initial questionnaire was distributed to three in-service design engineering teams that were distributed both internationally and in contracted-out more local sites. The follow up for encouraging respondent participation was sent by email to all teams; however, the researcher was available on the main site for the duration of the questionnaire study. A period of two weeks was provided for respondents to participate and reply. A small extension of a couple of days was provided to encourage locally contracted out teams to participate due to communication and contractual issues. However, due to both communication and contractual issues very few responses were received from

the off-site contracted out team and thus they have been excluded from the analysis sample.

5.3.1 Preliminary Questionnaire Directions

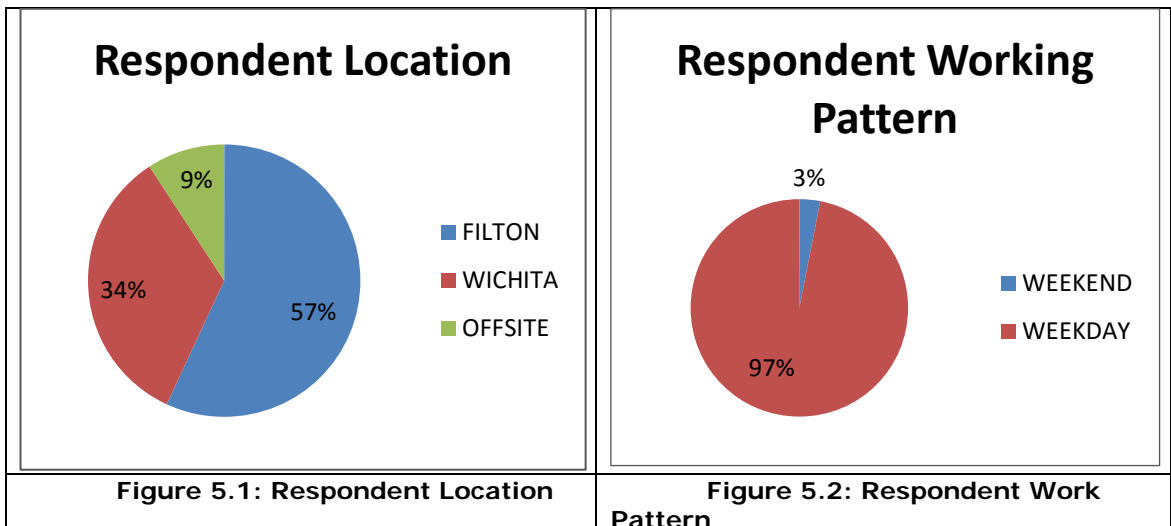
The preliminary questionnaire was distributed to randomly to a manager, an administrator and a number of design engineers to canvass the direction from a broad audience and to ensure the readability of any questions for a broad range of participants. There were six respondents from ten questionnaires preliminarily distributed and from these responses 24 amendments were made to the questionnaire wording and structure. One of the most significant changes was to make the ranking of options for "check box" responses easier to understand. Appendix 3 of this thesis is a full list of the amendments required as a result of this preliminary survey.

5.4 Results of the Questionnaire

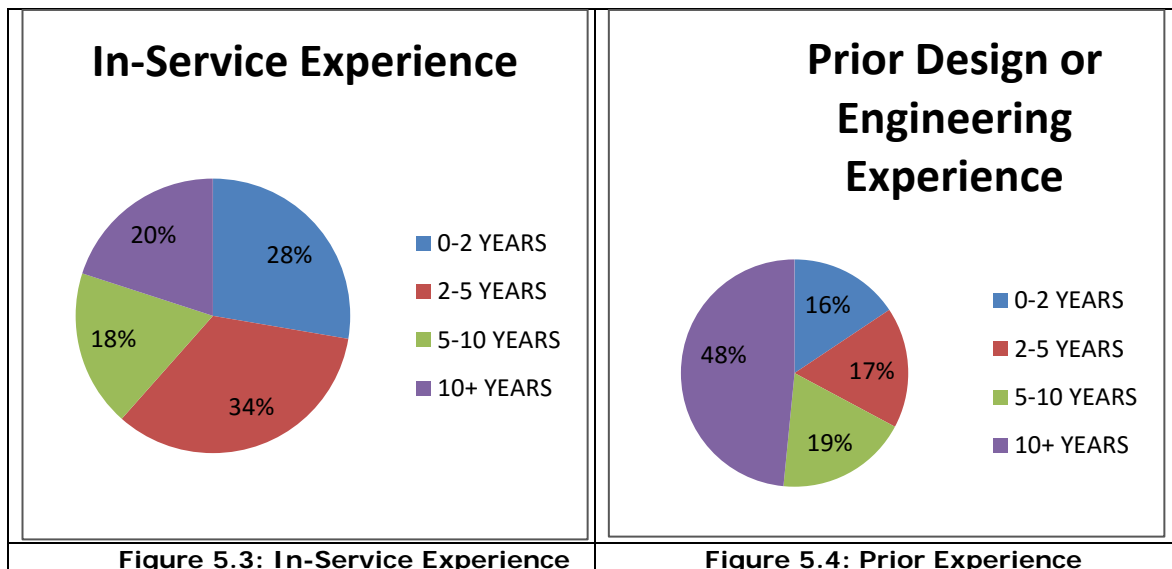
A total of 65 responses were received from 98 staff, hence the response rate was approximated at 67%. The lowest response rate was from the off-site contracted-out team. At the time of the survey the contract was under renegotiation and thus it is assumed that this has likely influenced communication issues and the poor motivation of the contracted-out design engineers to participate.

The questionnaire contained 29 questions, 10 general questions to characterise the participants design engineering experience, perception and role, 8 questions to understand more about the current working practices of latter stage design engineers and a further 11 questions to elicit more detail about the time design engineers spend using typical documents and the strategies they have developed to support them to use document information more efficiently. The questionnaire results are lengthy and thus the key results of the questionnaire are outlined below in this section, however complete results are provided in Appendix 4. The initial results presented characterise the respondents and the latter results presented provide more detail about the information utilisation patterns and strategies of respondents.

From Figure 5.1 the offsite design engineering respondents were the least responsive (9% overall). However, the response from one internationally based team was high (34%). This is surprising and can only be as a result of the management motivation to participate as little direct contact was possible with the researcher due to the remoteness of the team. Positively this does mean that any results are representative of internationally distributed teams that are typical in design engineering projects.

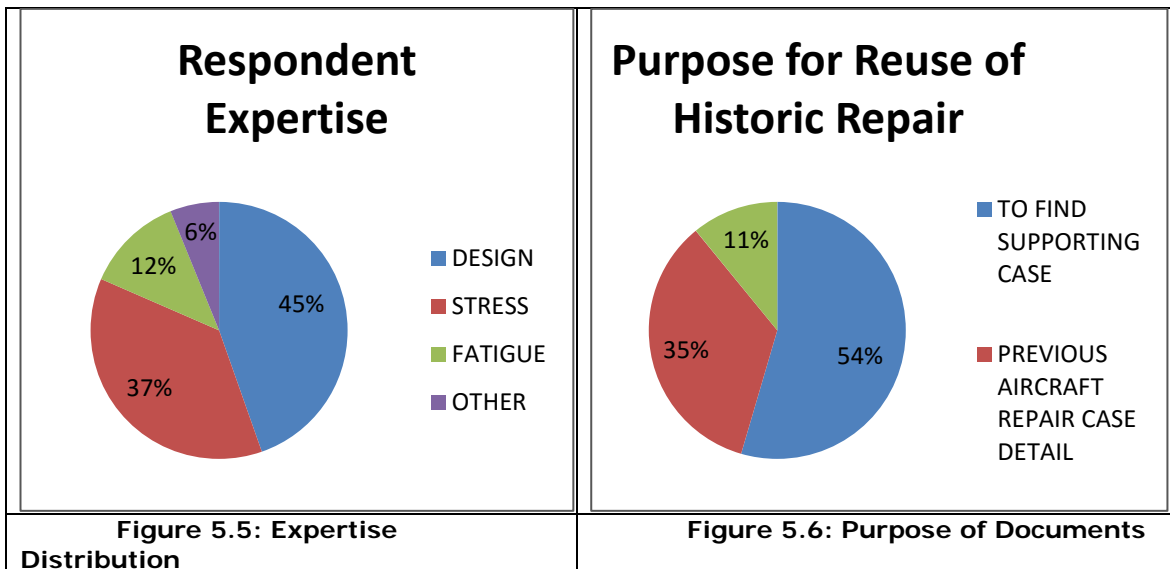


In Figure 5.2 the working pattern distribution of respondents is given. The small number of weekend staff is surprising for such a large customer focussed in-service department in particular for the internationally based departments. The character of responses of the weekend staff is particularly interesting due to the independent approach they have to take to design. It is more difficult for these teams to work in a more social manner that has become typical of design engineering experts (Robinson 2012) and thus their information practices could differ considerably. Further discussion of any significant correlation follows later in this results section.

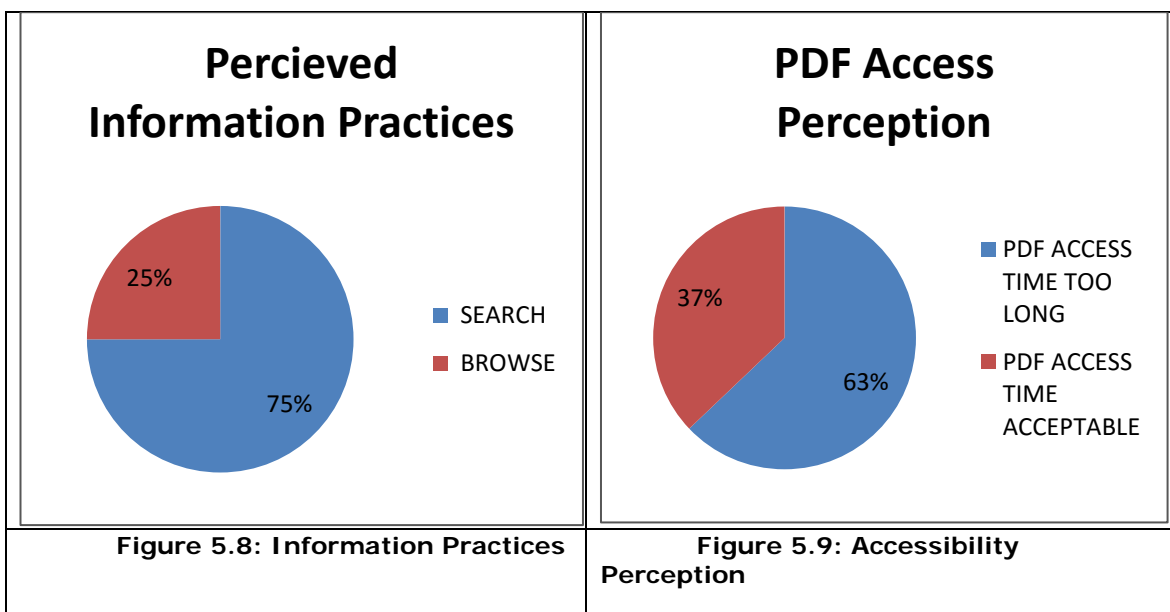


A vast majority of respondents have more than 5 years' experience (67% overall) in engineering prior to joining in-service design and 48% have more than 10 years prior experience. The number of years' experience of the in-service department overall thus is particularly high, though this distribution is cited to be typical for design engineering teams (Vianello & Ahmed 2012). Surprisingly, it is evident from the responses that a majority of the in-service team members have less than 5 years' experience specific to in-service design. This potential presents significant challenges for the team for both capturing in-service design engineering experiential knowledge and highlights the need for alternative "reuse" mechanisms for design engineering knowledge.

In Figure 5.5 below, the number of sub-expertise is represented, this adds further dimensions to the expertise challenges for design engineering teams, in particular for the latter stages of design. Supporting communication between differing expertise's is an issue that has been identified for design engineering teams between expert boundaries (Carlile 2004; Henderson 1999). This issue appears to be significant within the in-service teams for latter stages of design as it is evident that sub-expertise is highly distributed between "design", "stress" and "fatigue" factions. Supporting such variable information needs presents further challenge and compounds the identified issue of multipurpose data capture and reuse first identified in Chapter 2.



A significant issue identified for design engineering knowledge and information reuse is the capture of data for non-specific purposes. The illustration in Figure 5.6 shows that the historic design document collections although utilised 54% of the time for seeking previous design cases to support current design, they are also utilised 46% of the time for alternative purposes. (Potentially this is significantly less than the cited 70-95% of design process is design reuse and thus further clarification needs to be sought to understand the multipurpose nature of document collections).



This question was designed to understand how design engineers perceived their information utilisation practices. It was evident in the 75% of respondents that they searched for information (rather than browsed for it). However the nature of documented information means that information is likely to need to be browsed to find relevant information (Liu et al. 2007) and further results in this questionnaire support this hypothesis due to the significant amounts of time design engineers spend viewing document content rather than searching for specific documents. The perception of 63% of design engineers is that PDF documents are time consuming to use as information repositories especially for the reuse of information

corroborates and is suggestive also that the time they spend browsing documents to seek relevant information takes too long, thus limiting its usefulness.

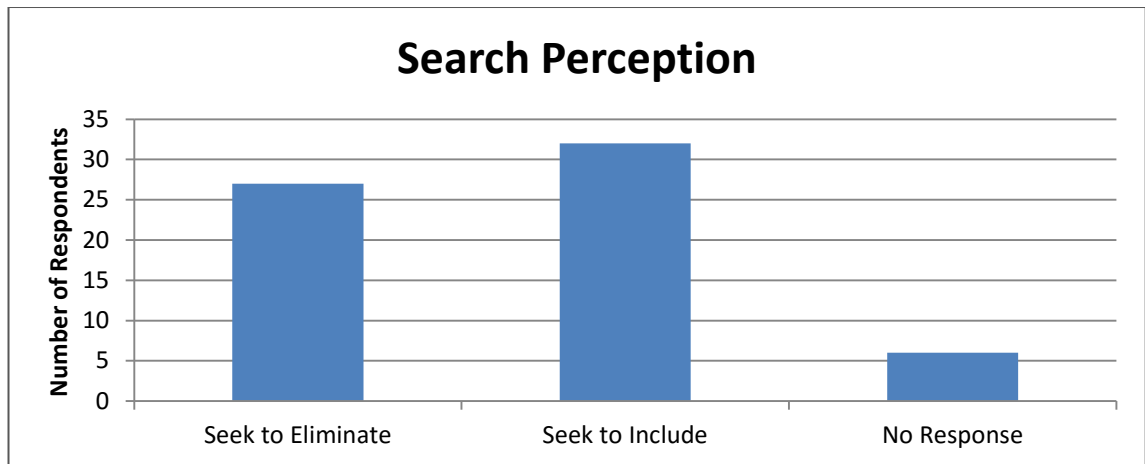


Figure 5.10: Information Seeking Strategy Perception

If a person seeks information to include it is their current task arguably that is more difficult cognitively than it would be to eliminate information from being useful when it is first viewed. The design engineers perceive that they seek information to enable them to include it in their current task. Further information needs to be sought to elucidate the strategies utilised as if design engineers could be supported to discriminate information that is not useful first, as with other search strategies it could limit the information they need to understand in full for their current task (Tang et al. 2010). Reversing this design engineering strategy in particular for information “overload” scenarios could reduce the cognitive load of design engineers (Coley et al. 2007).

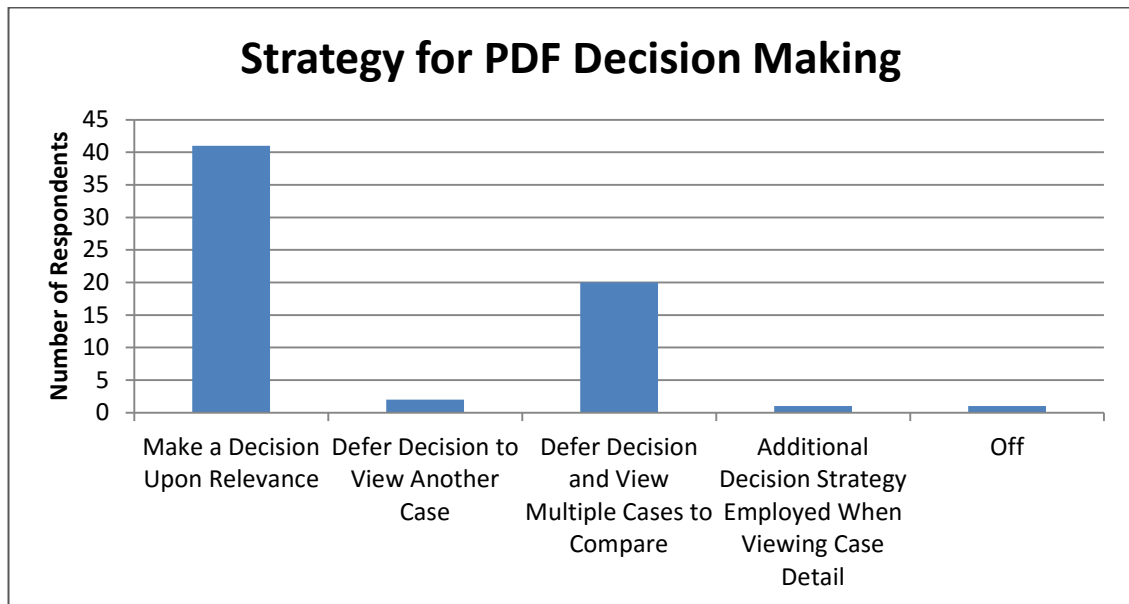
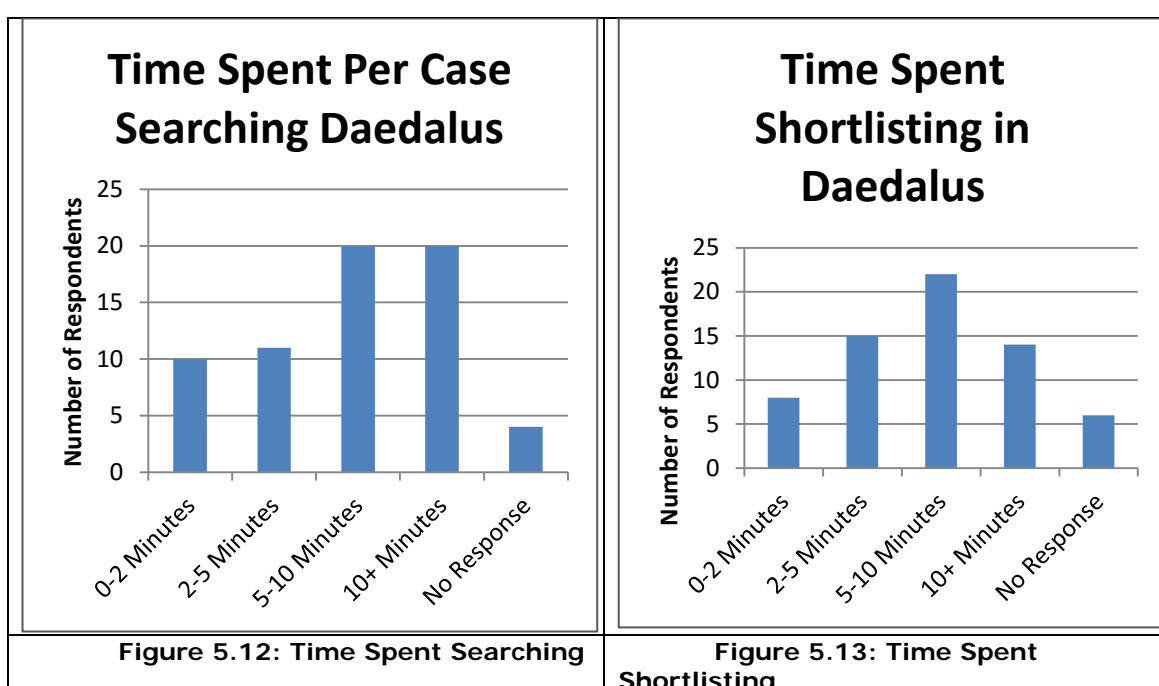


Figure 5.11: PDF Access and Utilisation for Decision Making

When describing the results relating to the utilisation of design engineering documents it is important to understand the information process being supported and the historic case documents being utilised. In Chapter 4 this historic case document and information supported process is outlined in 4.3.3 – 4.3.5 and in an overview of the process undertaken illustrated in Figure 4.4. As a reminder, each design engineer carries out the design process on average for 20 in-service repairs per week. Figure 4.4 illustrates the typical process undertaken for each of these

repair requests from the receipt of the request to the completion of a repair design. From this illustration the typical steps undertaken to design a repair case once it had been passed to a design engineer would be to seek a supporting historic repair case document (and thus information) similar to the current repair request. The questions in the second part of the questionnaire seek clarification about this information search process and the final part elaborates upon the utilisation of the historic case documents to create a design repair.

In Figure 5.11 the decision being supported by the document accessed is whether the historic case document accessed is suitable to support the current design repair task being undertaken. In this instance it is evident that 63% of design engineers will access a historic document and make a decision upon its relevance in that access. However, 31% of participants will refer to multiple cases before making a decision upon the best supporting historic case document. This is suggestive that 31% of the time documents need to be accessed multiple times to enable a decision upon its informative content to be made.



In Chapter 4, section 4.3.3 and Figure 4.4 the information search and retrieval tool for retrieving historic case documents is described named DAEDALUS. This excel based tool utilises text matching of predefined design case descriptions to facilitate retrieval of similar historic design repair cases. In Figure 5.12 to 5.15 the timescales and efforts to search for document information for each design repair case conducted are characterised. In a majority of initial document searches Figure 5.12 and Figure 5.13 suggest that it takes a design engineer somewhere between 5 minutes to 10 minutes or more to search in the DAEDALUS spreadsheet and a further 5-10 minutes to shortlist a number of potential similar historic case documents that may be suitable to view for information. Most frequently in total this would take a design engineer up to 20 minutes or more to find a number of potential documents to view for historic case information.

To characterise this search process further, the information that each participant likely processes to be able to shortlist a number of cases is textual. The key descriptive text terms utilised by the DAEDALLUS search tool and immediately viewable to participants in the search tool are given in Figure 5.14. This illustrates that for determining a historic cases relevance there are more useful text and terminology, the most useful appear to be "Title Description", "Aircraft Type", "ATA Number" and "MSN Number".

In practical terms this means that the description of the type of repair, the aircraft family, the location of the repair and the aircraft identifier are the most significant terms for determining similarity and thus the historic repair cases relevance.

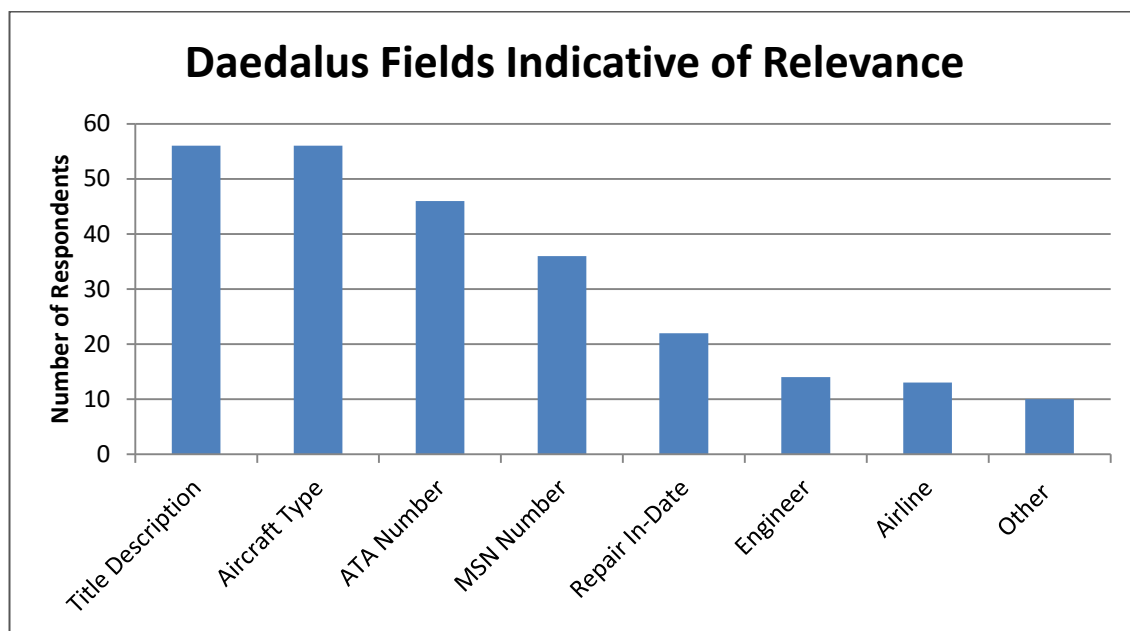
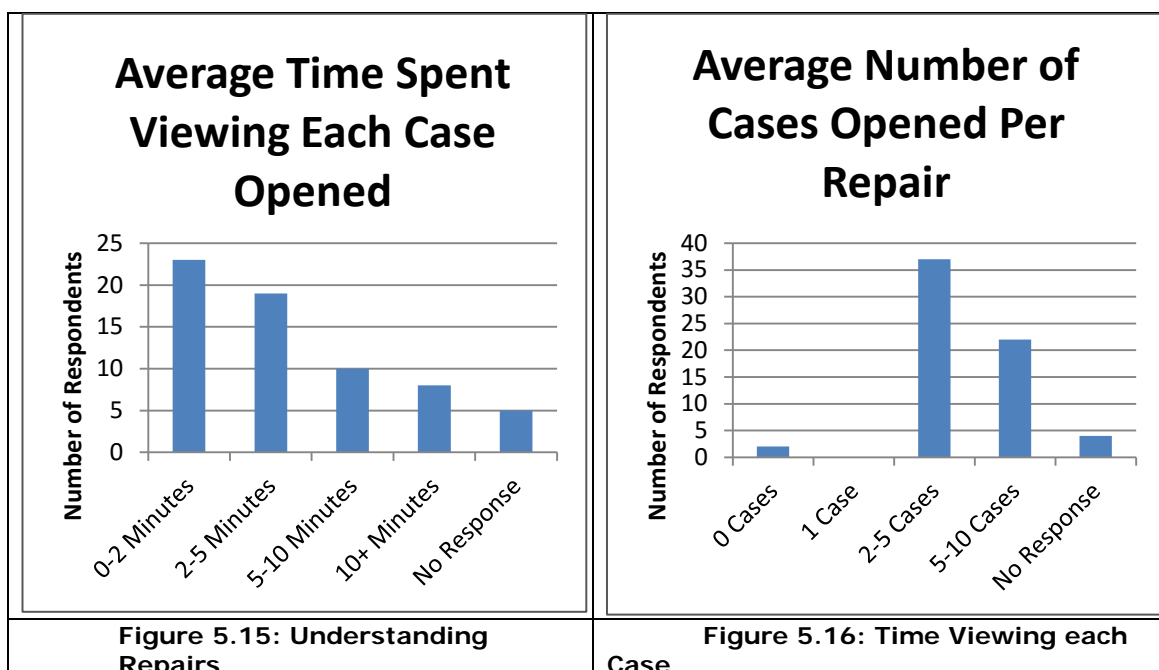


Figure 5.14: Text Terminology Indicating Case Relevance

The next questions characterise the time spent viewing the historic case documents to either determine their relevance or to utilise their informative content for the current repair case being undertaken.



The illustrations in Figure 5.16 suggests that for each repair case conducted 57% of the time 2-5 historic cases are viewed and 34% of the time 5-10 historic cases are needed to be viewed and from Figure 5.15, 65% of the time it takes 5 minutes or less to view each historic case. However in 28% of the repairs designed it takes over 5 minutes and 12% of the time over 10 minutes. This means that for each

repair it can take up to 34% of the time it could take between 50 minutes and 100 minutes to view the historic repair documents shortlisted.

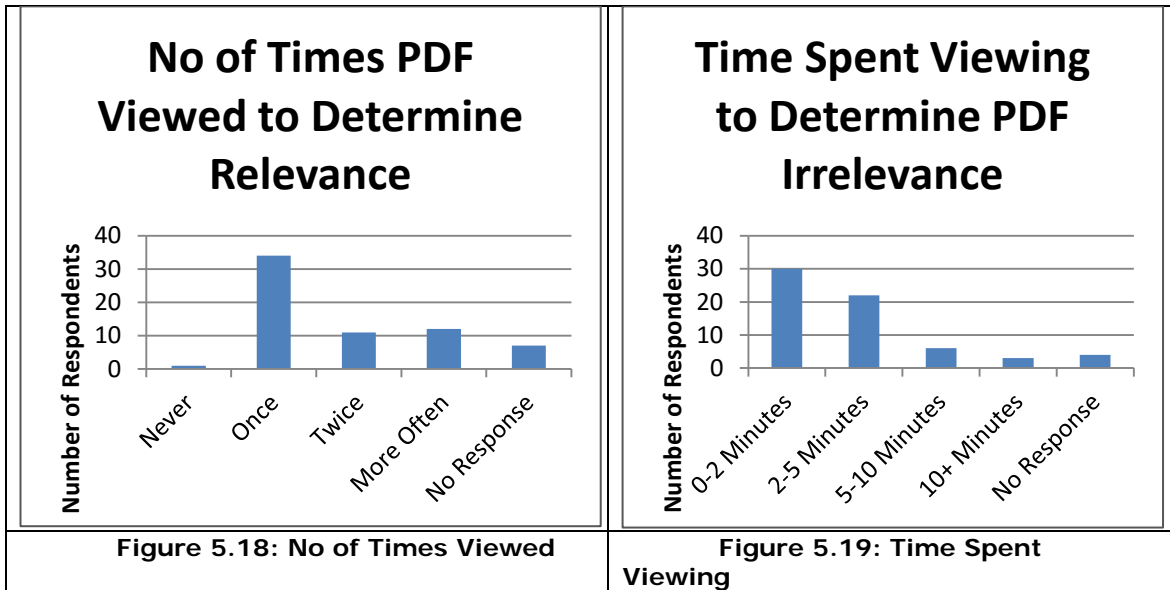
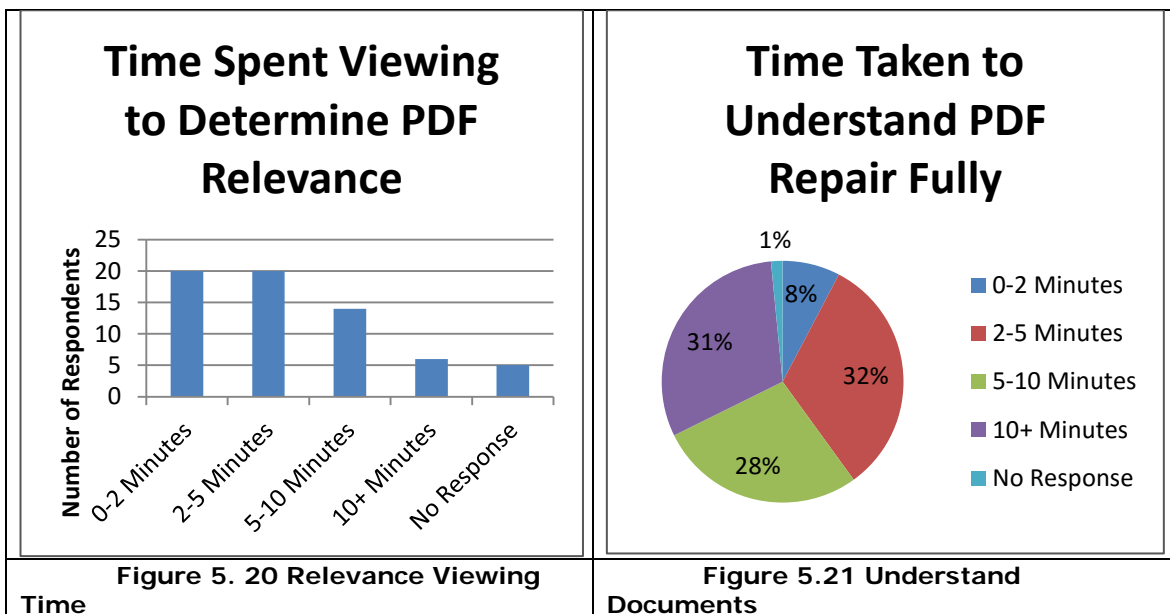
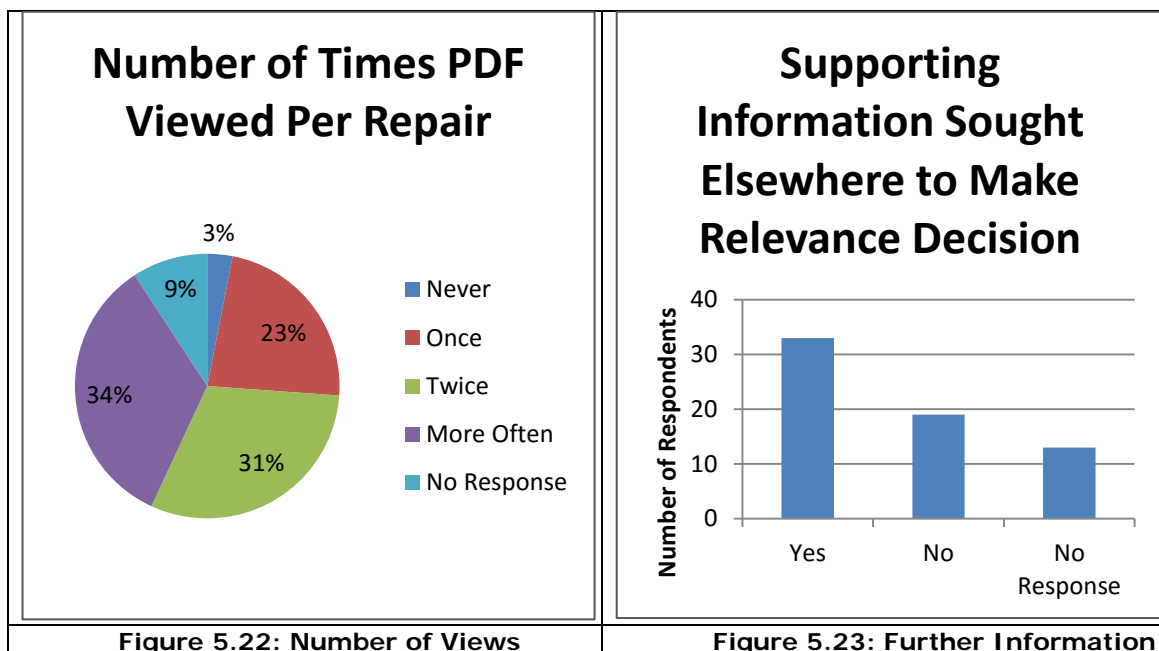


Figure 5.18 is suggestive that although 65% of the time it takes less than 5 minutes to view a document, it is likely 35% of the time that the document will need to be viewed two or more times to determine its relevance to a current repair design task. Although it is evident that to determine a documents irrelevance 80% of the time it takes 5 minutes or less (46% 2 minutes or less). This means that it is much faster to discriminate the irrelevance of document content that its relevance to task. This suggests that developing strategies to discriminate the irrelevance of information would be much faster.



In comparison Figure 5.20 illustrates that for determining the relevance of a historic case for 62% of respondents it would take more than 2 minutes (compared to determining its irrelevance in 46% of the time taking less than 2 minutes). Once a relevant supporting historic case is identified to complete the design of a repair it also then takes another 2 or more minutes for 91% of participants to understand the supporting case fully and 31% of respondents would need to take over 10 minutes to understand the document case fully. Figure 5.22 finds that there is

continuing need to refer back to the supporting case document twice or more for 65% of the repairs conducted on top of the time spent seeking a supporting case, then determining its relevance and understanding it in full.



Given the significant lengths of time participants report spending time utilising historic document information it is also necessary in over 50% of reported cases that further additional supporting information is then sought elsewhere for conducting a repair design.

The final part of the questionnaire sought to characterise the important informative content of design engineering documents and the strategies that participants employed to efficiently utilise their content. The questions relating to the number of pages that participants perceived constituted a large or small historic document varied tremendously with significant overlap in opinion of size. For a small number of pages within a document a majority of responses indicated the page range was between 0-10 pages, peaking at approximately 8-10 pages. However some responses indicated that a case with 30 pages could still be perceived as small. In contrast a large case page count could range from 0-60 pages, peaking at 20-30 pages. In some responses a large case was perceived to consist of over 100 pages. In practice the content audits described in Chapter 4 illustrate cases with up to 250 pages suggesting this perception is somewhat unrepresentative and would need further clarification.

A number of strategies to both view and seek information within the historic case documents are expressed in the results. There are also a number of strategies illustrated for seeking further additional supporting information. Each question provided opportunity to rank a number of given strategies for their importance in utilising the content of such documents, these rankings are outlined in the final results presented.

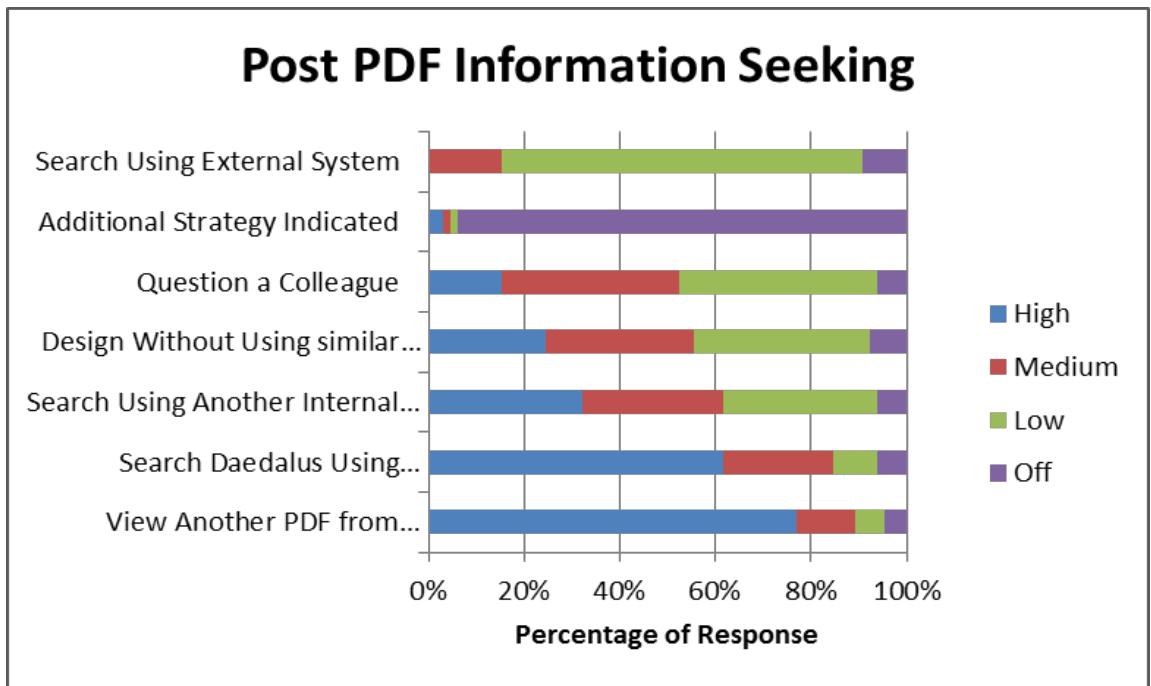


Figure 5.24: Additional Information Seeking Strategy

In Figure 5.23 a large number of participants indicated that they were required to seek further additional information after they have identified a suitable supporting historic case. The illustration above (Figure 5.24) highlights the importance of historic documents as in nearly 80% of the time participants ranked the viewing further historic case document information or searching for another historic case document in the DAEDALUS tool. The little importance shown for “questioning a colleague” suggests reliance upon explicit information resources for seeking expertise. This is significant given previous design engineering studies appear to suggest that seeking expertise from colleagues is such an important strategy (Wallace & Ahmed 2003). It is also surprising that the collective high and medium rank of “design without using similar” appears to indicate designing repairs from scratch is a suitable option for latter stage design.

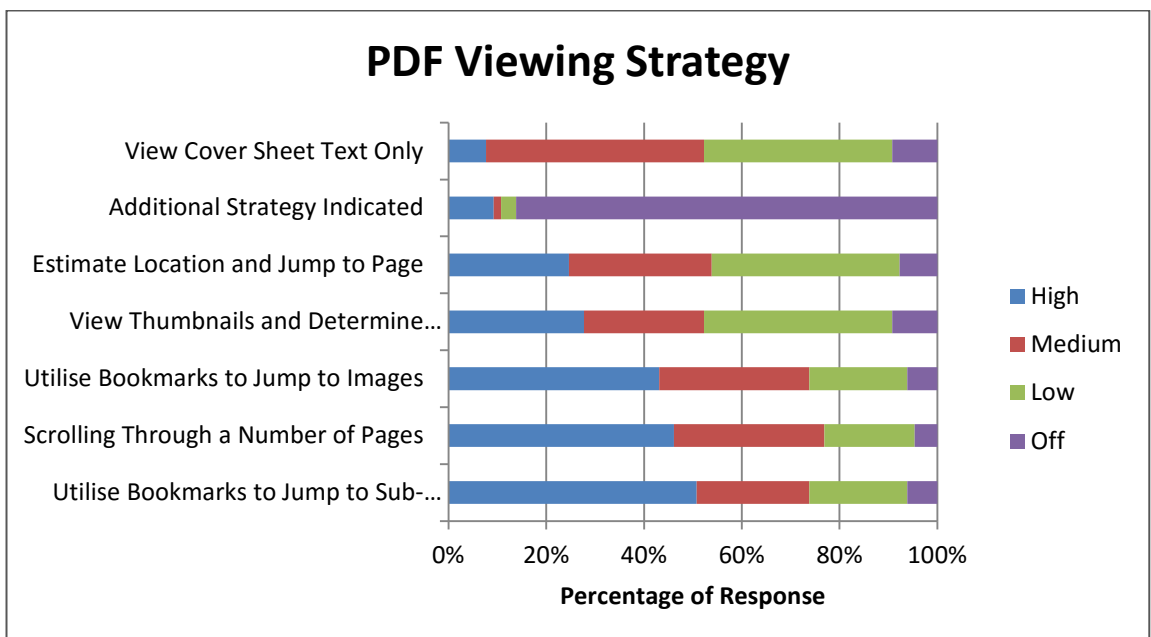


Figure 5.25: Strategies to Seek Document Content

The documents when opened have considerable content and can be decomposed into sub-documents or informative contents. The document content audit described in Chapter 4 has been utilised to suggest the ranking options that needed to be available for these questions and the strategy options for viewing are derived from the industrial administrative process described for documents in Chapter 4 and from the further scoping study reported in Appendix 6. For completeness the “cover sheet” option has been provided and it is derived from the textual content that is used from this sheet in the DAEDALUS search tool. However, the relative importance of this sheet is deemed insignificant to the respondents. Three most important document viewing strategies emerge, “bookmarks to subdocuments”, “page scrolling” and “bookmarks to images”. These strategies appear almost as important in rank as each other although the “bookmarks to subdocuments” appears slightly higher in rank. The importance of these features warrants further investigation as it is not possible to assume why these strategies are important.

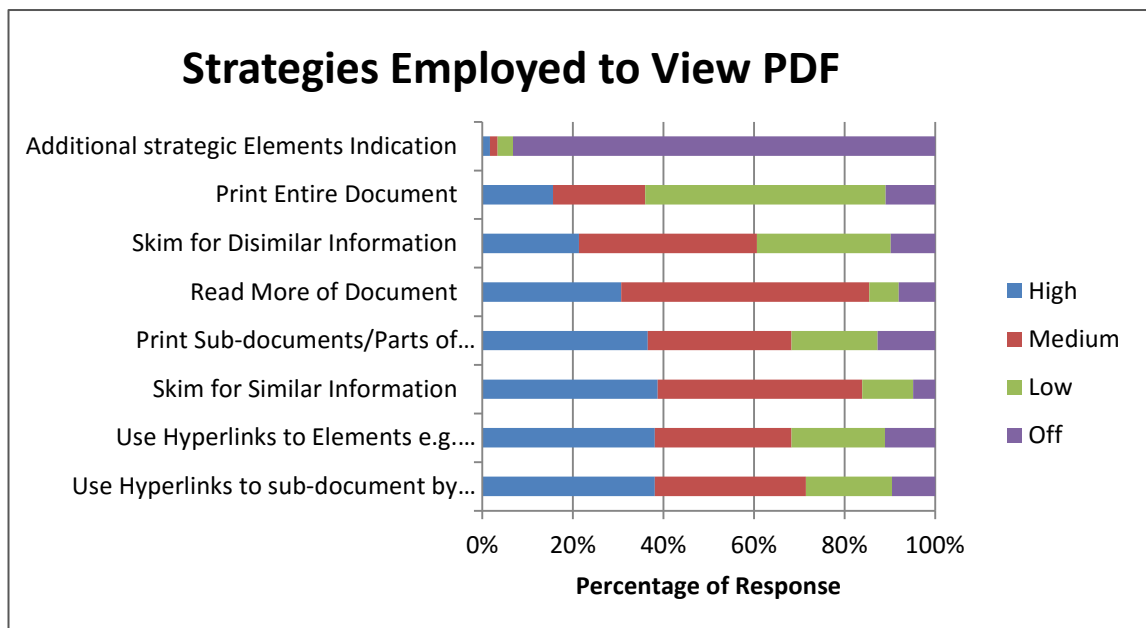


Figure 5.26: Strategies to View Document Content

Similarly in Figure 5.26 the importance of strategies such as “skim for similar information” and “read more of document” becomes apparent. Also highlighted is the utilisation of hyperlinks to subdocuments or specific elements such as photographs. Although printing the entire document is not selected as an important option, the printing of subdocuments or parts of a document are relatively important. If document content is being printed it could be challenging to elicit how many time that information is referred to in this questionnaire, however, it does highlight that if documents are being printed this could mean that they are required to be referred back to on regular occasion. This point would need further clarification as the printing of a subdocument could also be apparent due to some part of the industrial processing needs that are not yet evident.

From Figure 5.27 the perception of the respondents of the most important elements within a document to decide upon its relevance is clearly the more visual elements combined with the descriptive text. Utilising those elements ranked as high and in respective importance order, the most significant elements are the “supporting calculations” and “damage images”. Other important features in descending importance are “title description”, “location sketch”, “repair drawings” and “images with annotations”. Surprisingly the more formal visual design representations such as CAD drawing were ranked only mid-way. This is significant when considering the important document elements that are required to be viewed to understand its content in particular for matching its similarity or relevance to a current design

task. This ranking again warrants further investigation as it does not suggest the purpose of the information elements importance to our respondents.

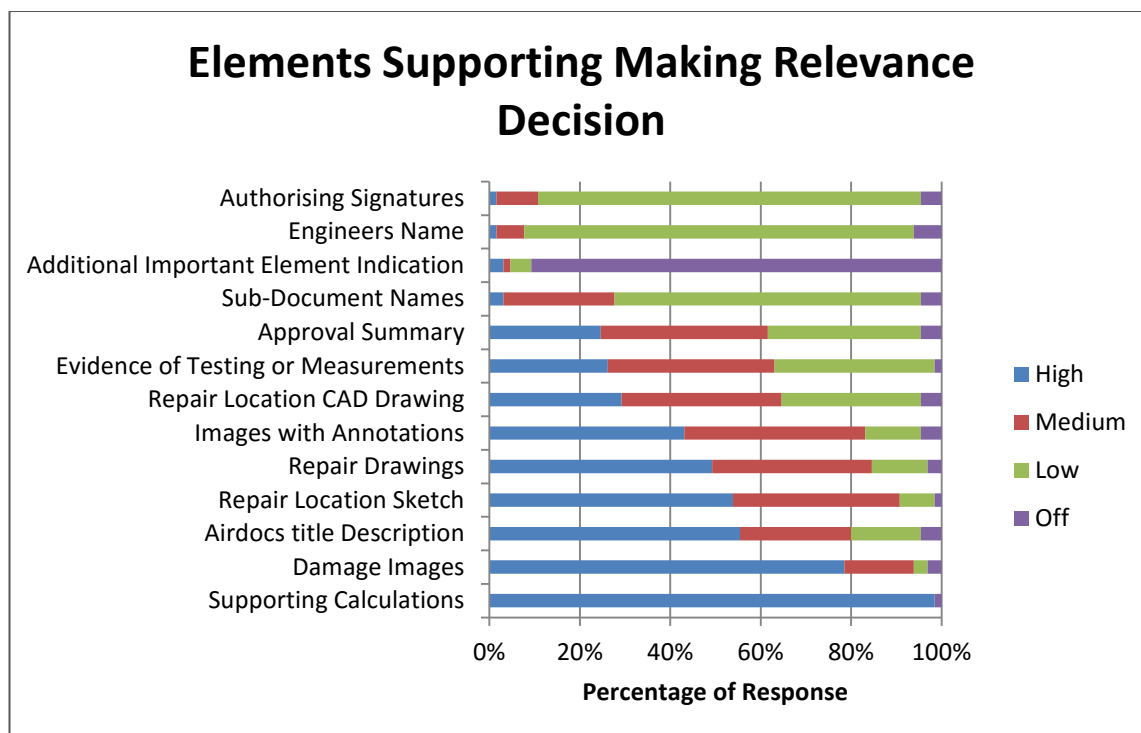


Figure 5.27: Important Content for Determining a Documents' Relevance

To understand a case fully rather than make a decision upon its relevance the information elements were ranked slightly differently. Although calculations were still important to understand a historic design repair case, they clearly have further purpose for indicating the relevance of being able to reuse and apply a repair design to a current task. The most important elements for understanding a case fully was "damage images", "repair drawings" and "images with annotations". There is a clear preference again for more informal content as per two of these options and the "repair location sketch" is also significantly ranked as important. The resulting finding of importance of informative document content in Figure 5.30 also corroborates the importance of visual elements in design engineering documents. This highlights the most informative elements of the documents as highly visual, ranking "photographs" and "images" as the most informative document elements and other visual elements such as "diagrams", "calculations" and "tables" emerging as significant also.

In Figure 5.29 the relative importance of subdocuments was assessed, this illustrated a clear preference for three such subdocuments, "damage report", "technical disposition" and "repair instruction". Although the purpose of these documents can be assessed by auditing them it would require much deeper investigation as to the role they play for design engineers in understanding historic case document contents.

A number of significant correlations are found between the higher expertise and preference for photographs, the higher expertise and denotation that using document collections was for multiple purposes and the perception that PDF document access limiting information usefulness is associated with higher photograph preferences. However, these correlations would require further investigation to determine the type of correlation (negative or positive) and the focus of this thesis is not upon supporting expert ranges within a team but to identify important informative document content. Hence this is potentially further investigative avenues that could be pursued as a result of the questionnaire. The

detail of these correlated variables is illustrated in the complete results contained within Appendix 4.

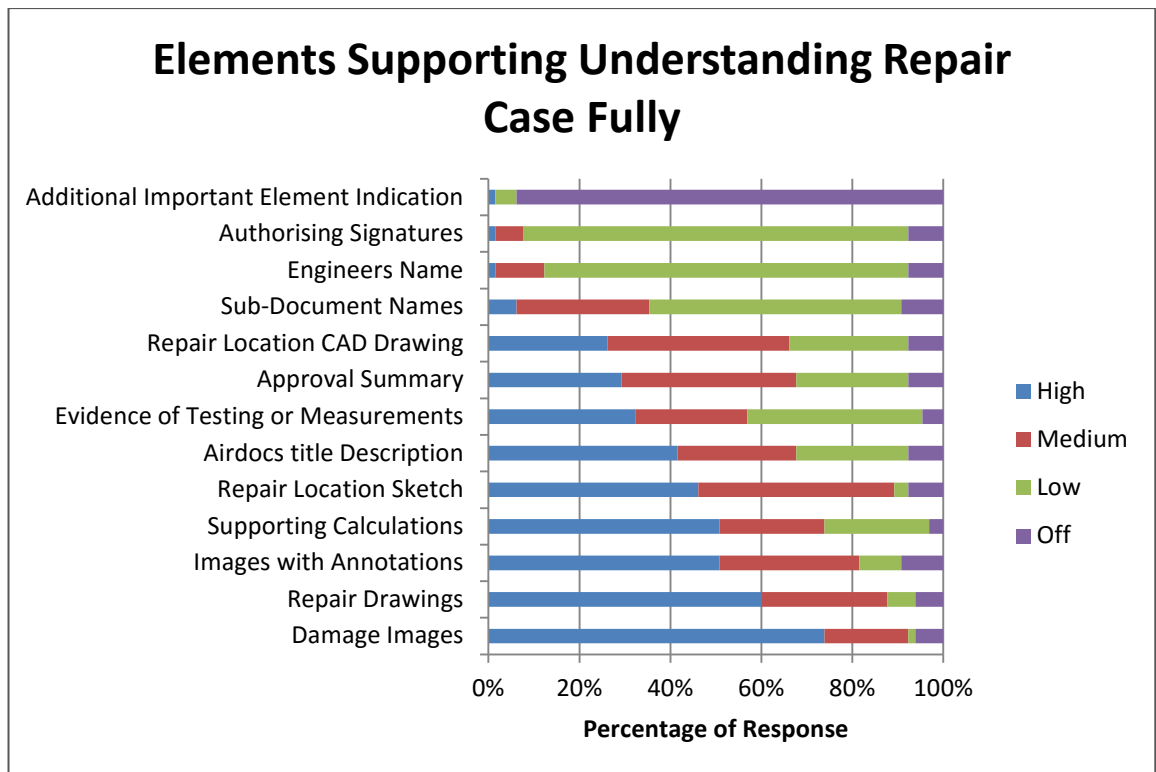


Figure 5.28: Important Content for Understanding Documents

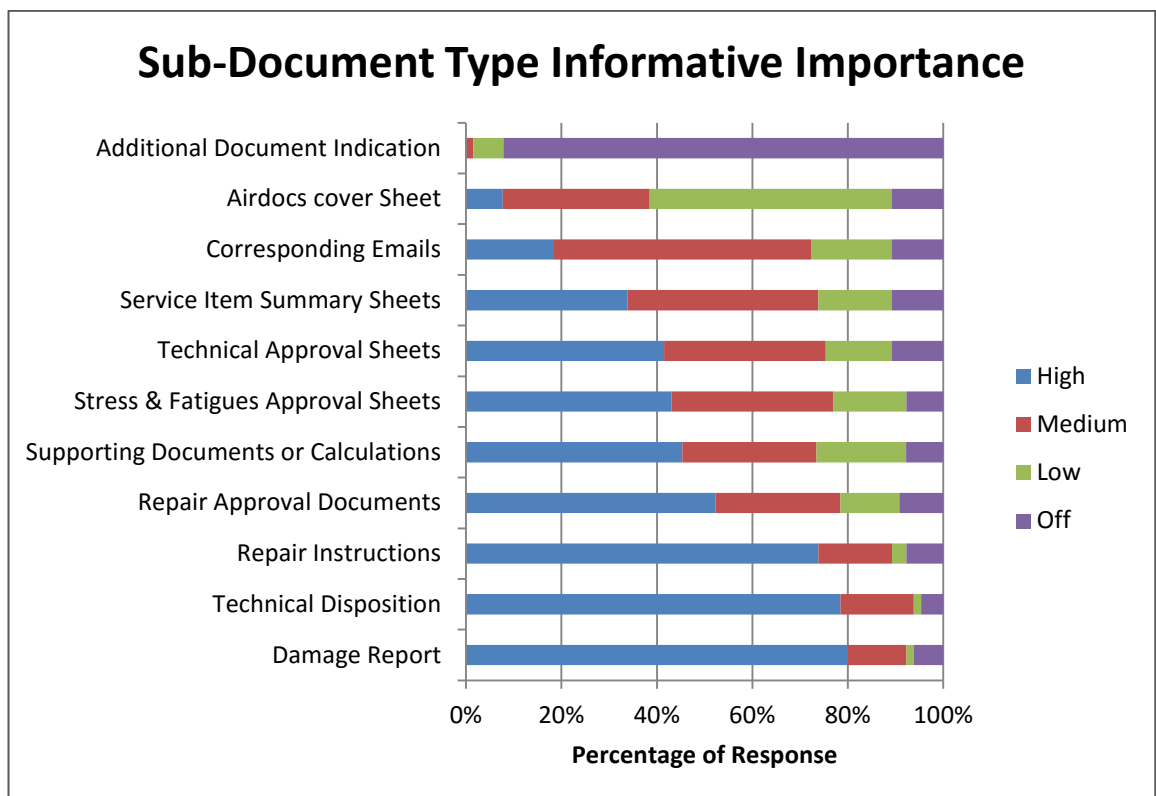


Figure 5.29: Sub-Document Decomposition and Relative Importance

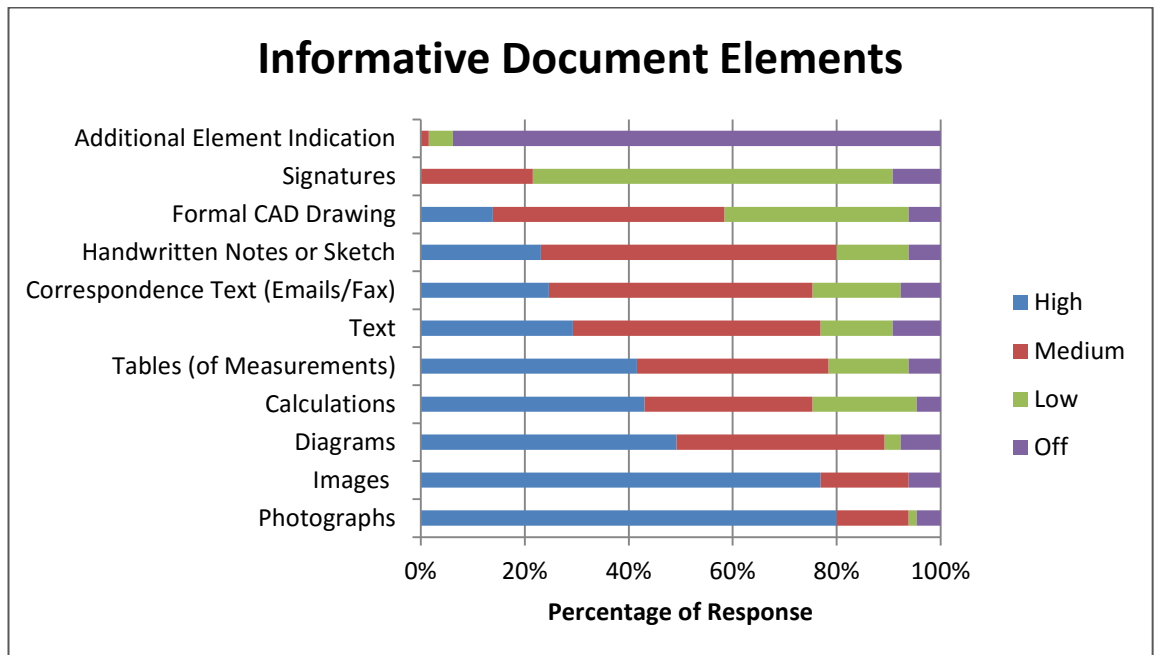


Figure 5.30: Most Informative Document Contents

5.5 Reflection of Findings and Reliability

The exclusion of the Off-Site team participants means that the results do not completely represent the structure of current industrial in-service design engineering teams, although the distribution of international teams and working practice is included. This is also the findings from one limited study of the use of one historic document collection. Comparing these findings with another additional in-service design engineering teams would be useful a useful comparison, both across differing product services and for smaller engineering teams. Another interesting comparison would be upon the time spent on understanding and seeking specific document information for the earlier stages of design engineering in comparison to the sampled later stage in this study.

The nature and differences in culture between international teams is much discussed within the industrial teams hence their design processing differences are recognised industrially by management. However, the results of this questionnaire do not make this apparent and is thus a weakness when making inference of further hypothesis about the utilisation of information to support their current practices and process.

The format of the questionnaire means that the times recorded as spent of specific information stages are approximated rather than actual timings. It is possible that this could be corroborated in future diary studies or computer implementations (although utilising the current document systems this is not yet possible as only the document opening event is captured, not how the viewing time and length). There are evidently also a number of aspects that require further detail to clarify the meaning of the result, including the perception of information access limitations and corroborative results for timing the length of time documents are currently being viewed and their information content utilised. It is expected that the study detailed in Chapter 6, the more qualitative Storyboard workshop will be able to corroborate some of these findings and to provide more detail about these aspects.

5.6 Discussion and Key Outcomes

In this chapter the conduct of an industrially focussed questionnaire study has been outlined. This has empirically collected data from a large in-service design repair team in the aerospace industry. The sample size and respondents was high meaning the results have potential significance for understanding the importance of

document information for design engineering. The questionnaire has in some measure quantified the document utilisation problems for design engineering in particular for the latter stages of design. It is evident that the content of historic case documents is relied upon as repository of expertise. The key findings for of this questionnaire are highlighted in the diagram for knowledge reuse from Chapter 2 to highlight its importance in researching and developing support for design engineers to reuse document information and thus explicit assets.

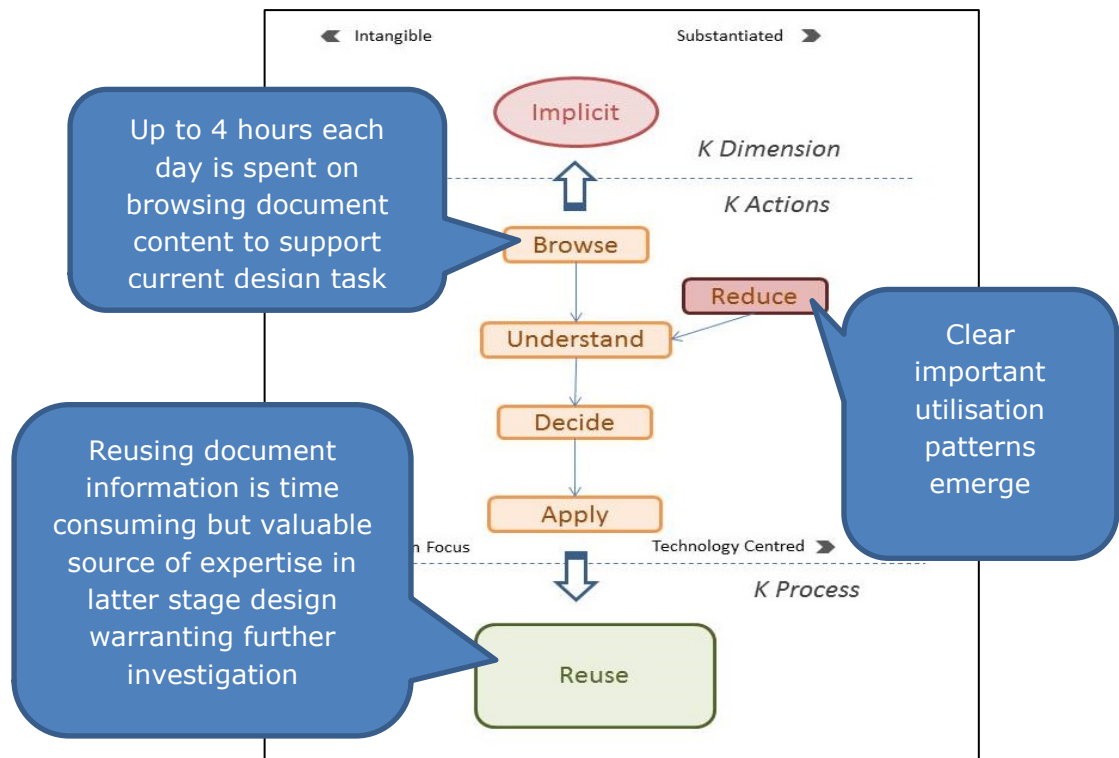


Figure 5.31: Knowledge Reuse Survey Findings

Two important key findings for this chapter are the time it takes currently for design engineers to find and utilise useful document information contents;

1. It takes between 25-70 minutes an engineer's time to *seek initial supporting information* for each task, irrespective of expertise and current practice results in frustration.
2. Up to 10 minutes is spent *understanding in depth* the contents of a document, this is for *each case that needs to be opened* and in most cases multiple cases are needed to be opened. There is a further need after opening documents to seek additional information elsewhere. Reducing both the number of cases that need opening (currently 4-9 PDF's) and the time spent understanding each document opened could save 8-45 minutes per repair conducted.

It is evident from these results that significant amounts of time are spent utilising the informative contents of document and hypothesis can be made about the important visual features in design engineering documents and the strategies that are employed that are sought to understand them and to discriminate the relevance of information for current task.

The role and thus relative value of such document utilisation strategies or the purpose of seeking such information elements however is not clear and further much deeper understanding and thus investigation is required. For further analysis in Chapter 8, the findings of this questionnaire are compared to external research findings in Chapter 2. However, the hypothesis that the visual elements have an

important role in understanding the contents of documents to facilitate their reuse is further investigated in the Storyboard workshops described in Chapter 6 that follows.

6. Storyboarding Design Engineering Information Reuse

The questionnaire findings have been used to understand further information importance for design engineers and to establish the document information strategies and content utilisation preferences of design engineers for the purpose of reusing their content to create repair designs. However, a number of aspects needed clarification, and deeper understanding to elicit “how” and “why” these document strategies were employed, and the informative content utilised.

To enable further evolution of this understanding of knowledge utilisation for design engineering documents, it is also necessary to understand in detail how the utilisation of information media supporting design engineering understanding and how it supports the purpose for which the information has been sought.

The study presented in this chapter therefore sought to gather much richer data, to gain a deeper insight of the cognitive information processing undertaken by design engineers when seeking to reuse document information, and to allow a deeper understanding of the utilisation of informative document elements most important to decision making.

This chapter thus details the research investigations conducted to delve deeper into the information related decisions and the processing activities of design engineers supporting their activities. It describes a Storyboard style experiment conducted with design engineers within the industrial case setting to collect rich, multi-stream data. It is interesting to note how little the Storyboard approach has been used in the engineering design field – only two examples have been found (Wilkstrom 2013; Andersson & Eriksson 2011) that are related to design engineering.

In terms of the knowledge re-use model outlined in Chapter 2, this experimental chapter seeks to characterise the information supported “understanding” and “decisions” being carried out by design engineers when reusing historic case documents.

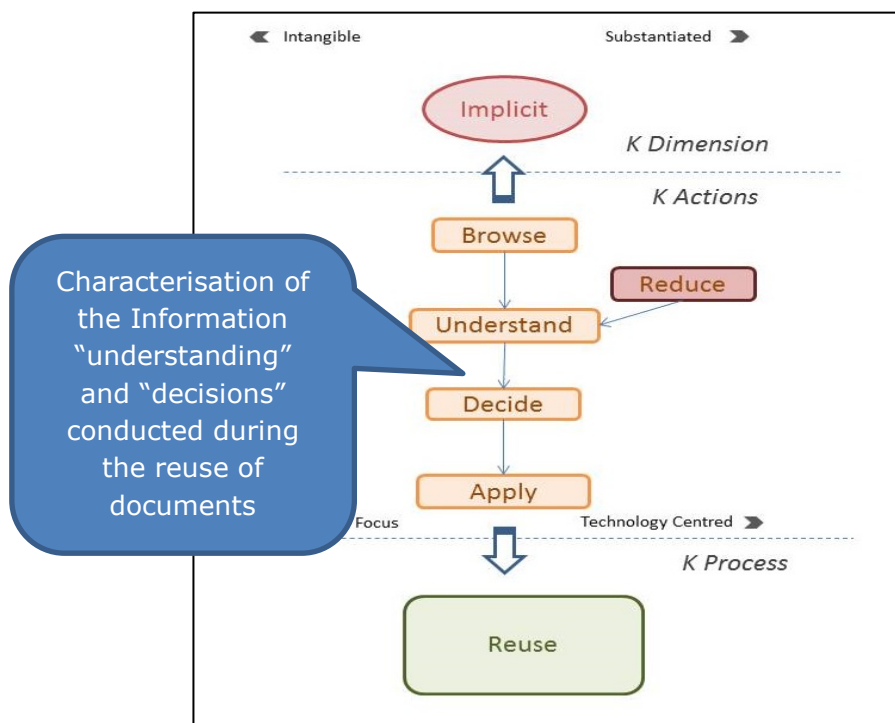


Figure 6.1: Storyboard Research Need for Reuse of Documents

Figure 6.1 shown illustrates how this experiment seeks to support understanding knowledge reuse for design engineering and its overlap to the findings of the

questionnaire study in Chapter 5. It is important to note that although there is overlap in the focus of these studies this experiment seeks to gain a much deeper insight into the utilisation of document information that was not possible in the questionnaire research conducted. The objective for this experiment is thus to characterise further the critical informative content of documents for design engineers, the purpose of the navigation strategies they currently employ for finding document content and thus to seek the value of this information in determining the relevance of document resources. The expected output from the analysis is as follows;

- First Case Summary Prototype for Case
- Evidence of Key Information Elements
- Ranking of Informative Element Value
- Chronological Information Sequencing

The next section describes the Storyboarding workshops that were conducted and the scientific experimental methods used therein.

In Section 2.4, the purpose of the information utilisation for design engineering process has been examined in more detail, embodying the information relevance decisions that are necessary, in particular as the body of information and "overload" phenomena increases. The next objectives identified for design engineering research that support the development of effective solutions for reusing explicit knowledge assets in design engineering are summarised as follows:

- Test the value of the visual and textual elements of design engineering documents to rank them
- Identify the key knowledge components of design engineering documents
- Identify potential methods for automating the extraction and reuse of informative document components
- Understand the process by which design engineers evaluate and thus determine what to reuse within design engineering documents
- Elicit the critical components and tacit human processes that underpin the utilisation of document and information from explicit assets.
- Consideration of the key human aspects of information browsing, decision making and reuse of information sources.

To enable the understanding and analysis of information that supports design engineering decisions and judgements, it is necessary to establish a basis for its understanding, especially for the discrimination of information relevance. The literature and surrounding issues outlined in this chapter specifically support the development of a theoretically supported framework to analyse the qualitative data and hence results - his objective being to suggest how best to both capture and analyse design engineering information discrimination and hence decision process.

It is widely acknowledged that design engineers and engineers in general have to make frequent judgements and decisions. These decisions are frequently based upon the information sought and the design task in hand. In Chapter 1 it is suggested that these information supported decisions are seen in other complex domains where there is reliance upon information. This also applies to the increasing information overload that industries and humans are now subject to. The complexities of these information supported decisions and the theoretical research that seeks to understand them is discussed further in Chapter 2 (section 2.4). It is evident that understanding the information that underpins the design engineer's ability to make judgements and decisions is critical to understand their information support provision needs.

6.1 Decision Analysis Framework for Engineering Design

This thesis has identified a gap in the literature that focusses the purpose for this research. A number of scoping studies have been utilised to further characterise the current knowledge and information reuse challenges for the latter stages of design engineering.

A number of times within this thesis it has been necessary to refer to design engineers and the decision making part of the information processing tasks they undertake. It is evident from Chapter 4 when the design engineering tasks and processes have been analysed in more detail, which under the burden of increasing information the rapid discrimination of information relevance is becoming a key concern. This is also true in a much wider human context with the era of information overload and the information relevance decisions discussed in section 2.2.

This section specifically addresses the need for Design Engineers to make decisions upon information relevance to inform their design repair process (or current task). First the research and theory behind decision making practices are discussed in relation to design engineering information tasks, cognition and reuse practices. In light of the need to make informed decisions, the applicability of such decision making frameworks for supporting complex informed decisions is highlighted. In particular the relevance of naturalistic decision making (NDM), its Recognition Primed Decision (RPD) framework subset created by (Klein 1993) with the need for additional support and techniques is outlined.

In the latter part of this chapter the application of the RPD framework to analyse engineering information relevance decisions is outlined, together with guidance of how it is utilised in this research to understand design engineering document and information processing and reuse. This chapter concludes by presenting the potential benefits that design engineering information support techniques could further derive utilising decision theory and investigation into applying naturalistic decision making support to design engineering information and knowledge processes.

6.2 Storyboarding Information Relevance Decisions

In Chapter 2, the literature surrounding design engineering and the need for knowledge and information support has been discussed. A number of research studies have been discussed highlighting the information rich processing involved as part of design engineering projects, hence the requirement for information management and support. In section 2.1 – 2.3 the increasing number of information resources available and the design engineering need to reuse prolific information sources is also emphasized. In Chapter 4 this is ever more evident for the in-service design engineering teams described, utilising huge historic collections of design engineering data, in cumbersome formats with few task specific supporting technologies. Figure 6.2 below shows information decision critical points in the knowledge asset reuse diagram established in Chapter 2.2, this illustration highlights the importance of decisions to design engineering information reuse. Much time reusing information is spent upon the information seeking and browsing part of the task, to enable the design engineers to make a decision upon the relevance of information resources available.

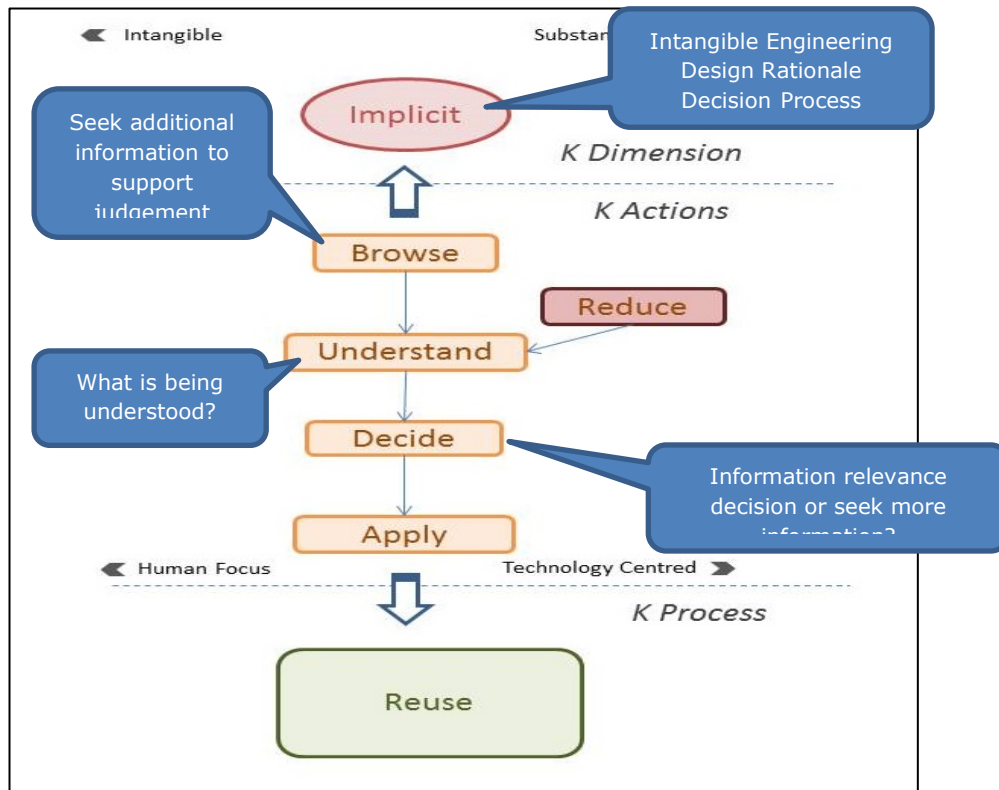


Figure 6.2: Decision points in Design Engineering Knowledge Reuse

It is the decision of relevance of the design engineering information that is critical to its reuse and it is this decision upon the relevance of information that is hypothesized to take significant time and efforts for design engineers. Hence, characterising the facets of this information and decision processing that is critical to understanding the necessary support that may be required by design engineers to reuse information. In particular the focus of this thesis is upon the prolific physical knowledge containing assets collated by design engineers, to support their effective storage and reuse. For the in-service teams discussed in Chapter 4, a significant knowledge asset is the heterogeneous media document collections amassed as part of the design engineering process throughout the life of the aircraft.

6.3 Storyboarding Workshop Proposal

The questionnaire described in Chapter 5 sought to canvas the views of a broad in-service design engineering team from international teams and hence differing working practices. One of the findings of this study is the nature of sub-expertise even within design engineering industrial teams. It is evident from the results of this questionnaire that each sub-expertise will have subtly differing information needs and hence alternative document viewing strategies or utilisation purposes, one such example is the need for team members to carry or document administrative tasks such as described in Chapter 4, section 4.3.5. This multipurpose nature of the historic case document collections has been identified as one of the issues in information re-use (Markus 2001).

Hence to understand the information support needs for highly specific design engineering experts it is thus necessary to ensure that any research investigations conducted sample only from those experts. It is also acknowledged within cognitive work analysis methods and domains that for the experiments to be successful they need to seek to investigate only those participants with specific and high expertise (Schraagen et al. 2000). This is one of the reasons that making inference from

previously conducted quantitative results leave some findings ambiguous and in need of further triangulation. For these reasons the Storyboarding Workshop invitees were sampled purely from the reactive repair design working team members that respond and work on the daily repair requests ongoing.

6.3.1 Storyboard Approach Theory

The hypothesis and grounding for designing the story board study is that there is a weighted advantage to the reuse or utilisation of differing media or information elements for differing roles, experts or tasks undertaken as suggested by the findings of the questionnaire study (see chapter 5). Richer detail needs to be sought to understand these subtleties and the user differentiations to enable effective supporting techniques tailored to specific users to be possible. This could explain the differentiation in intervention uptake for knowledge management within differing audiences (Carey et al. 2012).

Cognitive work analysis is a suitable approach for understanding the cognitive work undertaken by design engineers (Vicente 1999; Schraagen et al. 2000). This thesis has not sought to be a purely cognitive task analysis approach but simply to utilise some of the cognitive theory principles to ensure the research approach is rigorous. Hence the rapid approach to cognitive task analysis in (Zachary, Technologies, et al. 2012) illustrates useful principles for the design of this industrial experiment. For conducting cognitive task based experiments it is suggested in Figure 6.6 taken from table 1 of Zachary et al. (2012) that a simulated work based scenario is appropriate for;

- 1) Identify the 'knowledge chunks'
- 2) Characterise the features of and contextual cues for using 'knowledge chunks'

The complexity of the "what" constitutes a 'knowledge chunk' for design engineering is evident from the industrial case study in Chapter 4. The information and resources audits in section 4.5 began to characterise the potential information resources that presented 'knowledge chunks' for in-service design engineering. Due to the prevalence and need for document utilisation in in-service design repair process section 4.6 further sought to focus upon the historic document collections and their 'knowledge chunk' or informative content. This has been further built upon in the questionnaire study in Chapter 5 by developing a hypothesis about the critical information chunks and the strategies used by design engineers to facilitate their effective use.

Both of these illustrations have different variation from the originally described process that is given below. However it is evident that even at varying degrees of granularity the principles behind RPD are useful for understanding information loaded complex decisions.

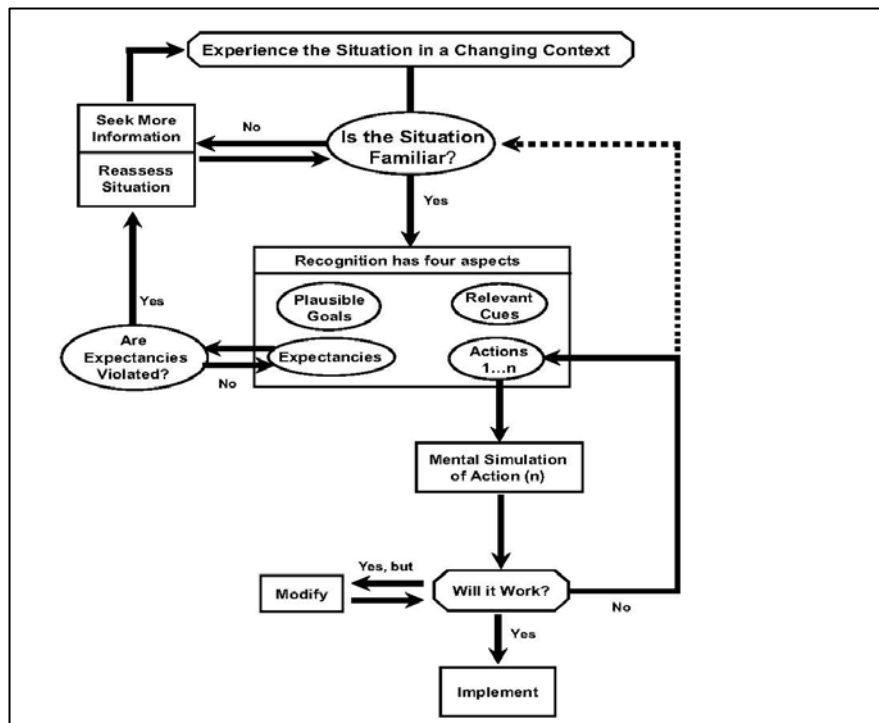


Figure 6.4: Klein et al. (1993) Original RPD Process

The illustration shown above (Fig 6.3) represents a complete RPD decision using a number of potential paths, this would be difficult to follow for encoding design engineering decisions and thus Lipshitz & Strauss (1997) suggest a smaller sequence of steps that are useful for following for design engineering decision purposes. This view is between the complex software implemented view of Yen et al. (2013) and the highly simplified approach taken by Diaz (2010). The suggested steps from Lipshitz & Strauss (1997) are;

- i) Situational Understanding (Situational Awareness)
- ii) Recognition of Typical Case (Recognition)
- iii) Serial Evaluation of Recognition Cues, Plausible Goals and Expectations, seeking additional information as required (Seeking Information)
- iv) Mental Simulation of potential actions (Mental Simulation)
- v) Decision upon best fit action (Decision)

This is a sequence of steps derived from the original RPD process that can be utilised to understand the engineering information supported decisions. However, it is not yet clear how it is possible to apply this to the industrial case. To help an example from Chapter 4 is given in the next section to illustrate how the application of these steps supports understanding of the design engineering decision process.

6.4 RPD for supporting Informed Design Engineering Decisions

Duffy et al. (1995) write about the need for not only the reuse of information for design engineers but the reuse of past design, referring to the entirety of the past design case. They discuss the support for case based reasoning as an attempt for supporting design knowledge reuse. Understanding this need for the entire story has led researchers to investigate the content of design rationale to support this need to reuse design knowledge (Auricchio & Bracewell 2013). In terms of decision making this is the experiential base from where design engineers recognise scenarios or design "situation understanding" for the purposes of Recognition Primed Decision making (RPD). It is evident from the perspective of design engineering research that much focus has been placed upon the act of information

seeking (Wild et al. 2010; Robinson 2012; Marsh 1997; Lowe et al. 2004), rather than *the process the information is sought to support*. A holistic approach to analyse the decision making process and the information sought throughout enables a more complete view of the design engineering information need to emerge (Bennett et al. 2010).

Analysis of the wider design engineering information supported decision enables a holistic analysis approach to be taken to the spectrum of information utilised to support those decisions; this is different to the approach currently being taken in design engineering information studies where audits of information are conducted in isolation from specific purpose (Wild et al. 2010; Marsh 1997) and then later correlation and significance is sought. To enable this approach to be taken the capture of entire design reuse stories need to be captured for further inspection, similar to the case based reasoning described as the reuse approach in Duffy et al. (1995).

A practical example of the wider design reuse story is illustrated in the industrial case in Chapter 4 in section 4.3.3 & 4.3.4. The in-service design engineering process for the reuse of information is illustrated again below for ease. The repair design process shown illustrates that design engineers in practice seek not only information to support them to make design decisions but that they seek entire case based histories to support them to recognise design scenarios.

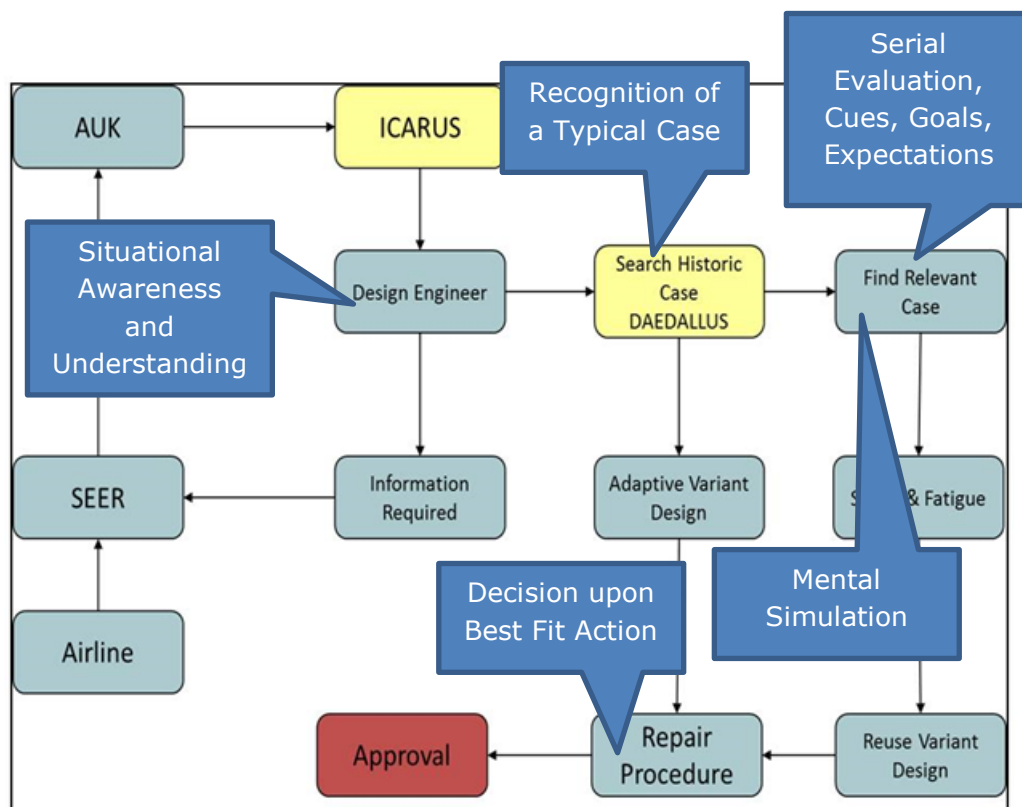


Figure 6.4: Repair Design Process and RPD Stages

Relating this design engineering process back to the significant RPD steps elicited in section 6.4; the illustration maps the key stages identified in RPD to the design engineering process.

Although we can hypothesise upon these decision stages as related to those mapped in the illustration, the assignment of a case to a design engineer instigating the awareness of a repair situation (SA), the recognition of potential best courses of action (R) all leading to a decision upon the best course of action (D). For design

engineers there is considerable ambiguity in the serial evaluation (SI) and mental simulation (MS) stages “what” are the “goals”, “cues” and “expectations” of information to support these parts of the decision and thus “how” do design engineers mentally simulate their actions to arrive at a “best fit decision” (D). It is the use of the RPD framework to analyse these design engineering decisions that will create an understanding of the design engineers information need at each stage.

The following illustration is synthesised from the RPD steps and the industrial design repair process as suggested to be applied to the information relevance process that design engineers undertake when deciding upon the best action to take in designing each repair case.

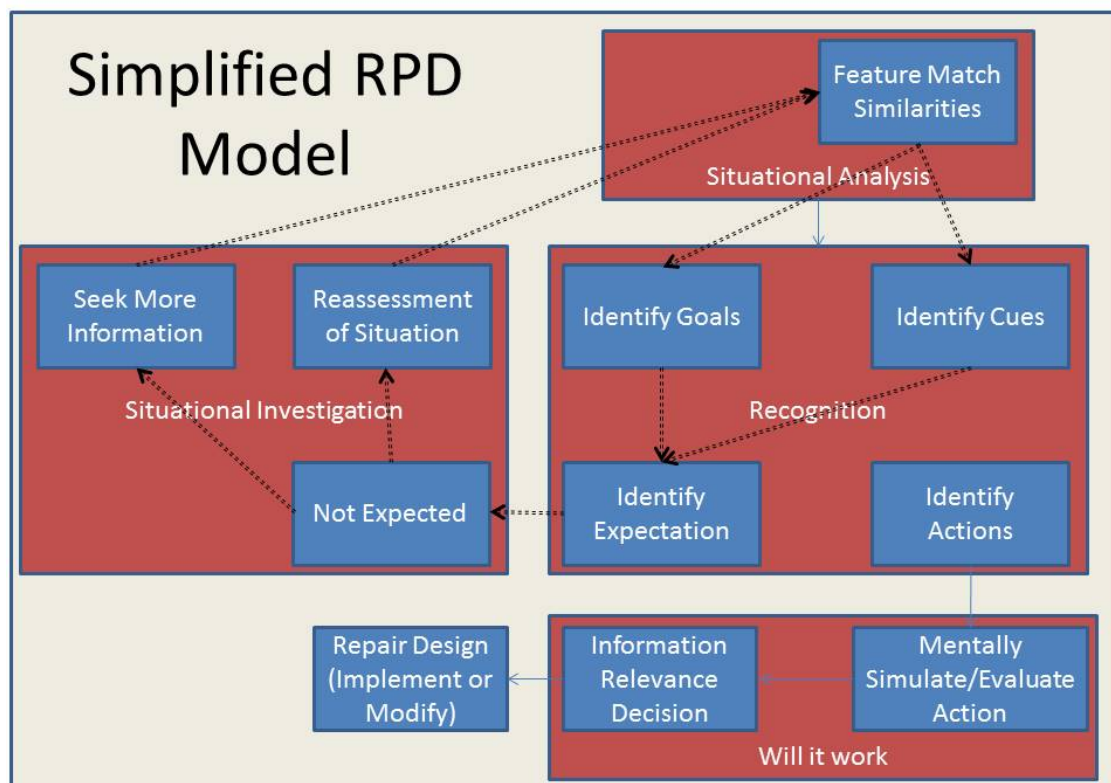


Figure 6.5: RPD Steps and Design Repair Process

The information process shown in Figure 6.5 is mapped to the stages in RPD elicited from Lipshitz et al. (2001). If the information utilised by design engineers during these RPD steps is captured then it is possible that encoding any information supported steps with the decision stage will enable a correlation to be made between any information and the thought process it is supporting. The capture of the decision process together with the supporting information is thus a critical outcome of this research. In the next section the process for capturing such design engineering decisions and information is outlined.

6.5 Storyboard Capture, Decision Decomposition & RPD Encoding

Oppenheimer & Kelso (2015) suggest that there is a new decision making theory paradigm shift or advancement into information processing as the basis for any decision making. They also suggest that the utilisation of information is for “story building” purposes in the awareness of a situation. Hence it makes sense that capturing the design engineering decision stories as they unfolds will provide a basis for studying the information being processed, the decision story and the

design engineering though process throughout. Similar storyboard approaches are been undertaken for cognitive systems engineering approaches in McNeese (2004) and thus their effectiveness for this purpose is noted.

Typically cognitive task analysis methods are considered lengthy research projects needing considerable expertise (Crandall et al. 2006); hence although these methods are needed for capturing cognitive data this limits the usefulness of such methods. However Zachary et al. (2012) suggest it is possible to perform a rapid cognitive task analysis much reducing the time the research takes and thus hosts useful principles for ensuring the cognitive aspects of the design engineering work being studied is captured effectively for later analysis. The table below is taken from Zachary et al. (2012) as an example of the rapid cognitive task analysis steps that could be taken. Stages 2 and 3 suggest that observations or simulated work are required to be analysed to elicit the major units of knowledge that are required and to describe each in detail. The purpose of the cognitive analysis in this research is to seek detail about these knowledge units and thus simulated work of design engineers is an appropriate study method for its capture.

Stage	Task	Activities and products	Time and effort required
0	Establish purpose of analysis and define the expected product.	Specify the expected outcome and scope of the analysis as well as the macrocognitive activities to be analyzed, the format of results, and the criteria to be used to establish completeness.	The sponsoring organization can complete this task in advance. Otherwise, interactive iterations are required, taking upward of two person months.
1	Describe work domain and context.		1–3 person months
2	Segment cognitive components and interrelationships.	Conduct interviews and/or observations of real or simulated work, and analyze to identify the major units of knowledge (also known as “chunks”) involved in the work. Break out declarative, procedural, perceptual, and motor skill knowledge, and identify which pieces are used together in performing the work.	2–5 person months
3	Describe the internal structure of each knowledge component and relationships to work processes.	Conduct more focused interviews and observations of real or simulated work. For each knowledge chunk developed in the previous stage, analyze and describe its structure, content, and attributes in more detail. Identify context cues or associations that activate the use of each chunk or affect how it’s applied.	3–8 person months
4	Establish formal representations (mathematical, computational, and so on).	Translate the detailed descriptions from the preceding stage into a selected formal representation language. Express precisely within that language, and conduct verification tests to ensure that the formal representation is complete and valid, given the criteria established in stage 0.	3–6 person months

Figure 6.6: Zachary et al. (2012) Rapid Cognitive Task Analysis Structure

The intention for the qualitative study of this research is to record and analyse such simulated design engineering work capturing rich “information supported” storyboards representing information relevance decisions. It is the cognitive process being undertaken by design engineers when considering and utilising information resources that are of interest to this research, thus these rich stories will need to be encoded and decomposed using both hypothesised informative content chunks (images vs text) and the RPD decision stages outlined in this section.

The Storyboard workshops for the capture and creation of design engineering information relevance decision stories are described further in Chapter 8 together with the results of the study. However these stories will need to be broken into knowledge chunks (Zachary et al. 2012) and encoded using decision steps to enable any correlation between the information and decision stage (or cognitive step) to emerge. In the last section the RPD process for design engineering information was outlined in Figure 6.5. These are the decision stages that will need to be given code labels to enable steps and knowledge chunks in the storyboard to be assigned.

Given the different RPD coding systems created and utilised by Diaz (2010) and Yen et al. (2013) it is evident that a number of approaches could have been taken to deconstruct design engineering decisions using RPD. The actual codes and steps utilised are shown in the previous section and how they apply to design engineering information relevance decisions. Further description of how the multi stream story data has been collected and analysed is provided in Chapter 8 in the analysis and results sections.

The suggested encoding follows the five main decision stages identified are situational analysis (SA), Recognition (R), Mental Simulation (MS), Situational Investigation (SI) and Decision (D) stages. These codes are utilised further in the analysis section of this chapter.

6.6 Summary of the RPD Analysis Framework

Naturalistic Decision Making theory provides an opportunity for Design Engineering research to understand and apply human behavioural traits to analysis methods, designed explicitly for the complexity of the decisions undertaken by Design Engineers. The literature regarding Recognition Primed Decision making complements human information processing analysis and qualitative methods for eliciting rich and detailed facets of the complexity of design engineering tacit or implied processes that support decisions.

Given the difficulties Jastroch & Marlowe (2010) emphasize about the difficulties experts have in coding their knowledge for expressing it and the emphasis Hayes & Krippendorff (2007) place upon the need to rigorously encode for analysis, a theoretical framework for understanding the information supported decisions of design engineers is critical. Oppenheimer & Kelso (2015) also suggest that there is a new decision making theory paradigm shift or advancement into information processing as the basis for any decision making, hence the application of decision making theory that utilises the need for information gives confidence in the approach to utilise RPD as a basis for encoding the information processes of design engineers in making decisions.

It further provides a human behavioural cognitive framework structure for decomposing and understanding the information processing that is undertaken by Design Engineers when making decisions upon document contents relevance. It facilitates the identification of the key purpose or support obtained by design engineers for stages identified in the cognitive process when reusing informative document elements. This creates a more in depth picture of design thinking process and is novel in its application for design engineering research. The literature does not yet have examples of these techniques being applied to understand design engineering knowledge processes and have not yet been used to elicit such rich detail in previous design engineering empirical studies. It thus enables us to identify and directly link stages in the cognitive document processing and suggest strategies that have potential but have not yet been researched. For example it is possible to compare the mind-set of the design engineer when viewing a subset of resources for example image media and its role in understanding design rationale, or damage reporting text and the key points in the text that design engineers need to seek further information about.

6.6.1 Storyboard Experiment

The focus of this research is upon supporting better the reuse of document information content for design engineers and thus the 'knowledge chunks' for this task based study are defined by the document information audits, the most highly ranked informative content elements from the questionnaire results and the strategies employed for utilisation of historic case documents. For building upon and triangulating the results from the questionnaire study it has been necessary to utilise a similar task based study to enable direct comparison of the results. This means that from Chapter 4, section 4.3.4, Figure 4.4 is again the work scenario that is utilised to simulate the working practices of the in-service design engineers. Figure 6.7 below is adapted from Figure 4.4 to illustrate the focus of this experiment and the work task simulation being employed.

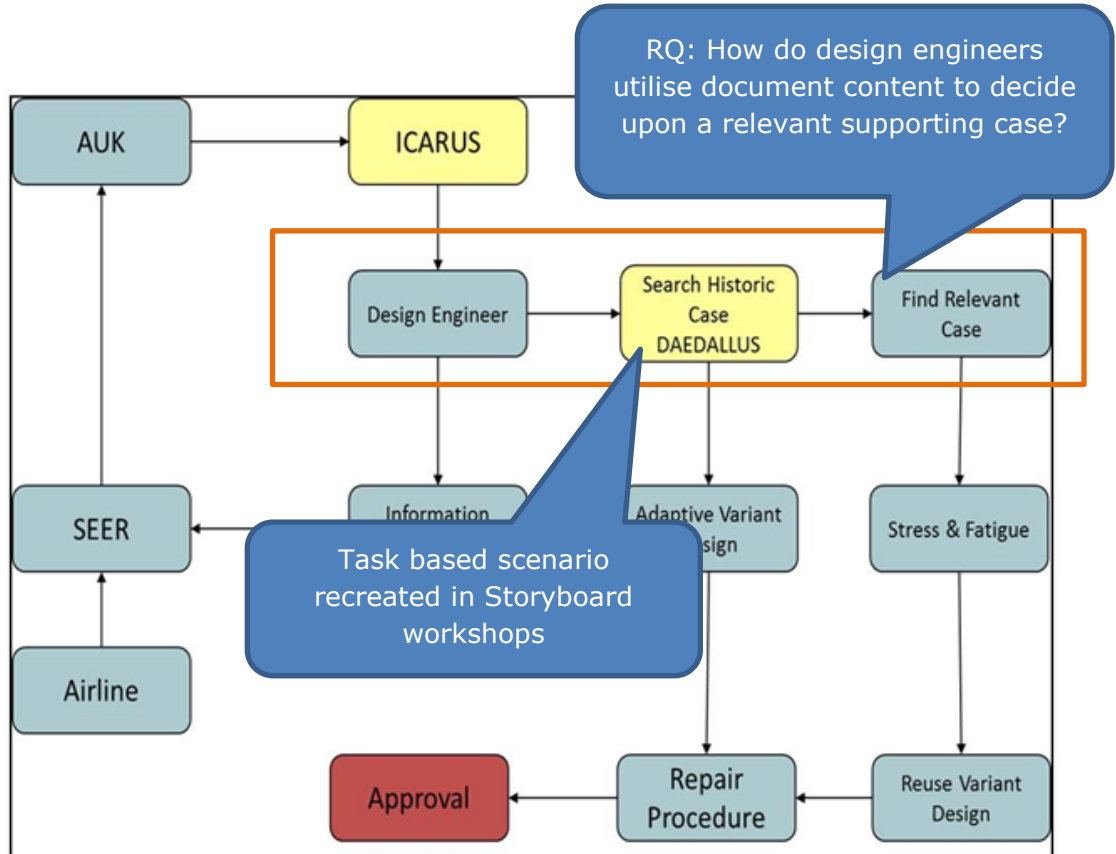


Figure 6.7: Storyboard Work Based Simulation Process

The task based scenario takes place in the part of the process ringed in the orange box and constitutes the document supported information gathering process at the beginning of an in-service design repair. In terms of the working tasks simulated for this experiment the following two illustrations are of the working tasks simulated to enable observation of design engineers carrying out and these tasks and creating their own information relevance decision stories for data collection purposes.

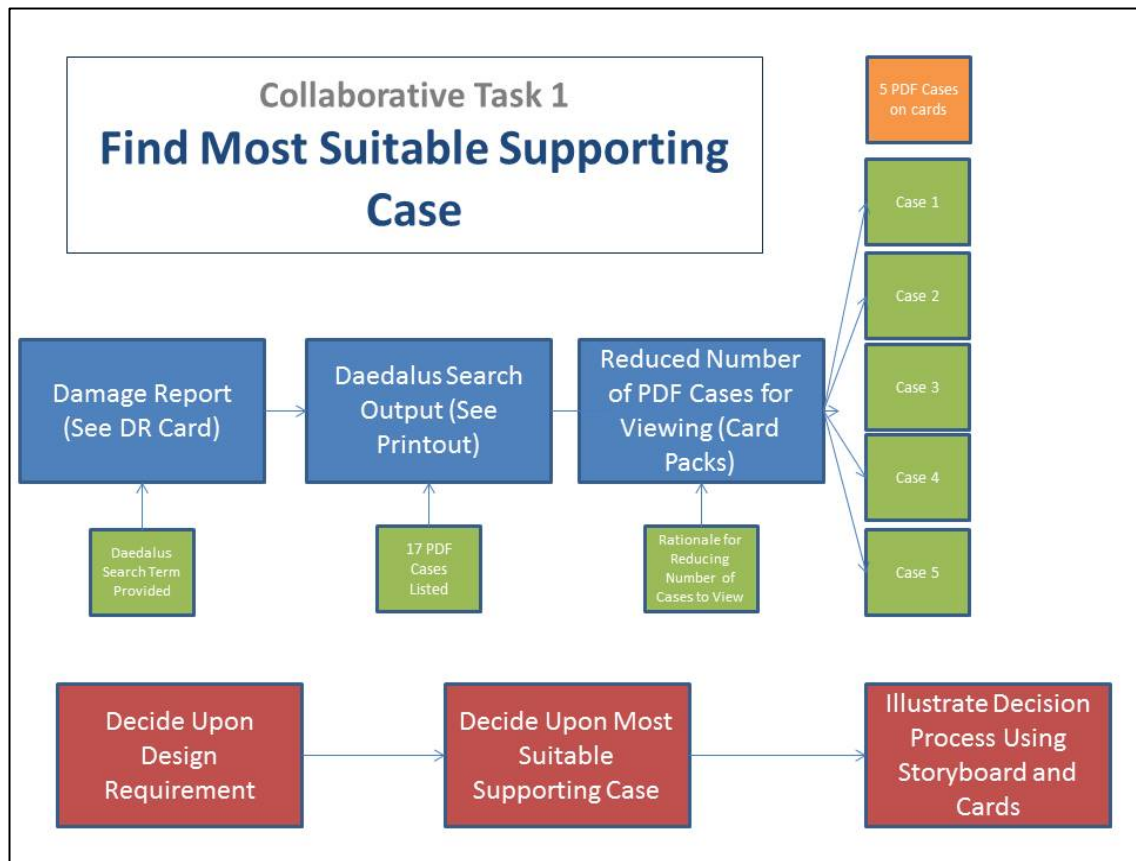


Figure 6.8: Storyboard Suitable Case Task 1

The simulation included two tasks the first was a longer collaborative or group focussed task and a second to enable individual differences in document information content and understanding to be observed. The first task used simulated an incoming repair case (see Figure 6.7.2, orange box and process outlined in Figure 6.8 above) to mimic the information relevance decisions undertaken when examining the content of historic case documents design engineers were given deconstructed document (into information chunks and strategies) and requested to create storyboards of their thinking process in conjunction with the physical information elements. The second task (process outlined in Figure 8.4 below) involved each engineer being asked study a document and to annotate the information content themselves that they sought and the ordering of information seeking to enable them to understand the historic case documents.

6.6.2 Data collection and Experimental Set Up

The data collected in this experiment was multi-stream, purposefully alternated between constructive and free format to enable the design engineers to work as closely to their normal environment as possible. The creation of the information storyboards was video recorded to enable reconstruction of conversation elements in conjunction with the evolution of information relevance and ongoing decisions. However, the researcher is aware that for encouraging participation recording and observing participants can introduce bias such as either the Hawthorne effect (Cash 2012; Blessing & Chakrabarti 2009) or create a reluctance to participate freely (Auricchio et al. 2013). For this reason it was made clear to the participants that the recording was not of them but only the creation of the information storyboards and only hands were visible in conjunction with the conversation stream. Direct observation was then left until after the experiment in the analysis phases.

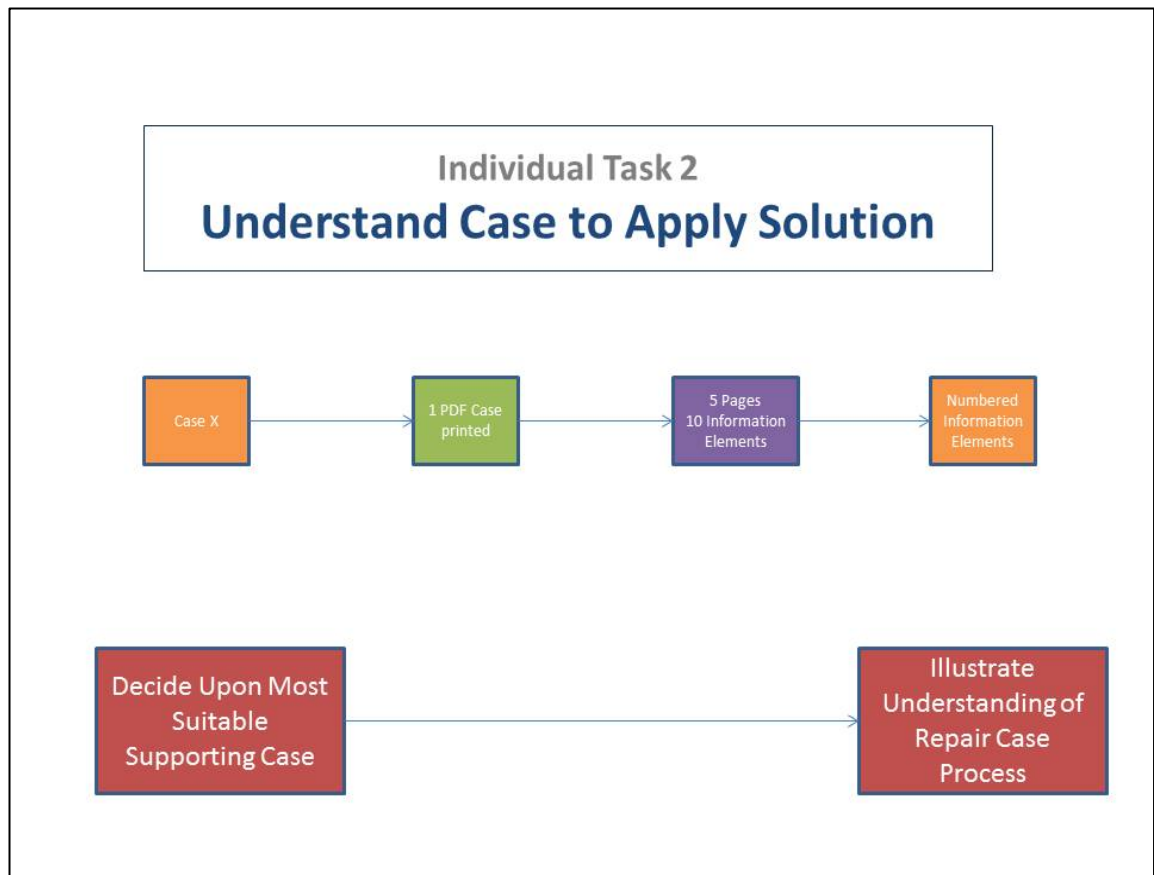


Figure 6.9: Storyboard Understanding Task 2

The second task again was not observed but annotation was requested using pens and highlighters for later analysis. It was also necessary to adhere to strict timings for the conduct of any tasks due to the time constrained nature of industrial engineering design, this meant that management could cost the resources taken and design engineers did not feel anxious about the time it could take to participate. The workshop was intentionally conducted in a relaxed atmosphere with drinks and snacks provided to put the participants at ease and to encourage full participation.

Earlier in this section the need for participants with specific expertise were required to ensure that the results elicited expert knowledge and perspectives rather than generalised. A number of considerations listed below from the questionnaire study presented in Chapter 5 have driven the population sampling for this experiment:

- Chapter 5, Figure 5.1 illustrates that 34% of the sampled population were based abroad. For practical purposes it has not been possible to sample international design engineers. From a wider perspective, this would be useful but sampling would need to be analysed independently due to the influence of local working practices.
- Chapter 5, Figure 5.2 illustrates 3% of design engineers work weekends. It is hypothesised that this result in differences in working practice(s) and for comparison should be included in the workshop sampling.
- Chapter 5, Figure 5.3 & 5.4, Although 28% of in-service engineers are within their first 2 years of experience in the department, 84% of design engineers have more than 2 years' experience in engineering (67% have over 5 years prior experience). Hence it is assumed that all of the design engineers will have significant expertise to be included in the sampling and thus it remains only to ensure that an equal distribution among participants is necessary.

- Chapter 5, Figure 5.5 shows that only 48% of the in-service engineers are experts in design (rather than other sub-expertise focussed) and thus it is important to focus the workshop upon participants with specific design expertise, thus the industrial sampling pool is more limited and the number of participants will be smaller, meaning qualitative in depth investigations will be more appropriate. However, it is possible with such smaller qualitative studies to support the design engineers to work as closely to their normal environment as possible to ensure the results are representative of real world design practices also allowing design engineers to collaborate and work together as is suggested to be important in literature (see Chapter 2).

Carey et al. (2012) also suggest that it is important for industrial interventions to engage users in the process to support the likelihood of their take-up. Thus for the purposes of this "real world" approach to the experiments that the design engineers also felt that they were participating on workshops that were a good use of their time and energy. Hence the focus of the workshop although primarily for data collection was also to ensure that the design engineers could socially engage to share best practice with one another for the utilisation of design engineering document information content, thus group focussed work was a key part of the tasks undertaken.

6.7 Detailed Data Collection Strategy

As previously described in the section above careful consideration of a multitude of factors has been necessary to ensure that the collection of data for this experiment has been rigorous. A summary of the considerations is listed below;

- Sampling of only a few experts was both possible and appropriate for conducting work simulation and multi-stream data capture.
- The task based scenario was created using the experience of a highly expert designer and using 'real world' scenarios.
- The selection of documents utilised as information resources were as a result of simulating real text searches in live engineering design systems as per current practice and already carried out for the design engineers.
- The document sample purposely included a number of typical examples for testing the variety of sizes and content combinations possible.
- The document deconstruction utilised the content audits and 'knowledge chunks' already elicited in previous industrial observations (Chapter 4).
- The strategy of data collection, although including video meant that participants could be comfortable they could not be identified making them comfortable to participate.
- The workshops participants included a member of the weekend team and spectrum of in-service experience to ensure any potential influences these differences posed for working practice were equally represented (information for this was provided by the industrial management team and has to remain confidential).
- Verbal commentary and thus annotation of the storyboards was not requested but inadvertently captured and thus represents truly the thinking practice of design engineers without being influenced.
- The video recording of the information storyboards as they evolved in conjunction with the verbal conversation and physical (textual and pictorial) annotations requested enables a cross reference approach to analysis to be able to be taken for analysing the results thoroughly.

Due to the size of the design engineering repair design teams it was only possible for up to 6 Design Engineers to participate in the workshop at any one time and thus two workshops were conducted, one immediately after the other so participants in the second cohort were not influenced by previous participants inadvertently. This also meant that the same task scenario and document case collections could be utilised in both workshops to make direct comparison between

the findings of each group. The participants were split between the groups as evenly as possible to ensure that the distribution of in-service expertise was equal across groups. The participant group and sampling is described in more detail in the next section.

6.8 Conducting the Workshops

At the time of the workshop there were 12 design (sub-expertise) engineers regularly conducting the daily repair requests supported by the historic case documents in the in-service team. Hence the participant groups consisted of 5 design engineers in group 1 and 6 design engineers in the group 2. Due to the significantly low number of weekend design engineers, it was not possible to ensure that a member of the weekend team was represented in both cohorts. However this likely reflects the low weekend design engineering population identified in Chapter 5, Figure 5.2 (3% overall). Group 2 had a representative member from the weekend design team in attendance.

It was not possible for sensitivity reasons to have access to the number of years' experience each member of the team held. However, it was possible to have access to an engineering experience ranking category for the design engineering team members. Utilising this ranking it was possible to calculate a typical range and distribution of expertise in the current design engineering team. Although it is not possible to publish the names and ranking of individual team members table 8.5 illustrates how the invites were distributed across the (experience) ranked design engineering members to ensure the participant distribution was similar to that of the current design engineering team. The ranking utilised is 0-5 where 0 is the least experienced and 5 is the most experienced. Unfortunately although 6 attendees were confirmed for each workshop, due to the management restrictions and departmental workload imposed it was not possible for the sixth person to attend with group 1 and a replacement from design was not readily available.

Experience Rank	Number of In-Service Design (Sub-Experts)	%age Sample to Replicate	Number of Invitees of 12 Participants
0	2	4	0
1	7	14	2
2	8	16	2
3	4	8	1
4	6	12	2
5	24	47	5
Total	51	100%	12

Table 6.10: Design Experience and Participant Sample Replication

Due to the nature of expertise it was important that both more naïve users were included in the group simply due to the difficulties experts have in describing their metacognitive processes. Frequently the more naïve user group are able to articulate what they do and the reasons for that as they are still in learning phases rather than the automatic approach that come with expertise (Hacker & Melzer 2009). In practice invites were forwarded to a distribution as close as possible to that shown in Table 6.10. This means that the distribution of expertise was weighted towards higher number of years' experience.

It was necessary for the workshops to be carried out over a period of two hours each with time for a coffee break between the two tasks being conducted. This allowed time for the tasks to be undertaken but considered the workload needs of the department. The next section details two preliminary studies that contributed to the evolution of the storyboard workshop method. This was necessary to ensure that the variables were controlled and that only those we wanted to experiment with did not remain static.

The work simulation staged and supported by an experienced design engineer to ensure that the initial part of the process was accurately created. This simulation required mocking up a repair request and staging the first part of the historic document search to retrieve a shortlisted number of potentially similar supporting cases. The simulated search was created using the text term "aileron hinge support" and filtering excel results by "rib 3" in the Daedalus information search and retrieval tool. The five first potentially appropriate historic cases were retrieved for creating physical packs. The historic cases shortlisted were compared for the purposes of ensuring that the sampling included a variety of documented information, the table summarising the document differences is presented in the next section.

The shortlisted cases were then printed, decomposed into informative elements and attached to card to create physical document packs that could be manipulated and boarded into information relevance decision stories. Each page and item in the physical packs was coded and labelled to record the case they belonged to, the page and content number. To enable the design engineers to utilise the document contents in a manner closest to how a document may be utilised with a computer bookmark strips were added and labelled according identically to the digital copy of the document. For example in Figure 6.11, the photograph shows how the physical document pack is segmented by coloured bookmarks that are labelled in the same way the departmental administrator annotates the PDF documents currently (see section 4.3.5 & section 5.6).

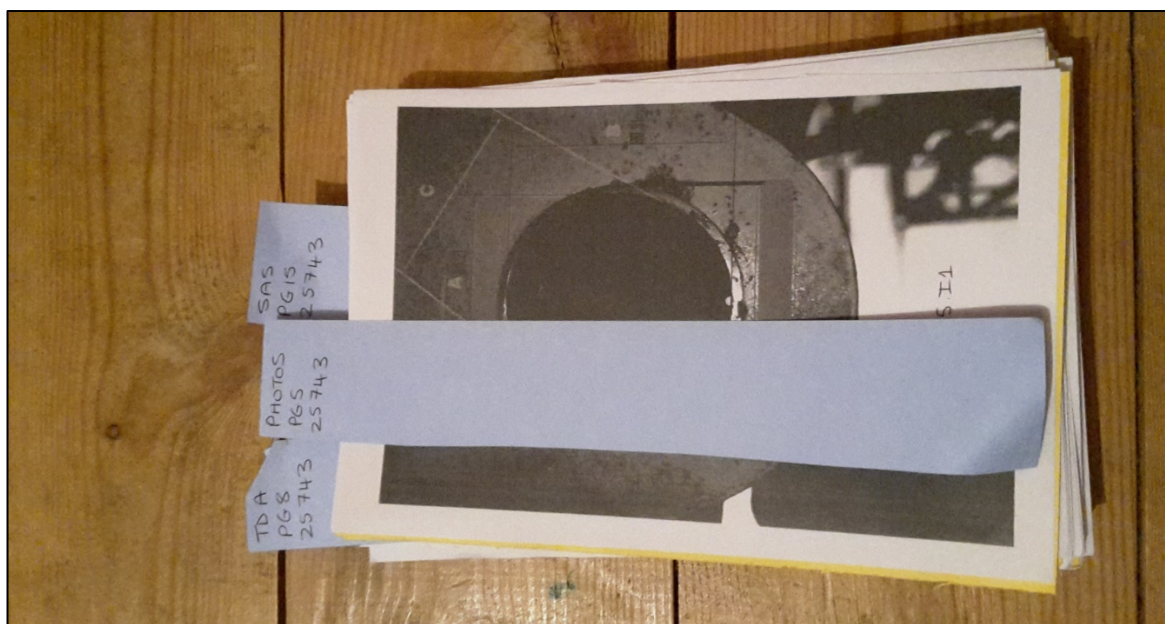


Figure 6.11: Photograph of Example Physical Document Case

This section has described the preparation of the physical document packs, the distribution of workshop participants and the task based work simulation in the mock up to enable the design engineers to create manual storyboards representing the information elements of documents that are utilised to make decisions upon their relevance to their current repair task. The work based scenario and the participants have been carefully controlled to ensure that the data collected represents only cognitive processing of the design engineers and the supporting document information elements. A number of trial experiments were conducted to develop the storyboarding of documents method, these are described below.

The second task involved each participant being randomly assigned a printed historic case document. The participants were given up to 10 minutes to understand the historic cases completely whilst annotating in chronological (numbered)

sequence the information elements that they viewed and the understanding they gained by viewing the informative elements. The participants were able to annotate utilising coloured pens and although the groups that participated were recorded it is not possible to identify the design engineer and the document they were assigned. For both part one and part two the document samples were created identically to enable a comparison to be made between the groups.

6.8.1 Storyboarding Trial Using Document Information Elements

Although it was not possible to conduct a preliminary workshop within industry the design of the experiment was tested with an academic audience to ensure that the approach was rigorous. On two occasions similar storyboarding approaches were utilised to develop the storyboarding workshop method. These workshops were not recorded and one of them was for a shorter period to scope how information elements could be deconstructed to enable a storyboard to be created from document information elements.

A picture of the first deconstruction approach utilising a deconstruction of the image and text components of a document is given below. This illustration is the reconstruction of the document as created by the researcher. The document was first printed and cut into individual hypothesised knowledge chunks; these knowledge chunks represent the document information audit components described in Chapter 4, section 4.6.3. This deconstructed document view was utilised to test with two highly experienced design engineering academic members of staff to evaluate their understanding of contents from the individual deconstructed components. The conclusion from this trial was simply that from the visual elements alone it is not possible to understand documents contents completely to be able to utilise that understanding. Hence rather than focussing upon the visual information elements it would be necessary to create storyboards of the entire document information content.

The second trial experiment was conducted with a researcher, as project manager and an academic member of staff at the University of Bath. This trial included sample physical document packs for creating information storyboards upon rolls of wallpaper to enable them to be persevered. There were marker pens provided for making annotations and notes to indicate the thinking and purpose of each element added or to indicate the strategy utilised. A further digital experiment was conducted with a power point representation of the documents and information elements for an alternative method for data capture and storyboard creation.

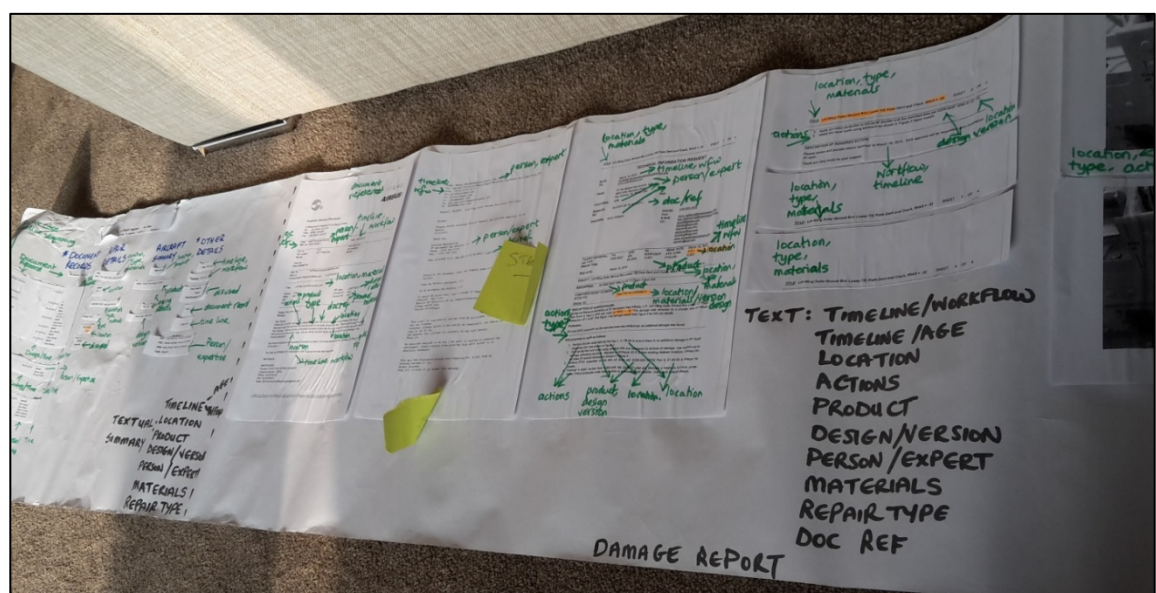


Figure 6.12: Photograph of Trial Storyboard

As a result of this trial a list of amendments to the method were made as follows;

- The physical document packs were colour coded using backing card to make it easier to identify a collegiate historic case.
- The physical document pack bookmarks were colour coded for each physical pack.
- The number of physical documents prepared was reduced from six to five due to the time it took for creating the storyboards and the time available in the workshop.
- The utilisation of physical paper slips for adding thinking notes to improve explicit coding of the thinking processes recorded, rather than less accurate paper notation.
- A simpler approach to the individual understanding of document content experiment was taken, using printed copies of documents that could be annotated using coloured markers.
- The historic documents and content topics utilised for the second part of the experiment were changed to be completely different from those in the first to ensure that preconceived understanding could not be introduced inadvertently.

As previously explained both of the workshops were conducted on the same day and in the same location, in a conferencing room on the industrial site. There was a 5-10 minute researcher comfort break in between workshops but they were conducted close together to minimise the risk of information being passed between participant groups. A second researcher attended the workshop to practically support with refreshments and operating video recording to enable the other researcher to act as facilitator. Although the researchers had to be present they observed from a distance to ensure that they did not influence group participation in the task.

6.9 Results of the Workshops

The data collected from the Storyboard workshops as explained in this Chapter thus far is multi-stream and has many facets. It was the intention of this experiment to create qualitative data to enable rich and illustrative results to be collated. A number of approaches have been taken to analyse the results of the workshop that are outlined below. Each analysis approach yields although slightly different results that are discussed in turn. The overarching aim of the analysis has been to establish the critical informative elements and content of the design engineering historic documents and the role of the visual elements for design engineer document understanding. However, as already established, it is not possible to understand the information content of document with visual information content alone and thus the analysis focussed on the entire document contents rather than the visual information content.

The workshop data collected has been analysed in respect of the need for understanding it for this research project. There is considerably richer data and understanding that could be sought if further analysis approaches were utilised. The appendices for this document include further data collected including a transcript from each of the workshops, this has not been analysed in any succinct detail purely due the time consuming nature of this approach and the benefit of any results. Hence critical and relevant audio statements are included in these results to supplement the findings rather than form the primary findings. It is possible that with further work this data could be analysed subjectively and elicit more detailed results.

In Chapter 2, section 2.4 it was established that there was a need when utilising information to make regular decisions upon the relevance of information resources to the current task being undertaken. Earlier in this chapter, a framework was

outlined that would enable the analysis of the storyboards to be based upon a theoretical approach from the naturalistic decision making literature. The decision making framework established as the most appropriate in the Recognition Primed Decision (RPD) framework first described by Klein (1993). For the effective utilisation of this framework, the storyboards not only need to be recorded or encoded but they require deconstructing into information relevance decisions to enable the framework to support its interpretation. For analysing the results of the first part of the workshop this decision deconstruction for the storyboard is the approach taken before seeking to understand the data further. This was not necessary for analysing the second part of the workshop as the purpose was to understand a document completely rather than the relevance of information elements.

6.9.1 Detailed Analysis

To efficiently analyse the storyboards results they were first separated and recorded into a sequence of chronological information element and cognitive steps. These steps were further decomposed into individual information relevance decision sub-stories. Once this decomposition was completed it was then possible utilising the content of the individual steps to encode them using the RPD decision framework to overlay the RPD stage process that was also being undertaken. This enables the decision stage encoding for each of the chronological steps to be correlated with the content of the information storyboard. The recording of the storyboard steps, the decomposition of storyboard steps into decision stories and their encoding using the RPD decision framework are illustrated in sequence in Figures 6.13 & 6.14 below. Due to the qualitative nature of the data collected these illustrations are provided to be clear about the analysis steps that have been taken to understand the data.

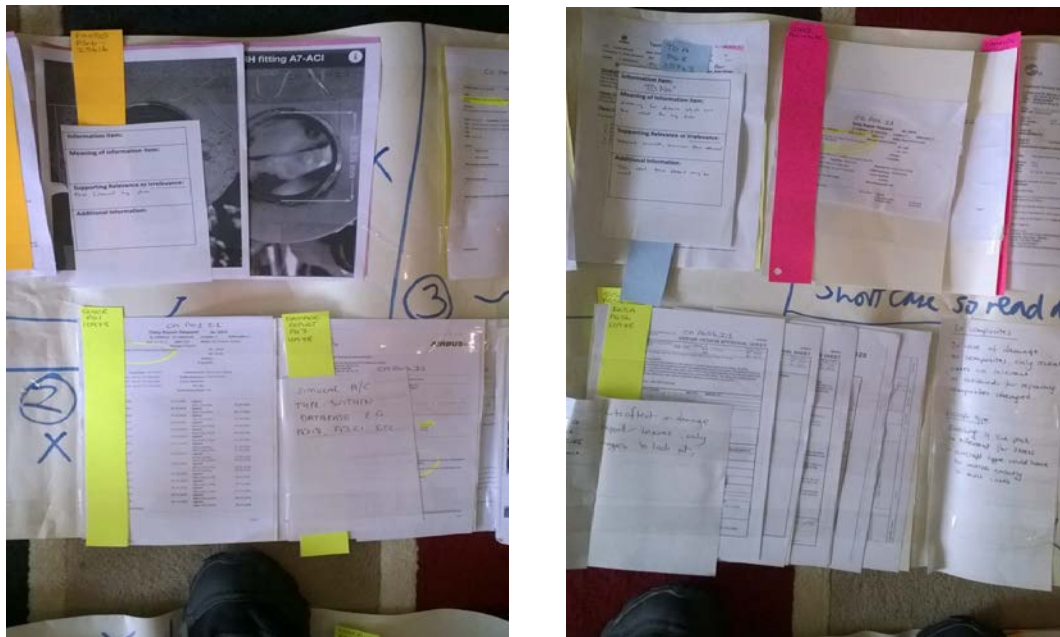


Figure 6.13: Photographs of Completed Storyboards from Group 1

4.Start Sub 1: Take case 25616 and open at Coversheet.
5.Skim read to seek "Title" field of repair on Coversheet.
6.Elicit key text/terminology in title.
7.Compare repair title to repair request understanding.
8.Go to Damage Report using Bookmark provided.
9.Skim read text throughout correspondence until reach damage reporting details.
10.Skim read damage reporting text to seek key description detail.
11.Elicit key text terms/terminology to compare to current repair request.
12.Thinking Detail: Text Term Sought "Ref:SRM 57-26-16".
13.Thinking Detail: Text Term Sought "internal diameter of bushing P/N NSA5101276".
14.Go to Photos using Bookmark provided.
15.Scroll through each page with Damage Report images until all viewed.
16.Thinking Detail: Text is followed by images.
17.Compare images to current "thinking".
18.Thinking Detail: Seeing image supports thinking that case is irrelevant.
19.Make Decision Case is irrelevant to current task.
20.End Sub 1: Case Understanding complete.

Figure 6.14: An Example Story Encoding for Document Information Decision

The photograph in Figure 6.13 shows the raw storyboard data before it has been recorded and translated into information relevance decision steps. The second Figure 6.14 is one example of a step wise deconstructed decision with brief description of the storyboard content for each step undertaken. Each of the thinking steps illustrated were provided by additional note cards placed on the storyboards by the design engineers. It is possible to view each of the information decision stories by correlating the recorded informative content and extracting it from the original document to create an information story as it was utilised from the original document. An example of this story is illustrated in Figure 6.15 below.

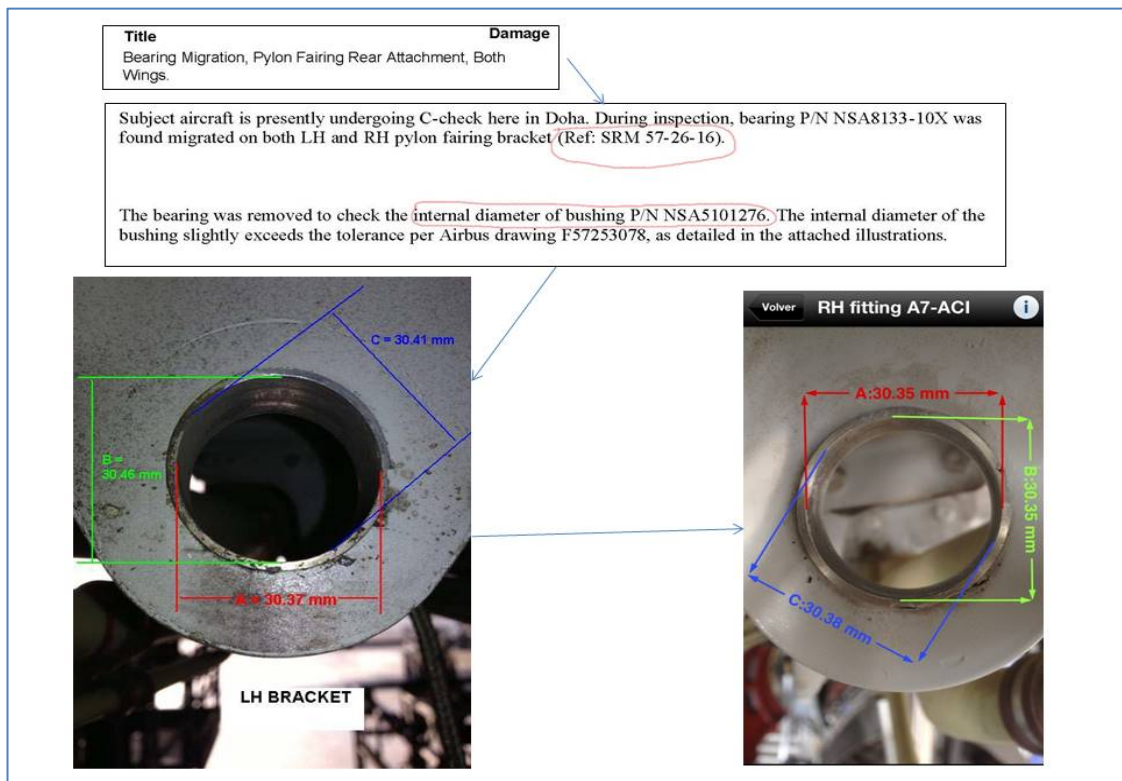


Figure 6.15: Document Information Represented Relevance Decision

Using the document information summary approach above it is further possible to compare the group decisions for each document side by side to see how they potentially correlate. Figure 6.16 below is the same information decision story for both groups to compare them side by side. The differences between the information elements utilised becomes apparent when viewing them illustrated side by side. The similarity is between the images utilised, the imagery being viewed after the textual document parts, the "title" and "description" at the beginning of the information trails and the need to seek further textual information to understand the relevance of the historic case document.

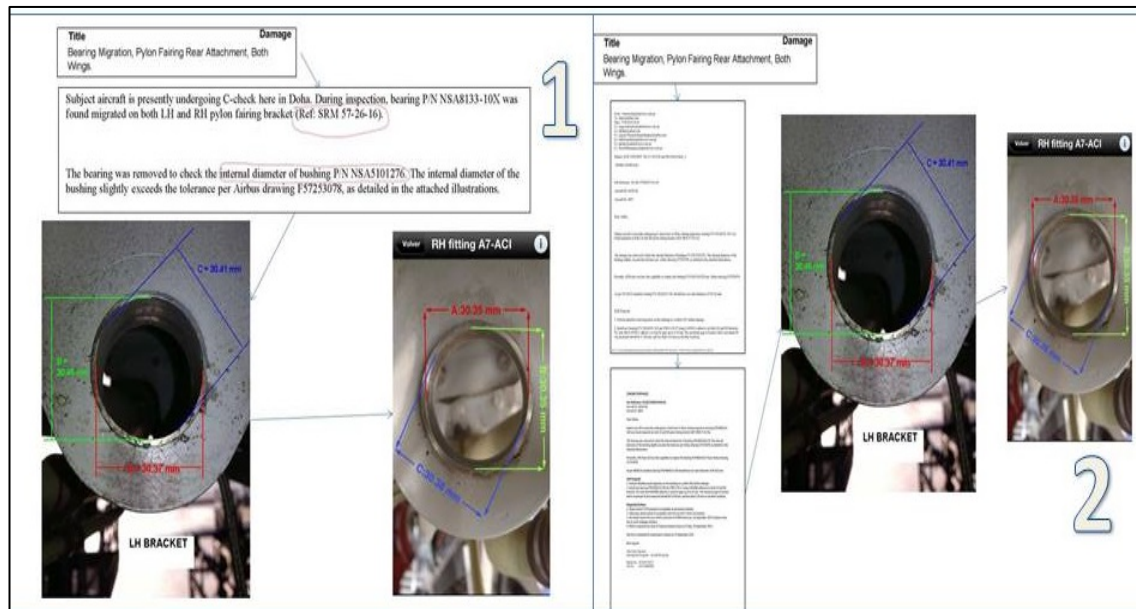


Figure 6.16: Comparative Information Decision Stories between Groups

The steps shown in the example Figure 6.14 and for each decomposed information decision were later encoded in spreadsheets to view any representative correlations for the steps to the RPD decision stages established in Chapter 6, the strategies employed for document information viewing, the subdocument being utilised with a historic case and the information media and format types being utilised. Initial overviews are provided first to draw comparison between the two groups and their respective information stories. More detailed results follow to further investigate the roles and relationships between document information contents and the cognitive processing it supports.

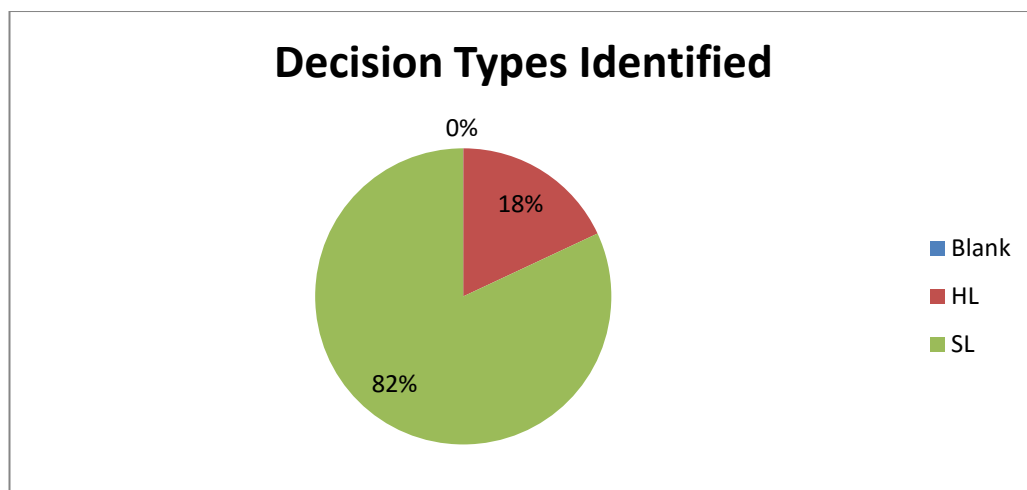


Figure 6.17: Design Decision Decomposition

6.9.2 Initial Results

The descriptive text created about each of the storyboard steps in Figure 6.14 was as previously explained decomposed into step chunks each representing a separate decision story. It was evident from the descriptive text that to find a similar supporting historic design case that there were two types of decision processing being undertaken by the design engineers in synchrony. There was the higher level decision and purpose for seeking information support;

- 1) Overarching decision upon "best fit" historic case to support current repair request (HL).
- 2) Sub information relevance decision discriminating relevance of each historic case (SL).

The relative time spent upon each level of decision making is shown in Figure 8.12. It is evident that a majority of the information supported efforts are spent in the lower sublevel of decision making about each historic document (82% of the story steps focussed on this). Although it is not the concern of this experiment to understand the different types of decision, it is useful to be aware that both levels of the decision making are cognitively interlinked and returning to differing levels of thinking and abstraction are evident throughout. Hence when analysing the information supported steps it becomes clear that the many of the supported by differing types of knowledge, such as prior knowledge or knowledge about the incoming repair request. In the Figure 6.18 an overview of the entire decision stories and its relative knowledge resource utilisation is given. This illustrates for example that none of the steps in the story sequences were unsupported without knowledge (Blank) and 5% of the steps were supported by the current repair request (current repair correspondence). Surprisingly only 9% of the overall steps were supported by prior knowledge (PK) and the Historic Case information (HC) supported 82% or a large proportion of the steps. It was necessary to create another category during the analysis processing to indicate the need for further information about the current repair to enable a similar supporting repair to be identified (NIRR). This new information repair request accounted for 4% of the overall steps. However it is evident in the next Figure 6.19 when comparing the groups this knowledge supporting process is not used by both groups.

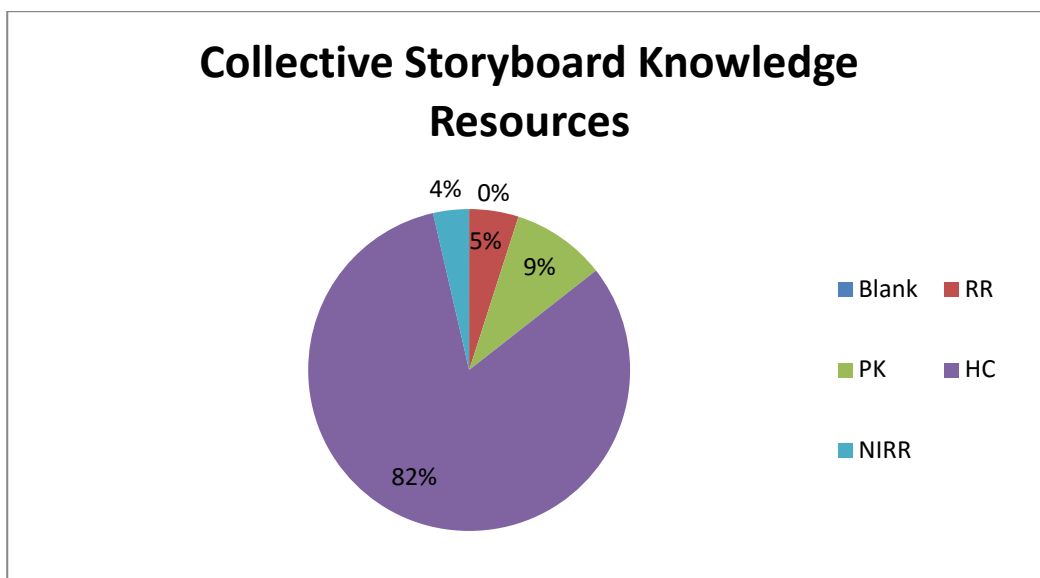


Figure 6.18: Knowledge Resources Utilised

6.9.3 Results - Knowledge Resources

In itself it is not surprising that the historic case information supported steps form a majority of the story steps (HC). However the differences between the groups potentially reflect the levels of expertise within the groups or the independent traits

associated with working patterns of some of the design engineer. In group 2 it is evident that the historic cases supported only 75% (HC) of their steps and they also sought further information about the repair request to be able to select a similar case more efficiently (8% NIRR). If the number of alternative resources supported steps is summated for group 1 (12%) compared to group 2 (26%), it becomes evident that group 2 focus over twice as many additional information supported steps than group 1.

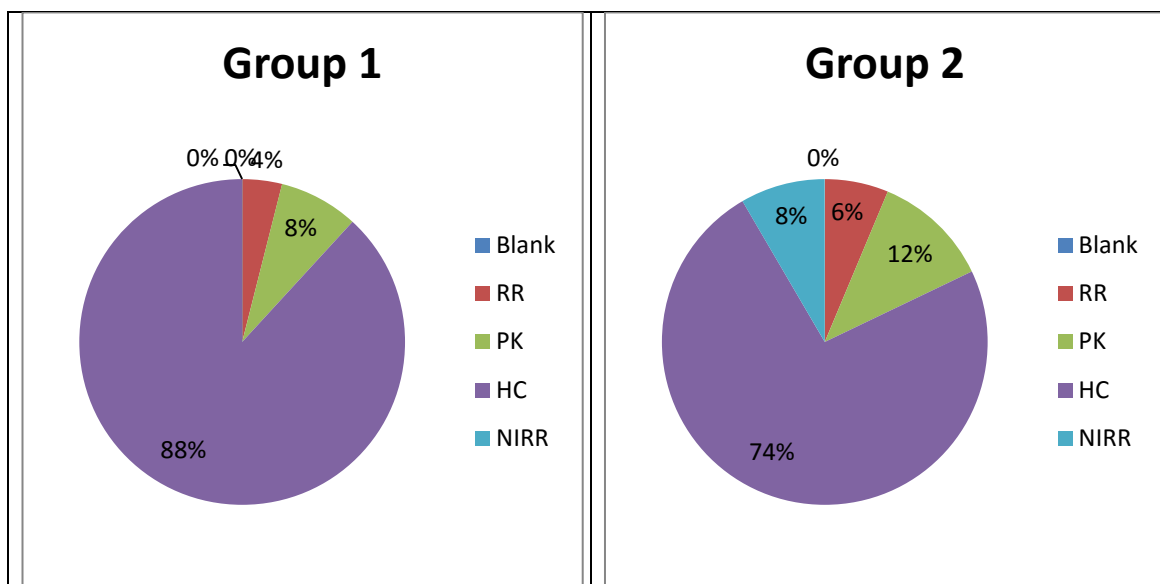


Figure 6.19: Group Knowledge Resource Comparison

The historic case sub document utilisation patterns have been reported in Figure 6.20. Each colour represents a particular subdocument type within each historic case and the utilisation patterns are clearly distributed amongst different subdocuments, suggesting the importance of them all. However, significant amounts steps and thus time appears to focus upon two subdocuments (45% DR – Damage Report and 25% C – Standardised Coversheet) in particular and thus this is a point that is characterised further in the results that follow.

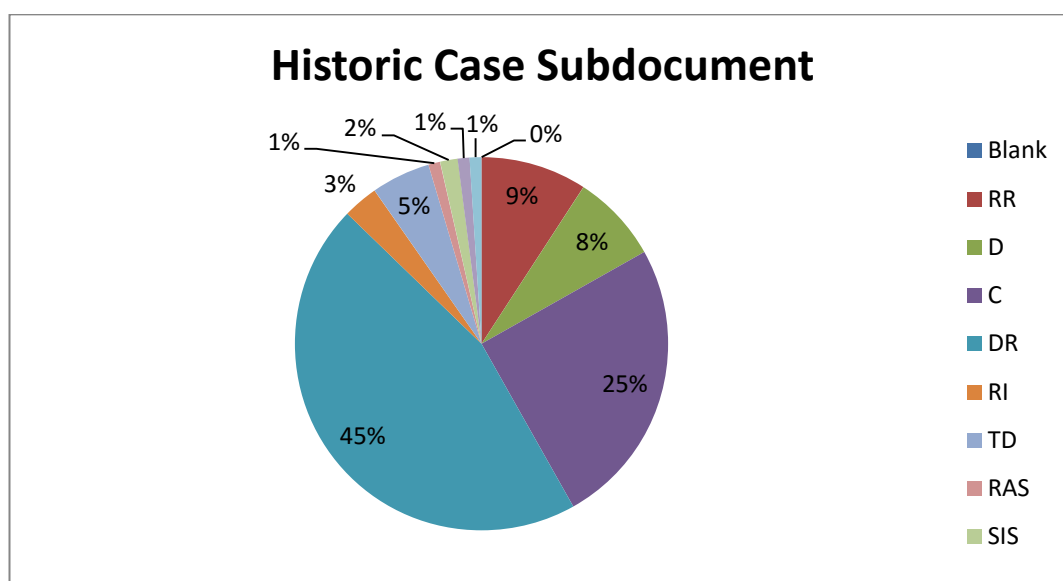


Figure 6.20: Historic Case Subdocument Utilisation

6.9.4 Results - Use Strategies

The questionnaire results in Chapter 5, the Industrial Case information in in Chapter 4 and the scoping studies in Appendix 6 all highlight current strategies utilised by

design engineers for making document utilisation more efficient. One of the aims was to be able to capture the strategies utilised for documents such as the creation of physical bookmarks and these are included in the descriptive text steps of the storyboard. Hence it has been possible to capture a number of strategies being employed by the design engineers in using document content summarised in Figure 6.21 below.

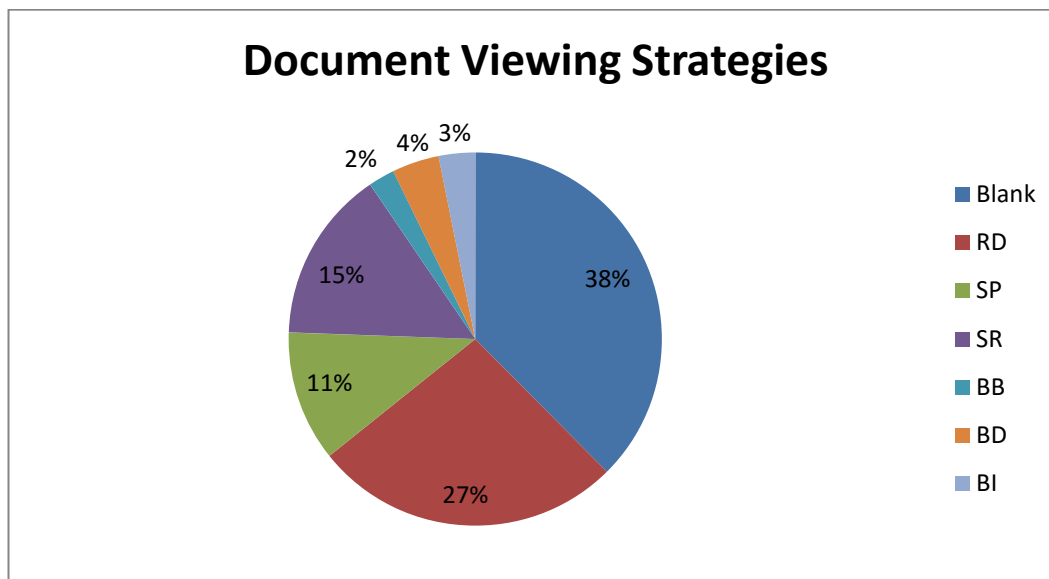


Figure 6.21: Document Information Viewing Strategy

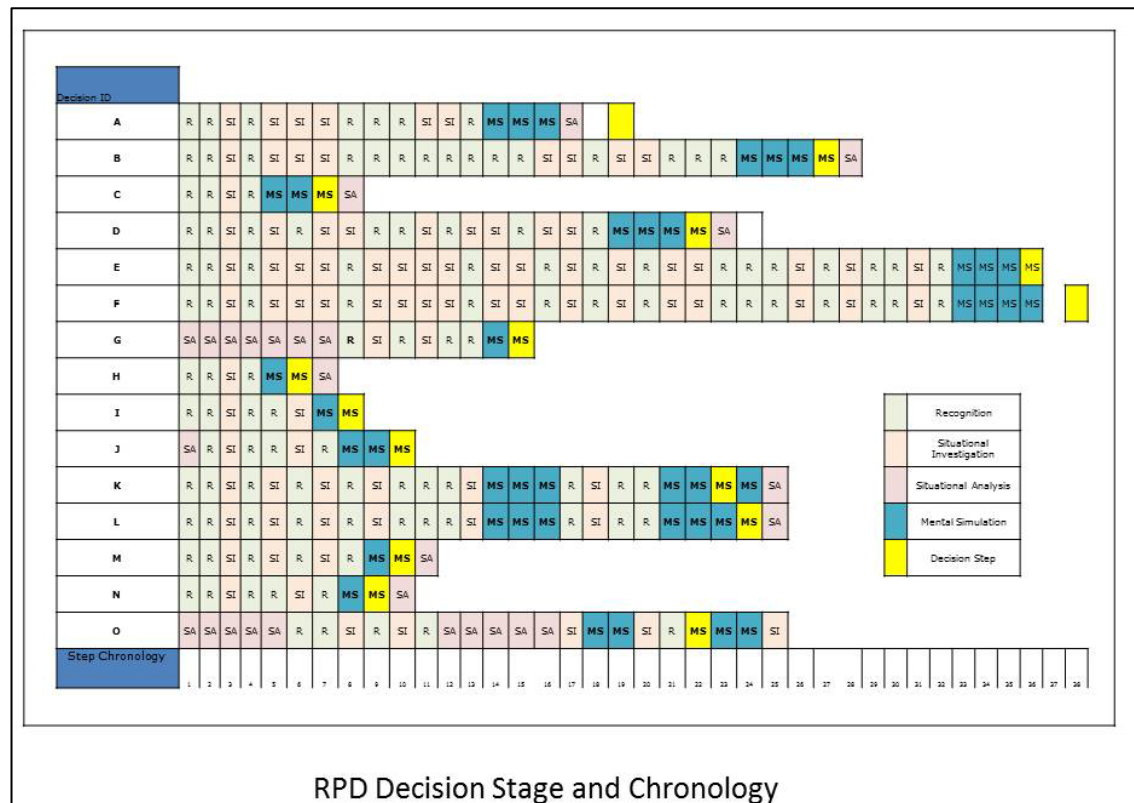
A majority of the 38% of steps that are left blank relate to the steps not spent upon the historic case document. However, in some instances it (10%) it was not possible to directly determine the viewing strategy being employed and thus these are not included in the analysis. An important finding is the huge 27% of the steps that relate to reading a document in detail (RD) and the additional 15% of the steps associated with skim reading (SR) and 11 % skimming pages (SP). In total it is apparent that reading content to some level of detail was necessary in 53% of the steps. This is a large proportion of time spent simply reading and assimilating from text, especially since reading in detail potentially presents a significant time cost for design engineers when utilising document content.

The results presented thus far assume a two dimensional view of the stepwise decision stories. The results presented next are from the analysis of three dimensional data to draw correlation between decision stages, the strategies employed and the informative elements and content of documents being utilised. As previously discussed the storyboards had been decomposed into separate information relevance decisions for the purpose of analysing the patterns in information utilisation throughout. This part of the results utilises individual decision stories and their correlated information utilisation or strategy to infer the importance or role for decision steps.

6.9.5 Results - Process Analysis

Between the two workshops and thus storyboards elicited it has been possible to decompose the stepwise data into 15 different information supported decisions. These decision stories can be traced back to the groups and workshops from which they originated but have been analysed independently for the purposes of understanding the individual information relevance decisions that are being undertaken. Hence the following results present 15 decision stories and their patterns labelled from A – O. The figures shown are for illustrative purpose; due to the comprehensive size of the results and the multi-stream nature of the data collected the complete results are available upon request; however Appendix 5 of this thesis contains more comprehensive results including the audio transcript.

Note: For these results it is important to look at the labels on the figures as these indicate the key learning from this particular sequence. Additional keys are provided where required for specific illustrations; please refer back where needed to the keys for interpreting the text codes for individual decision steps. This is in particular for interpreting subdocument types, decision type and viewing strategy.



Recognition
Situational Investigation
Situational Analysis
Mental Simulation
Decision Step

Figure 6.22: RPD Decision Stage and Decision Story Chronology

In Figure 6.22 each decision is represented by a letter and consists of a sequence of encoded steps. The making of a decision as recorded on the original storyboard is indicated in the yellow square for each decision. It is important to note that it is possible for a decision to be positive or negative as it simply represents a choice over the relevance of information to current task. It is thus possible that the historic case document and information was not considered applicable and thus a decision was made regarding its unsuitability. In some cases the decision steps appear to continue, this denotes the return of a design engineers thinking to the higher level decision making process of the repair case they are working on assimilating the next steps for finding a supporting historic case or in designing a repair. The RPD stages are defined and coded as described in Chapter 6 and shown in Figure 8.17; however a larger key is duplicated above for ease of viewing.

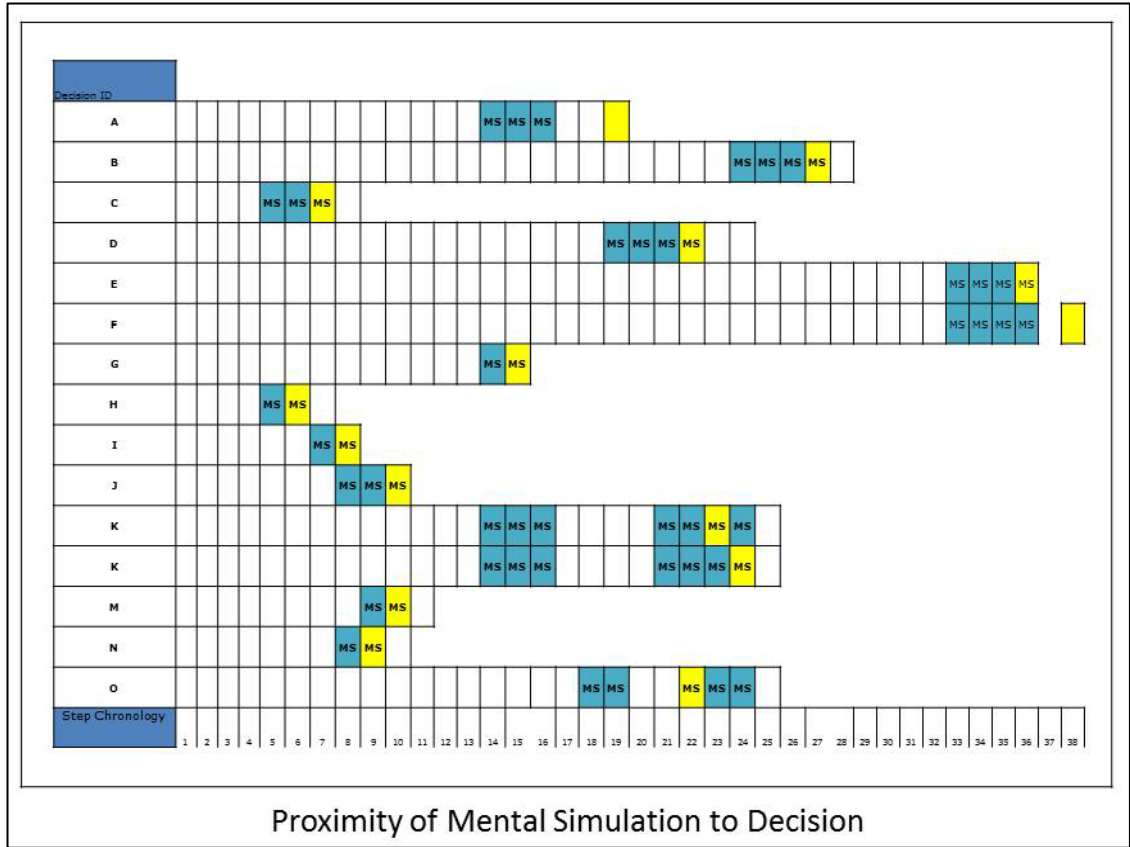
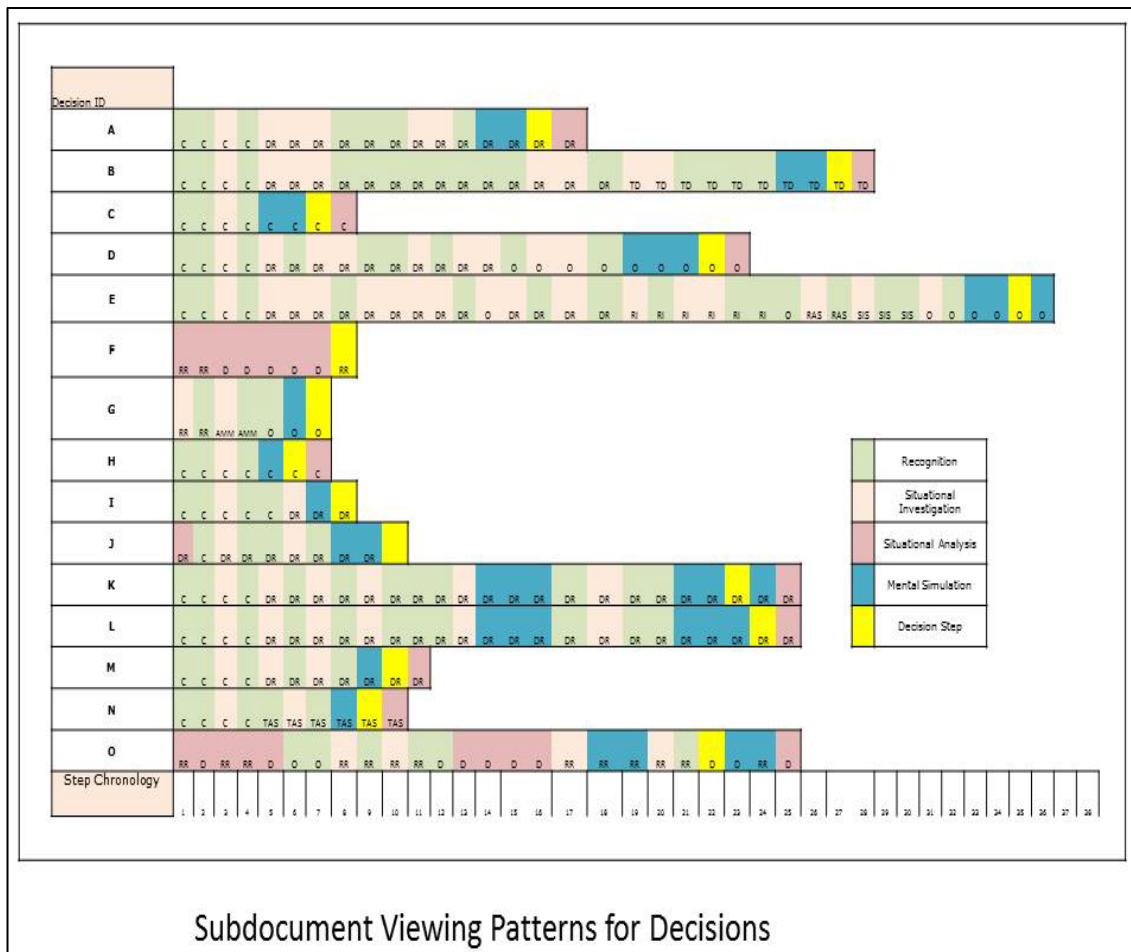


Figure 6.23: RPD Mental Simulation Stage and Decision Proximity

In Figure 6.23 the all of the decision codes have been removed to clearly illustrate the proximity of mental simulation steps to the making of a decision (proximity of turquoise to yellow). Although when thinking back to the RPD process presented earlier in this chapter, this makes sense at the mental simulation stages can be followed either by the need for more information (Situational Investigation) or in the cases where the mental simulation of action is favourable it will be followed shortly by a decision. The illustration thus demonstrates what we would have expected it to in this instance. Another expected observation is that in all of the decisions made there is a mental simulation stage that precedes the decision. This also makes sense in practical terms if it is indeed the RPD decision that is being followed by design engineers when viewing information.

The Figure 6.24 below is an illustration of the RPD decisions stages correlated to the sub document type that is being viewed, the subdocument codes and decision step keys are provided below the diagram for reference. The illustration shows that informed decisions can take a highly variable number of steps, the shortest decision took only 7 steps and the longer decisions took 26 steps to complete. This suggests even within one process of repair request that the decision complexity is highly variable and potentially related to each individual document that is viewed. It is not obvious from this correlated diagram whether certain decision stages are related to a particular subdocument and thus this cannot be assumed without further analysis. However what is evident is the relative number of steps that relate to specific subdocument types, suggesting their relative importance in the decision making process. It appears that the most utilised subdocument types for making information relevance decisions (for historic case documents) are the "coversheet" and the "damage report". The other interesting finding is for those decisions where the step count was longer (over 17 steps), 4 of those 6 instances required further steps paying attention to information from other document types. This suggests there are differing case content requiring different decision strategies, possibly requiring information of a different type. However in 8 out of the 15 decisions it was

possible to do so referring only to two of the subdocuments, namely "damage report" and "coversheet".



C	Correspondence
DR	Damage Report
TD	Technical Disposition
RI	Repair Instruction
TAS	Technical Approval Sheet
RAS	Repair Approval Sheet
TA	Technical Adaptation
RR	Repair Report
D	Daedalus
O	Other Technical
SIS	Static Information Sheet
AMM	Aircraft Manufacturers Manual

	Recognition
	Situational Investigation
	Situational Analysis
	Mental Simulation
	Decision Step

Figure 6.24: Historic Case Subdocuments for Information Decisions

Below in Figure 6.25 the decisions are correlated to the information type that was being viewed, this did not relate to the subdocument but simply to whether the information element was visual or image content based (see Chapter 4, section 4.6 for full list of audited visual contents) or textually based (as in letter correspondence or report content). This finding has further been overlaid with the decision stages closely related to completing a decision, the mental simulation (shown as MS) and decision step (denoted in yellow).

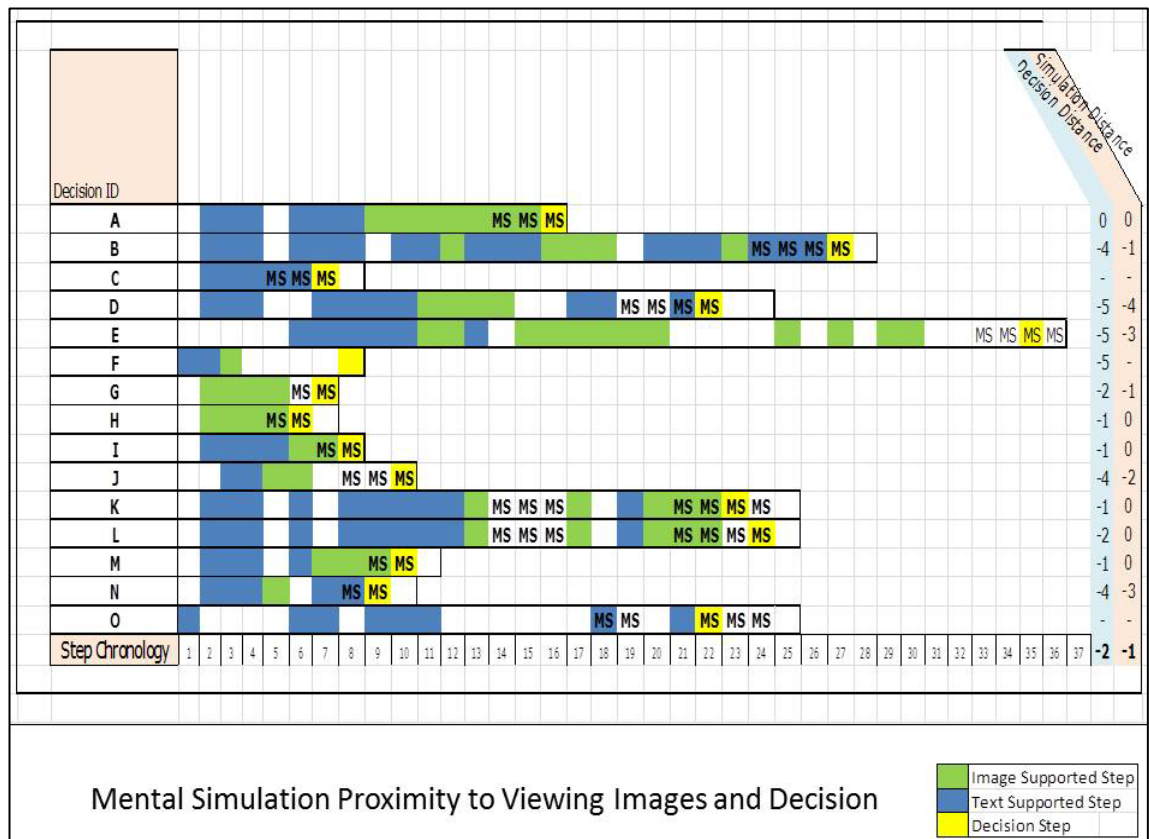


Figure 6.25: Proximity of Image Viewing and Mental Simulation for Decisions

This illustrates not only the prevalent utilisation of images in every decision that is made but also that the proximity of each decision is always after the visual information content has been viewed. This proximity has been measured in steps and illustrates that on average a visual element is viewed no more than two steps from making a decision and no more than one step away from mental simulation. This is significant for indicating the importance of visual information types in supporting design engineers to be able to mentally simulate and thus consequently be able to follow with a decision. It is also evident that in the one instance of document information relevance decision where the visual elements do not appear before making a decision (C), there were no visual elements contained in the document.

The prevalence and requirement for text cannot be ignored due to the significant number of steps that appear to be supported by utilising textual information elements. However, this does allow us to interpret that images are highly regarded as information resources and do play a significant role in supporting design engineers to mentally simulate the effects of applying such information to their current task. However, the comparative value of text and images are not possible to assume from this result and this means they are at least equally important thus far. This is a point that is thus evaluated further in the experiments following in Chapter 7.

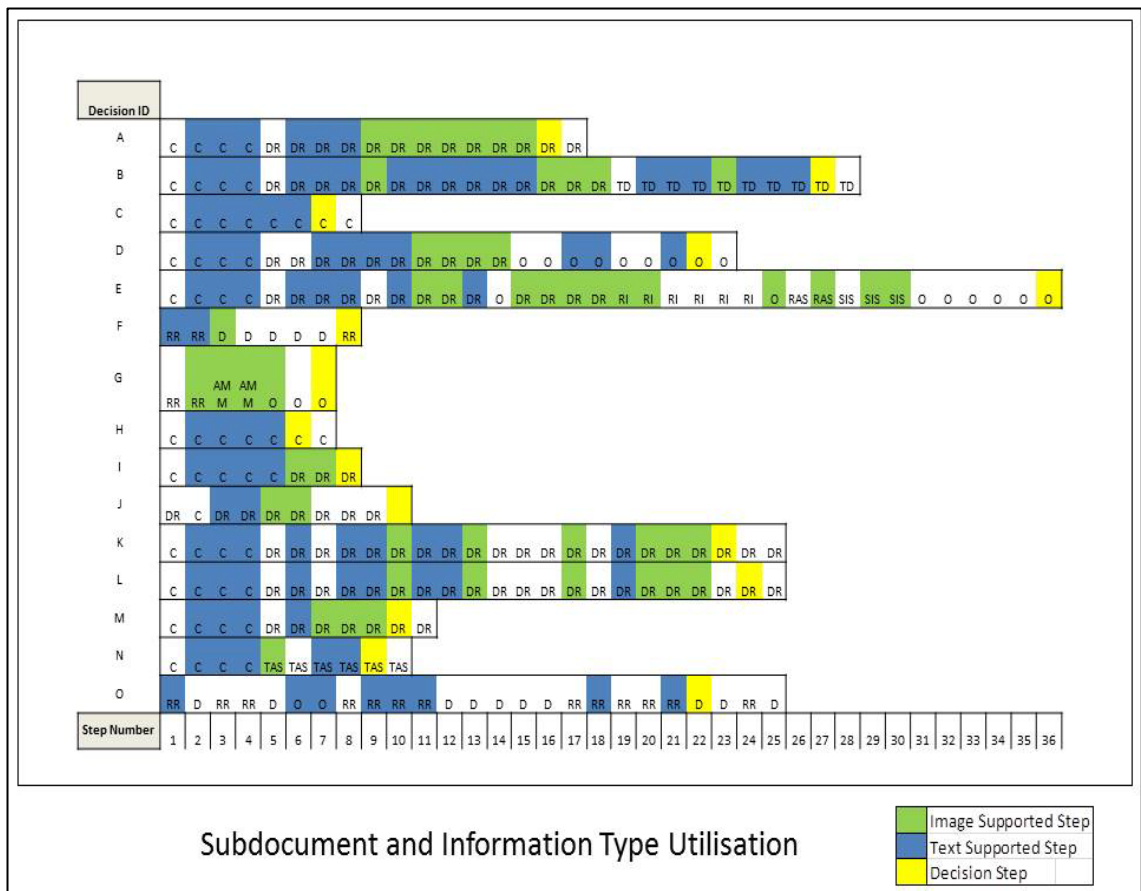
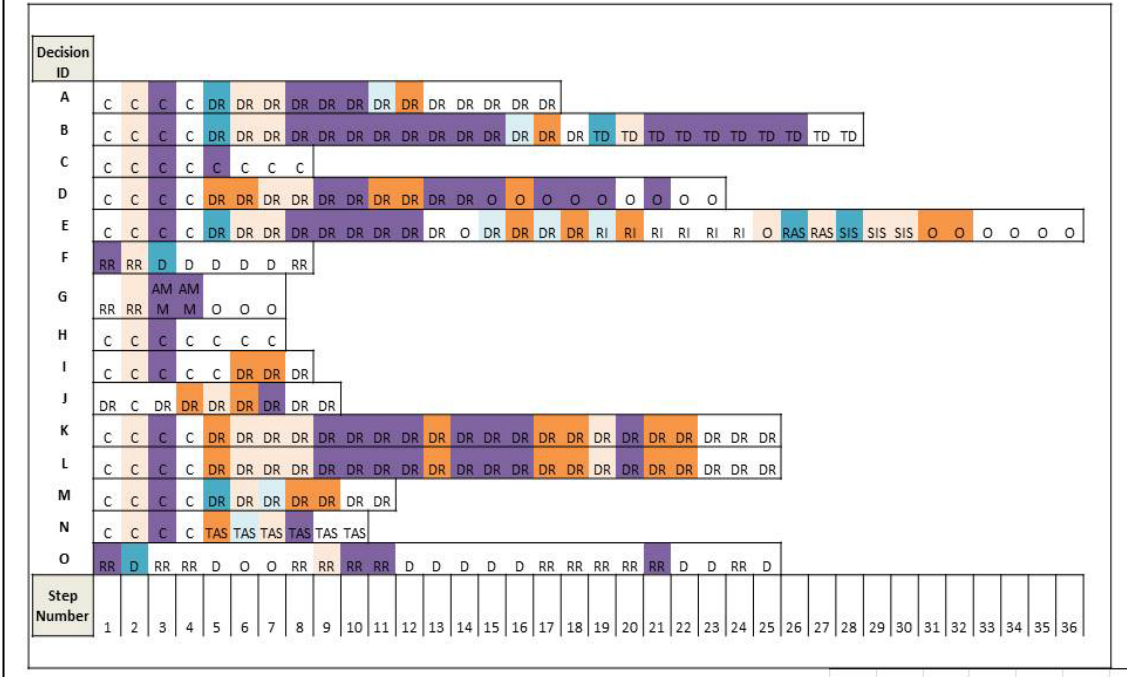


Figure 6.26: Historic Case Subdocument and Information Type Preference

Given the relative importance of visual information and a number of the subdocument information resources, the above Figure 6.26 illustrates the correlated view between the subdocument resource being utilised in a step and the information type being viewed at the time. It is evident that although images are viewed in a number of subdocuments there is a particularly high proportion of them sought from the damage report subdocument (75% of visual information steps overall). Of the damage report supported steps 37% are visual information element supported and 31% textual information supported (40 visual content steps: 33 textual content steps: 34 non-specified). This could demonstrate the importance of the damage reporting subdocument information, however the textual element damage report supported steps are similar in proportion and thus further investigation is needed to determine the respective value of each information type within the damage report subdocument.

This issue is potentially characterised further in Figure 6.27, where the viewing strategy for each step is overlaid with the subdocument type being utilised. It is evident from this result that the damage report subdocument is read in detail, skim read and skim read. The most prevalent strategy for the damage reporting subdocument is to read in detail in 35% of the steps and further skim read in 16% of steps. This totals 51% of the steps spent in viewing the damage report are spent reading its textual content, suggesting the value of this document in making informed decisions. It is possible from this result to assume that if 82% of a design engineers time is being spent on the historic case document (Figure 6.18) and 27% of their time is being spent reading in detail and 15% of the time is spent skim reading. Overall approximately 51% of the time they are viewing historic cases is spent reading its detail. This potentially could also apply to the time that design engineers spend on information resources and is a large proportion of time to spend reading text in detail.

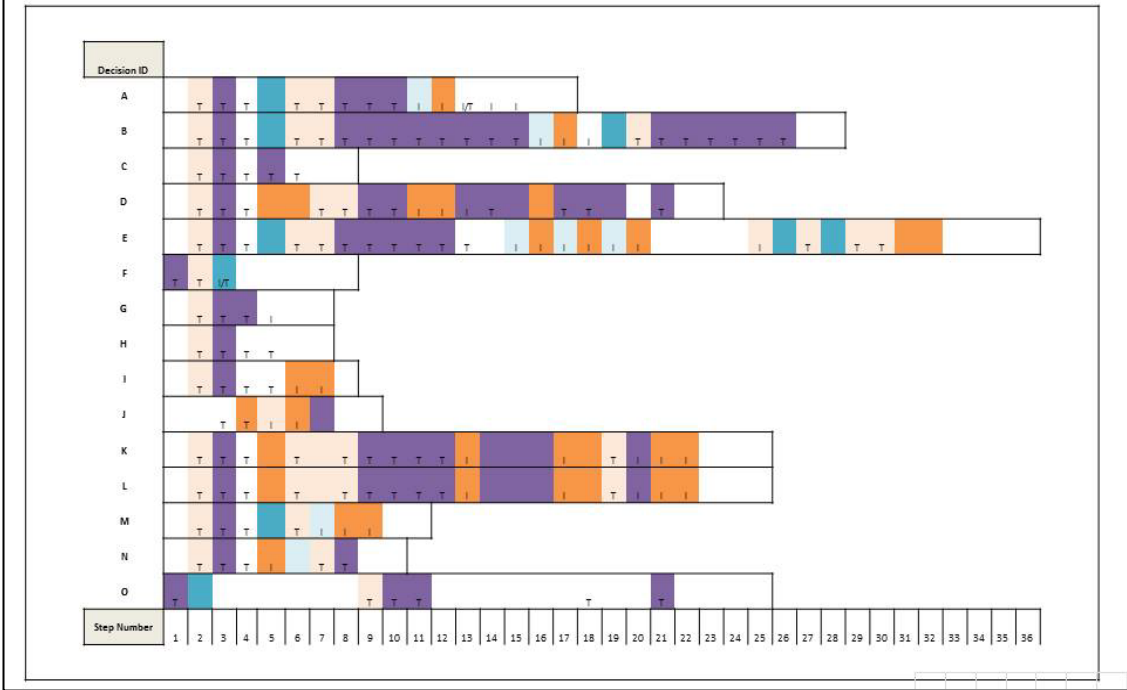
Association of Viewing Strategy to Subdocument



	Skim Read Pages
	Skim Read Text
	Read in Detail
	Bookmark to Document
	Bookmark to Information

Figure 6.27: Subdocument Type and Requirement for Viewing Strategy

Viewing Strategy and Information Type Utilised



I	Image
T	Text
I/T	Image & Text

Figure 6.28: Viewing Strategy and Associated Information Type

In the Figure 6.28 shown above is demonstrated the strategy being employed by design engineers when they view information types. As we would expect the time spent reading in detail is associated with the viewing of textual elements as would be expected and gives confidence to the analysis results presented.

6.9.6 Results - Final Part of Workshop

The final part of the workshop related to a second task that the design engineers carried out. It was requested that they each read a paper copy of a different historic case document for the purpose of understanding its content in full. The participants were requested to annotate on the paper version the information elements they viewed in order to do this in a chronological sequence with highlighters and adding notation as to the understanding they gleaned from the information elements denoted.

The resulting data was collected after the workshop and scribed into excel spreadsheets to create sequential steps that included highly specific textual terms that were elicited by the participants, or visual element that were highlighted as required for understanding. One such understanding sequence is provided in Table 6.29 below to illustrate the data collected. Each chronological stepwise entry in the Table 6.29 is labelled with a step number, the sub-document location and the text or textual terms that are highlighted. Indication is also given to illustrate if the information element resource used within the document was presented visually (image annotations) or textually (descriptive text). In the findings of this part of the workshop a number of strategies to use document information emerges that had not previously been identified. One participant described how he passed through the document information at least twice. On the first pass an overview of the contents was elicited to create a general understanding and in the second pass highly specific textual reference terms were elicited from the visual elements and from the text reporting. Some of the data is highly sensitive and thus an overview is given in the table only.

It is also evident from this study that different approaches are taken to understand document contents in full, although the pattern of information elicited remains largely sequential, this could be enforced by the document format of the information. For example the coversheet is again viewed first in each instance and then the damage reporting. This could be due to the document formats rather than the preference of the subjects and would require further evaluation. Another point that emerges from analysing this data is that the visual elements are frequently decomposed when viewing them into acronyms and further references. The suggestion being that they lead to other documents or visual information that supports further understanding of the repair design request requirements. The damage reporting also appears in this particular case to continue over a trail of correspondence documents, these documents appear to be read fully in a similar manner to the damage reporting subdocument and could influence document by document or case by case the differences in strategies employed or patterns in decision making and information sought. This certainly reflects some of the complexities of document information contents.

Step Number	Item Viewed	Information Element Utilised	Understanding Gained
1	PG3 - Damage Report Form	"REPORT During routine generator feeder cable inspection at ENG 2 a	Read the location of the damage (Refer to

	Text	corroded nut at the rib 7 forward pylon attachment fitting was found."	SRM/AMM for more details)
2	PG3 - Damage Report Form Text	"ENG 2"	Read the location of the damage (Refer to SRM/AMM for more details)
3	PG3 - Damage Report Form Text	"a corroded nut"	Read the location of the damage (Refer to SRM/AMM for more details)
4	PG3 - Damage Report Form Text	"rib 7 forward pylon attachment fitting"	Read the location of the damage (Refer to SRM/AMM for more details)
5	PG3 - Damage Report Form Image	Drawing image of location of damage utilising entire wing view	Read the location of the damage (Refer to SRM/AMM for more details)
6	PG3 - Damage Report Form Image	Detailed closely viewed image of internal fixtures and fittings and damage location	Read the location of the damage (Refer to SRM/AMM for more details)
7	PG7 - Outgoing Correspondence	"Nut Corrosion, Pylon Forward Attachment Fitting, Right Hand Wing. XXXX-XXX-XXX;MSN:XXX "	Use the answers as a starting point to create your own answer
8	PG7 - Outgoing Correspondence	"Service Bulletin A320 SB57-1074"	check this document
9	PG7 - Outgoing Correspondence	"washer corroded also"	Use the answers as a starting point to create your own answer
10	PG7 - Outgoing Correspondence	"remove the corrosion without removing the nuts"	Use the answers as a starting point to create your own answer
11	PG7 - Outgoing Correspondence	"nut become loose"	Use the answers as a starting point to create your own answer
12	PG10 - Airline Incoming Correspondence	"As just discussed on the phone, please find here our comments regarding your request for additional information with Ref (a). Service Bulletin XXXX-XX-XXXX...."	
13	PG12 - Outgoing Correspondence	"We are in receipt of the Operators Damage report XXX-XXXXX-XXXX,XX-XX. It is not acceptable to leave the nut in its current state until next C check "	Use this as a starting point to create your answer.

Table 6.29: Chronological Informative Elements for Document Understanding

It is not possible to directly compare the understanding part of the workshop with the decision making data collection directly. However, the information element contents can be likened somewhat, Table 6.29 above shows the detailed number of references that are elicited to infer meaning when understanding a document in full.

Using the stepwise descriptions in the results a further analysis was undertaken which is based on categorising the extracted information elements and their respective utilisation. If this Figure 6.30 below is then compared to the number of information elements highlighted in the Storyboards as informative elements there is considerable similarity in the types of acronyms being denoted as relevant or important to understanding or for making relevance decisions. Although these acronyms are highly specific to the industrial context, it is clear from the audio comments and annotations that these elements form critical links to further information seeking requirements (or additional documented resources). This is also evident in the results of the questionnaire in Chapter 5 Figure 5.23 & 5.24 where considerable further information is sought to make decisions upon a historic document cases relevance to a design engineer’s current task. For example from Figure 6.30 is the elicitation of (PN) or part numbers is common to the utilisation of documents for multiple purposes such as making information relevance decisions and for understanding their content in full. This part number (PN) is then further investigated by seeking standard design document manuals.

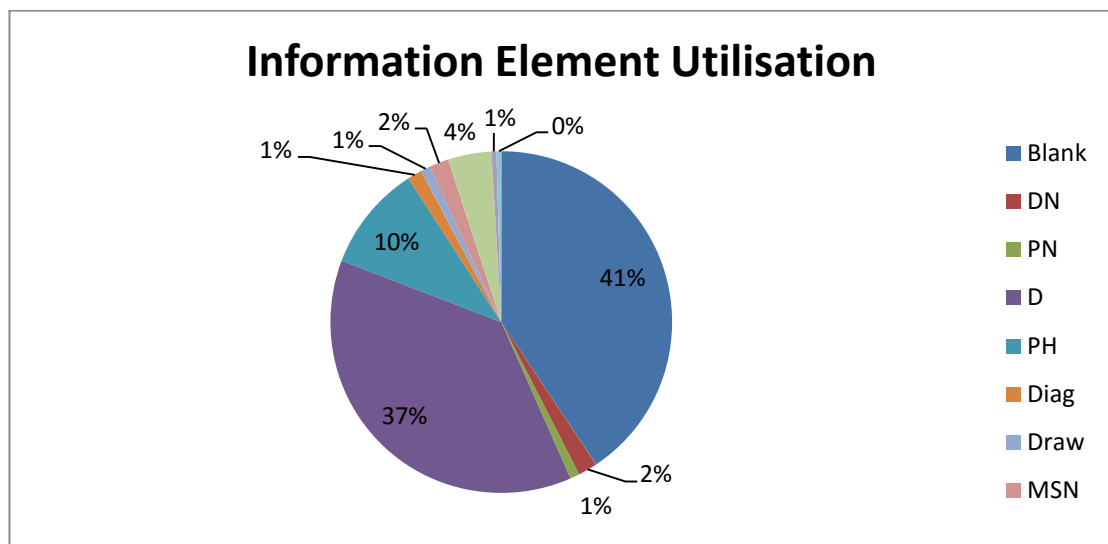


Figure 6.30: Information Elements Supporting Story Steps

6.9.7 Further Results and Considerations

The nature of the qualitative data collected during these experiments mean that there are still a number of data sources that could be further analysed in future. Whilst it is expected that the results would be largely the same, they may add richer detail to the understanding of document information element utilisation already gleaned.

Further, a number of comments that were recorded from the video recording for the workshop experiments are highly suggestive of their respective value for supporting design engineering thoughts when making decisions. These comments are highly intuitive in a human approach to information resources as we already understand the value of imagery, but it remains that the evidence collected is a valuable source of understanding for the design of supporting methods and tools. These verbal comments are suggestive that visual information elements both support the relevance and irrelevance of document information for a current task. These

relative meaning of these statements are evaluated further in the experiments conducted in Chapter 7. In the final section of this chapter a summary of the mitigations for this experiment are considered and this is followed by a summary of the key findings.

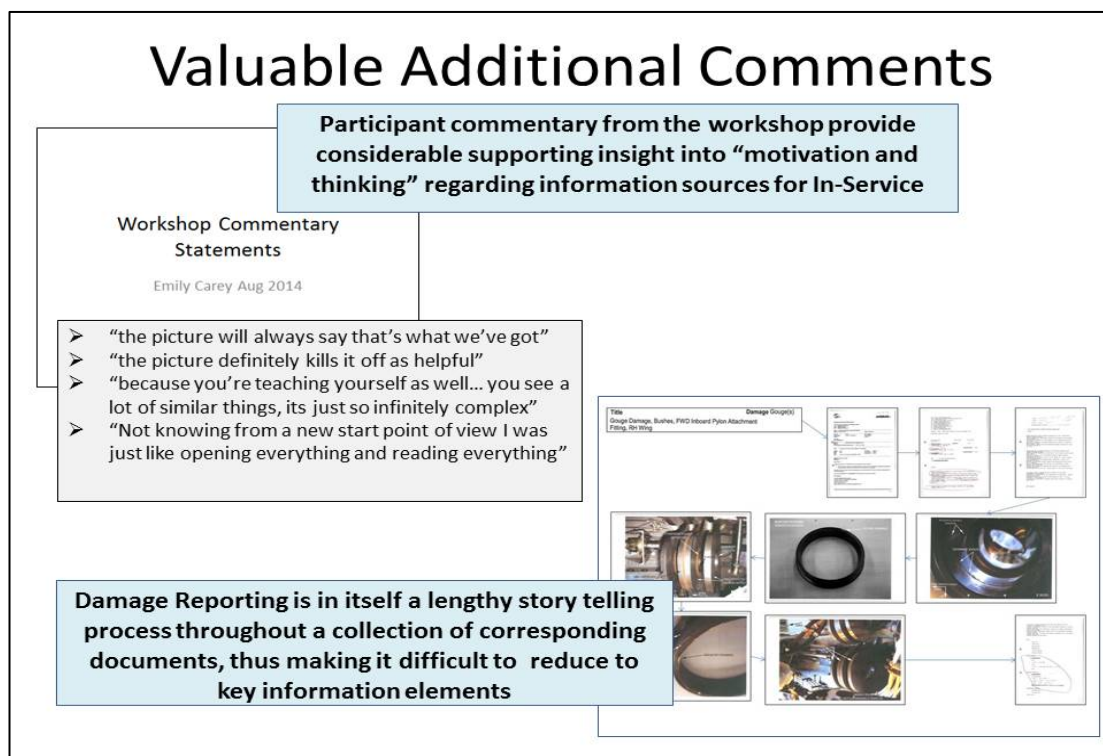


Figure 6.31: Key Audio Statements for the Value of Visual Elements

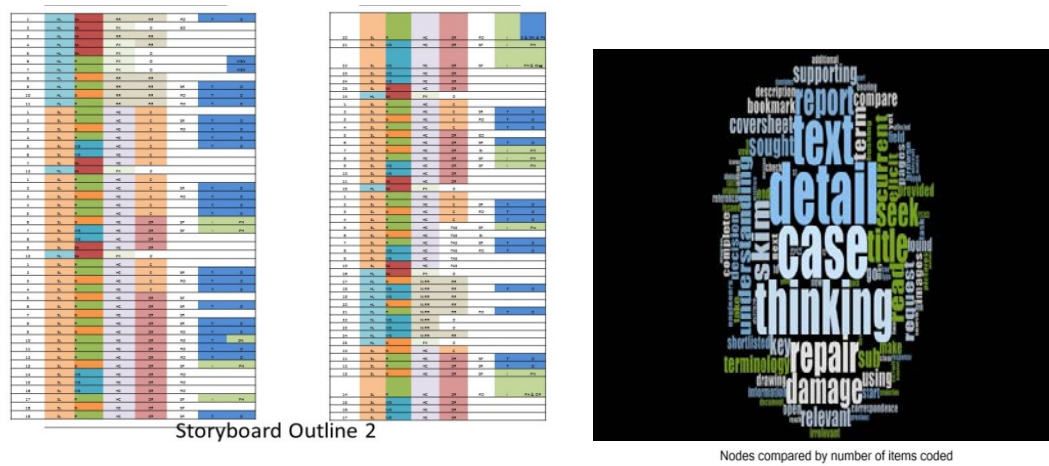
6.10 Considerations for the Reliability of Findings

The results of the workshops represent a very rich source of multi-stream data that has been collected. This means that it has been possible to select a number of ways in which to analyse the data. The empirical coding and analysis provided is one such method. A number of other avenues were explored and may also have been valuable if approached using qualitative methods. The output from some of this analysis is provided below as examples from the NVIVO software application. The reason for not exploring this further was the length of time it would take to correlate the video data stream in conjunction with the storyboards, and thus this remains potentially valuable but additional further work that could be conducted.

It is evident viewing the data collected in this manner means that other findings could emerge and that the complexity of the data mean it is more difficult to analyse the merging patterns. Thus a number of the steps were encoded independently by another researcher for intercoder reliability purposes. This resulted in a similar step wise encoding and is included in the appendices for further information.

Given the industrial restrictions meaning there were a low number of participants the multi-stream nature of the data collected means that there has been significant qualitative benefit. The benefits of real world findings and collection however make this a worthwhile journey and the validation of the second study part also make this more reliable. The findings however, represent the view of a highly specialist sub-expert population of the latter stage of design in-service team and thus to make more generalised suggestions this experiment would need to be carried out with

other sub-expert populations. There now follows a summary of the key findings in this chapter.



Nodes compared by number of items coded



Figure 6.32: Alternative Analysis Representations

6.11 Discussion of Key Outcomes

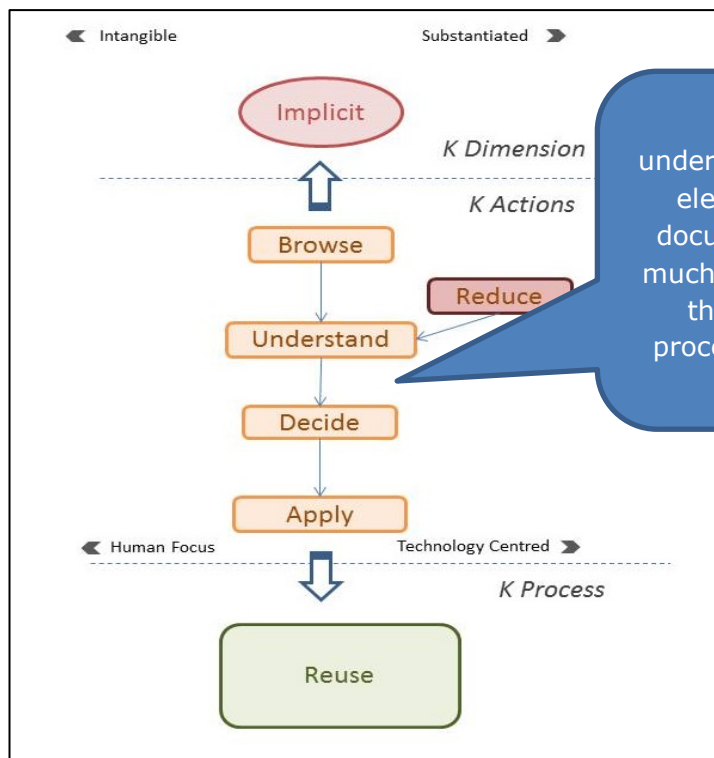
This chapter has sought to understand the content of documents within design engineering that support the creation of design repair. It has collected much information that has extended beyond this remit and includes data to prioritise the strategies and the important information content for design engineers.

The Storyboard workshops have provided detailed insight into how information is utilised within in-Service by Design Engineers and how this differs to the perception from questionnaire results. The key findings are listed below:

- Mental simulation decision stages are always close in proximity to viewing images.
- Image provision (affords) supports mental simulation in the decision making process (“Thinking Process”) and is a requirement to make decisions; hence information relevance decisions require images.
- Damage Reports are key providers of significant informative images (most images are sought from this sub-document), however a lot of time is spent reading them in detail.
- Information seeking process and decisions are in the main generic for more simple historic cases as the early stages of decision process is generic, Cover Sheet for title and then Damage Report description followed by Damage

Report Images. As a document case story becomes more complex the process becomes more variable.

- Cover Sheet and Damage Report are the most utilised Sub Documents and hence most important.
- Large proportion of steps involve reading in detail indicating this is time consuming compared to looking at an image.
- Engineers are initially seeking information elements to exclude irrelevant “supporting cases”, this is different to perception in questionnaire.
- *“The information relevance decision making process potentially supports moving from inexperienced to experienced”*, supported by participant commentary.
- Damage Reporting should be referred to as a damage story, as within each case reporting damage is not from singular documents.
- The key informative elements, current information presentation use and design engineering “thinking” process data has been collected.
- It is evident that complex and personal decision making processes require support within in-service process - this is in addition to information provision requirement.



This Chapter sought to understand the critical information elements within historic case documents. In fact it has found much more than that surrounding the entire knowledge reuse processing for design engineers.

Figure 6.33: Relating Back to Knowledge Reuse

The findings above create a hypothesis for the utilisation of historic document information that remains to be tested with the design engineers to validate their needs in using document information resources. Hence an evaluation of how best to “utilise” and “present” document contents tailored to Design Engineering needs is described and conducted in the next chapter. In the next chapter we utilise the findings from the questionnaire in Chapter 5 and the findings from this chapter to design evaluation experiment that is conducted with design engineers within an industrial setting to both validate and further triangulate previous findings.

7. Evaluating Information Relevance Decision Making for Design Engineers

As described in Chapter 3, the previous two chapters have detailed two experimental studies: i) a quantitative survey data collection and ii) a qualitative storyboarding workshop collecting multi-stream data for later analysis. A number of findings have been outlined and discussed in the respective chapters as a result of these experiments. The results of these experiments have thus far built upon the findings of the scoping studies outlined in Appendix 6 and what has already been discovered in the Industrial Case context from Chapter 4.

The work in this chapter deals with utilising the collated findings of this research so far to test principles to evaluate the support needs of design engineers in making document informed decisions for relevance to their current task.

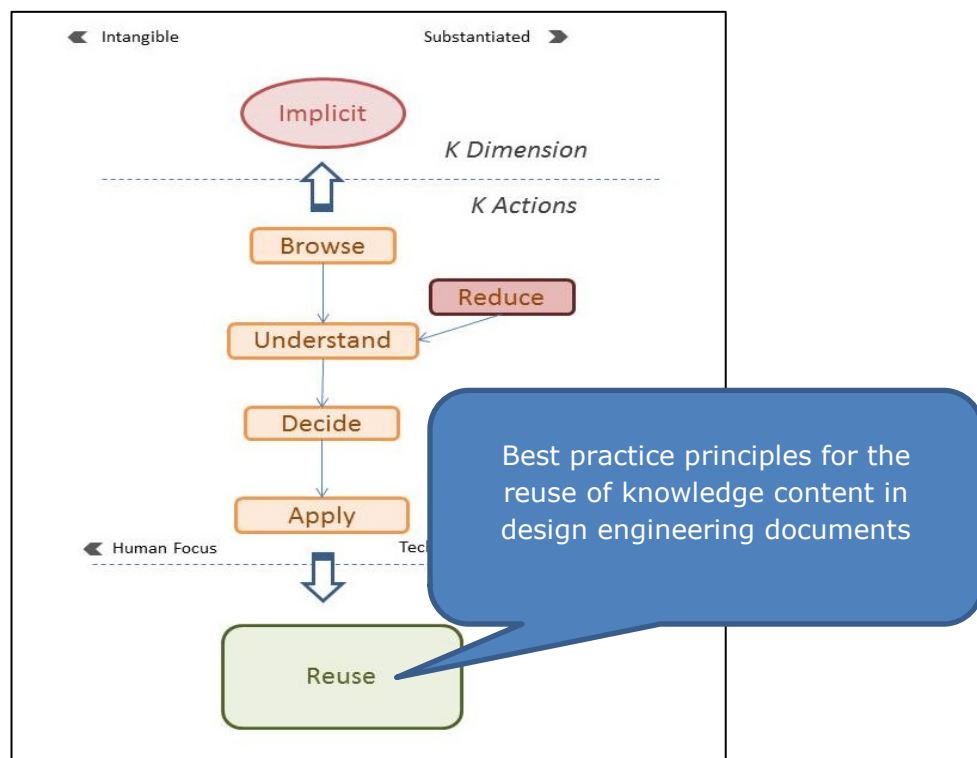


Figure 7.1: Evaluation of Knowledge Reuse Principles

The work described in this chapter relates to the overall aim for this research by evaluating the findings thus far. Hence it seeks to suggest the good practice principles to support design engineers to reuse the knowledge content of documents more efficiently. In particular, the aim of this chapter is to provide evidence and understanding for the following:

- Understand if it is possible to reduce the time spent reading document contents in full to be able to make a decision upon the information's relevance to a current task.
- Compare the importance of textual information elements and visual information elements.
- Understand the role of visual information elements for decision making in document information.
- Suggest and evaluate the preference of design engineers for alternative static and interactive document information presentations.

The next section begins by summarising the key findings that support the hypothesis for improving the reuse of knowledge from design engineering documents.

7.1 Constructing the Experiment for Evaluation of Hypothesis

From the previous experiments, it is hypothesised that there are critical information features of document information that enable design engineers to make decisions about its relevance to their current task. It is also evident that there are common reuse patterns in the utilisation of informative elements, subdocument content and strategies for using historic document information suggesting it is possible to design more succinct representations of document information to enable design engineers to utilise their content more efficiently.

To evaluate this hypothesis it was necessary to design an experiment using the experience of industrial engineers to test the derived common utilisation patterns and to evaluate the value of the elicited critical information elements. Due to the industrial nature of this research it was also necessary to consider the direct benefit for any such time cost to the in-service engineering team and the wider applicability of such supporting methods to design engineers. The experimentation was needed again to be based upon a work simulation and thus the audience would need to have relative expertise in the current repair task processing to effectively evaluate. The participants thus needed to be design engineering experts familiar with the historic case document collections and repair process but would not be required to be part of the current daily repair team. This meant that the participants in this study also were aware of the research from the survey study but would be independent of those that participated in the workshop experimentation. This was important to ensure that bias was not introduced by evaluating from the same sampling that also created the hypothesis.

7.1.1 Evaluation - Theoretical Basis

This evaluation is conducted in accordance with the suggestion of Zachary et al. (2012), highlighting the need for verification of any formal (or mathematical) representation of the findings in the "rapidized" cognitive task analysis" research methodology. It also completes a triangulation of any results from the quantitative focused research methods and the qualitative methods for this thesis. For any mixed methods research for information systems it is suggested by Venkatesh et al. (2013) that this is the validation required to make the findings rigorous and reliable.

The research thus far in the main has utilised a task based scenario to make it easier for the design engineers to understand "how" to participate and to ensure that any findings are in fact relevant in the industrial design engineering setting. Hence the approach taken for the evaluation follows a similar pattern and utilises the repair request process to simulate a work based repair scenario that is supported by the utilisation of design engineering historic case documents. The process illustration shown in Figure 7.2, below, shows the work based scenario simulated and is the same summary diagram provided to the participants to inform them of the working basis for the experiment.

A work based scenario for design engineers to use their information skills in a real world setting was derived in a similar way to that used for the storyboarding presented in Chapter 6.1. In this way, real time data has been able to be collected for this evaluation, the work scenario is shown in Figure 7.3, below.

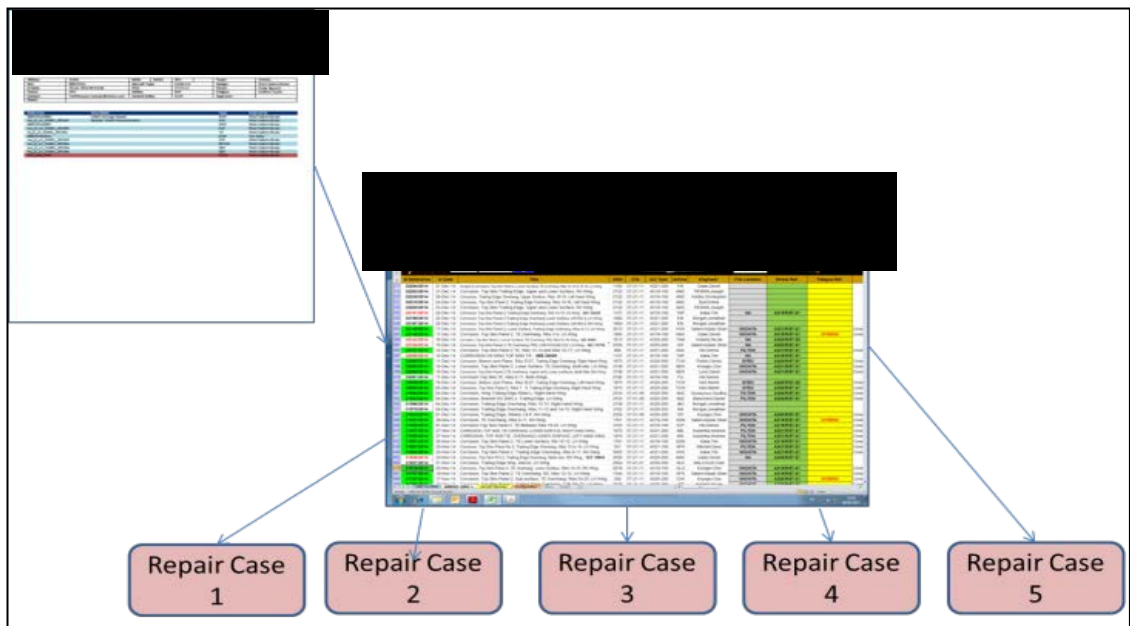


Figure 7.2: Evaluation Work Based Simulation Scenario

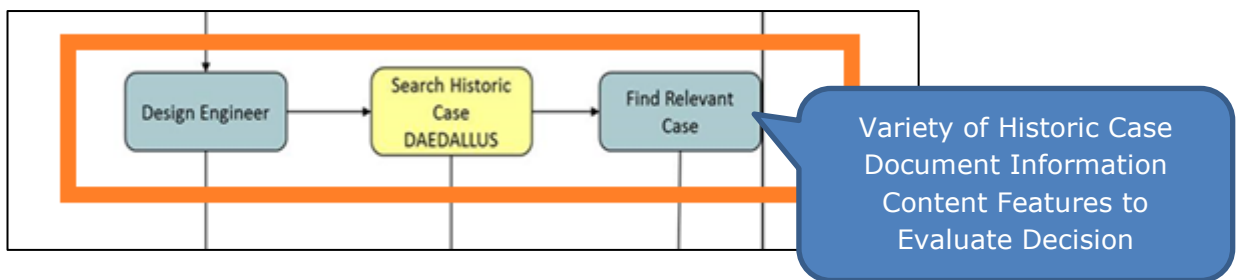


Figure 7.3: Repair Design Process for Evaluation Scenario

7.1.2 Evaluation - Experimental Approach

It was necessary to create and present a number of differing document information content views to evaluate the performance of design engineers in their ability to make a decision. This decision process being evaluated was the historic case documents relevance to their current (scenario based) task and the performance of information elements and presentation formats provided to them. In a similar manner to the storyboarding workshop it did not matter whether the information was relevant to current task or irrelevant. It was purely the capability of the design engineer to make a decision based upon the informative content presented that was important. The focus of this research is to ascertain the value of informative document content in informed design engineering decisions in particular the role of visual informative content. Table 7.4 below outlines the informative content and presentation variations that were prepared for this evaluation.

Each of the information element variations is designed to test an alternative hypothesis. The hypothesis for each is based upon the premise that there is critical document information elements elicited from the storyboard workshop that are needed to be able to make a decision upon an information resources relevance to current task. The critical information elements are the subdocuments "coversheet" and "damage report" and "significant textual elements" and "visual elements". From the results of the second part of the workshop for understanding a historic case document fully, it became more apparent that one purpose of the "visual elements" are in fact they shortcut access to many further "textual elements". One of the findings was the significant amounts of time that are spent reading document textual elements in full, for more efficient access it makes sense that reducing the

reading overhead thus potentially increases the efficiency of utilisation. The proximity of Recognition Primed Decision making (RPD) “mental simulation” to making a decision was also found in the storyboard workshops. This suggests that visual elements not only shortcut access to textual terms but also serve a higher level cognitive purpose and thus this is also evaluated. It is evident from the equal distribution of visual and text supported steps from the storyboard and the preliminary storyboard experimentation in Chapter 6, that to eliminate the textual elements would not be possible and to retain some textual information is thus necessary for understanding.

Presentation Name	Informative Element Contents
Full Document	Complete document with no eliminated elements
Key Elements A	Key text terms from Coversheet; MSN Number, ATA Number, Title. Key Descriptive text from Damage Report; Summarisation of Text from trail of incoming correspondence.
Key Elements B	Key text terms from Damage Report; MSN Number, ATA Number, Part or Drawing Numbers, Other Ref Numbers. Key Descriptive text from Damage Report and Damage Report Images.
Key Elements C	Optimised Key text terms from Coversheet/Damage Report; MSN Number, Title, ATA Number, Part or Drawing Number, Other References. Damage Report Images. Repair Approval Sheet sub-section descriptive; Two paragraphs of text post “Description” subtitle.
Imbued Elements	Framing of Key Informative Elements with additional text terms and utilising ordering of informative elements to prioritise or influence relevance rating of certain elements by user. Enabling faster learning by using accelerated learning techniques. Inclusion of Repair Request text?

Table 7.4: Informative Document Element Content Variations for Evaluation

Table 7.4 provides a description of the information elements to be provided in each of the document differentiations, and in Figure 7.5 a more detailed specification plan for the related to the in-service historic case documents is given. The full document presentation referred to in the Table 7.4 is to be able to measure and record a static baseline case for each of the participants. As suggested, the Key Element variations include documents with carefully restricted information content. This informative content varies in A, B & C to test how the limitation of informative element content affects the informed decision making performance. Key Elements A is the first variation based on the premise that the important text elements come from the two most important subdocuments found in the storyboard workshop. The visual elements in this presentation are completely removed but access to the text from the coversheet, damage reporting and correspondence trail documents are provided. Although the storyboard findings suggested that the damage report significantly read, from the document understanding part of the workshop it is evident that textual terms are elicited also from the correspondence documents that trail.

Presentation Differentiation

		Coversheet					
Presentation Name		Title	ATA Number	MSN Number	InDate	Engineer	
			Full Document X	X	X	X	X
		Key Elements A X	x	x			
		Key Elements B X					
		Imbued Elements X			X	X	
		Extended Key Elements X			X	X	

		Damage Report									
Presentation Name		A/C Type	ATA Number	MSN e	Descriptiv e	P/N	SRM	AMM	Drawing Number	Document Reference	Damage Image
			Full Document X	X	X	X	X	X	X	X	X
		Key Elements A			X						X
		Key Elements B X	X	X	X	X	X	X	X	X	X
		Imbued Elements X	X	X	X	X	X	X	X	X	X
		Extended Key Elements X	X	X	X	X	X	X	X	X	X

		Technical Disposition Summary	Repair Instruction Summary	Repair Approval Sheet Repair Description	Stress Approval Sheet Summary	Fatigue Approval Sheet Summary	Other Summary	Repair Request Matching Elements Highlight Matching Text Terms
Presentation Name		Full Document						
		Key Elements A						
		Key Elements B		X				
		Imbued Elements		X				X
		Extended Key Elements X	X	X	X	X	X	X

Figure 7.5: Detailed Historic Case Document Information Differentiation

In the Key Elements B prepared document very similar textual information elements are provided. However, the text that can be read is reduced somewhat to remove the trailing correspondence text to limit the reading strategy that could be possible in this reduced features document. The significant difference is that the visual elements from the damage reporting subdocuments are provided in lieu of the additional textual elements. The aim of this subdocument is to test the role of the visual elements in decisions about document information content and its relevance to design engineering tasks. (Also to evaluate if design engineers are pre-programmed cognitively to satisfice with information resources Sternberg 1999; Duggan & Payne 2011).

The Key Elements C reduced features document provides only the key text terms without inclusion of any descriptive text from the damage reporting subdocument. A further additional textual description is provided from an approval subdocument (repair approval sheet), usually filed at the end of the historic case. This repair approval sheet has been highlighted by an experienced member of the weekend design team to be particularly valuable, even over that of the damage reporting to provide a summary of the repair “what”, “why” and “how”. This is supplemented with the visual information elements such as photographs from the damage report subdocument. Hence, the purpose of this evaluation is to test the substitution of informally text descriptions that may be lengthy for the formalised single paragraph descriptions recorded by the design engineers for making relevance decisions. This will evaluate the performance of shorter formalised descriptive text content created by a design engineer over the lengthier informally provided customer descriptive text for deciding upon a documents relevance to a current task.

The final reduced document is prepared to combine the more comprehensive textual descriptions of Key Elements A & C, the visual informative content throughout the historic case and the original repair request for the current task. This includes comprehensive informative content but is ordered to evaluate whether

it is possible for design engineers to be influenced to utilise information content in a prescribed priority order, such as in framing information for cognitive purposes (Sternberg 1999).

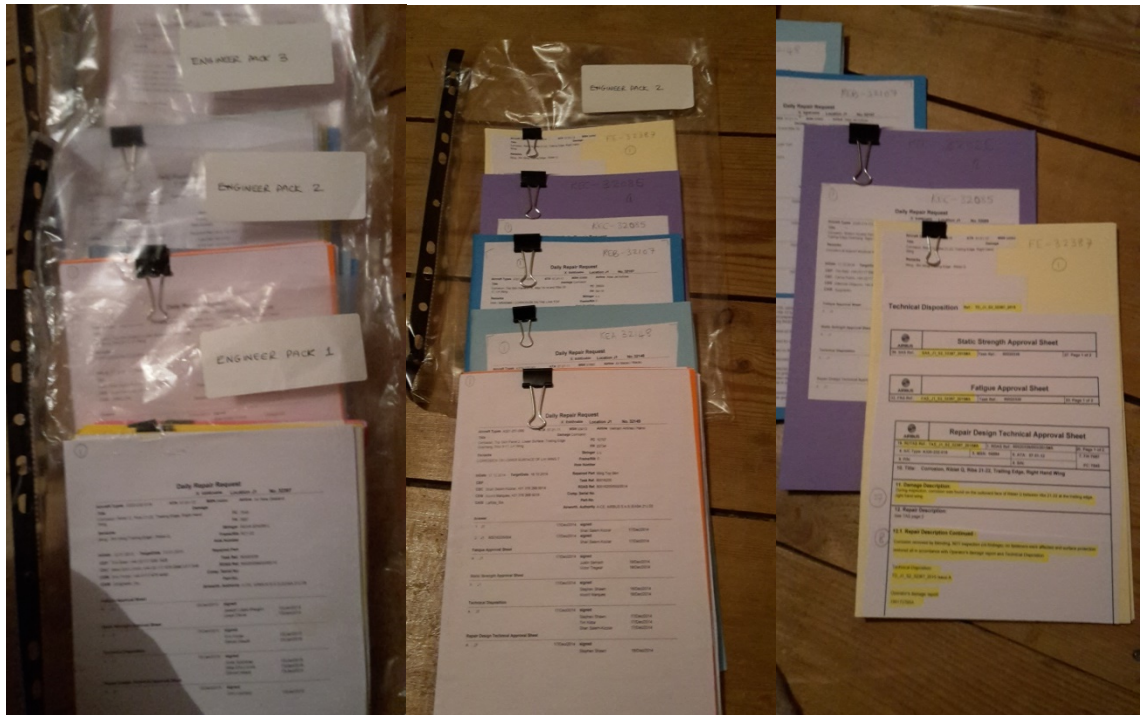


Figure 7.6: Photograph of the Historic Case Document Packs for Evaluation

Similarly to the storyboard work based scenario method (see Chapter 6), the first part of the historic document supporting case search was pre-prepared by the researcher and a senior member of the design engineering team. The scenario based information provided to each participant again included an original repair request, the Daedalus document search tool output list and the selection of staged historic cases in a physical prepared format. Figure 7.2 illustrates the work based processing that was prepared in advance for the experiment to be conducted and was provided as a basis for sharing that understanding with the participants to the study. The photograph shown in Figure 7.6 above is an example of the collection of document packs that were provided for the participants in the evaluation interviews.

7.1.3 Evaluation - Experimental Operational Considerations

It was necessary control create some experimental controls in terms of the document samples utilised to be able to directly compare the results and to measure any impact of the document information content variations (see Table 7.4 & Figure 7.5 above) and design engineer decision performance. The variables that were controlled for were the time a design engineer was able to view document information content, the variable document information content provision (Table 7.4 & Figure 7.5) and the historic case documents sampled. It was necessary to measure the design engineering understanding for each historic case information content variation and the ability of a design engineer to be able to make a decision upon the relevance of the historic case to the scenario based task prepared.

The time allowed for each design engineer to view the content of each document presented to them was limited to control for the potential of a person to uptake any informative content. Although it is necessary to accept that different personality's process information differently it was felt that this is a measure that needed to be controlled in the method. The time given for each viewing was 3 minutes; this was derived from the results of Chapter 5, section 5.4. In Figure 5.20 for 62% of design

engineers they are perceive they can make a decision upon a historic case document relevance to their current task in up to 5 minutes, of those 31% perceive it takes them up to 2 minutes to make that decision. Hence, 3 minutes was deemed a reasonable amount of time to establish an appropriate understanding of a documents informative content and to ensure that the evaluation interviews were did not take too long to conduct as there were five document evaluations and the secondary information behaviour evaluation to be completed.

It was also a concern of this experiment to consistently present historic cases of equal value that all participants were able to evaluate. This is a particular concern due as the participants were purposely not controlled for expertise levels as any approach implemented would need to be appropriate for varying levels of expertise. A creative approach was needed to enable a number of standardised samples of historic cases and document content formats were thus presented but to enable consistency for directly comparable results. Hence a document rotation approach was designed to be able present to each participant a range of documents that had been prepared in accordance with Table 7.4. The photograph in Figure 7.6 shows the 5 participant packs that were rotated throughout the evaluation interviews; an example of one of the 5 prepared documents for one such participant pack and shows one sample of the prepared documents. The rotation of the participant document packs and the documents sampled in illustrated in Table 7.7 below.

		Supporting Hypothesis					
		Baseline Measure	Decision Support v1	Decision Support v2	Decision Support v3	Decision Support v4	
		Full Document	Key Elements A	Key Elements B	Key Elements C	Imbued Elements	PACK ID
Subject Sample	ENG 1	FD1	KEA2	KEB3	KEC4	IEB5	1
	ENG 2	FD2	KEA3	KEB4	KEC5	IEB1	2
	ENG 3	FD3	KEA4	KEB5	KEC1	IEB2	3
	ENG 4	FD4	KEA5	KEB1	KEC2	IEB3	4
	ENG 5	FD5	KEA1	KEB2	KEC3	IEB4	5
	ENG 6	FD1	KEA2	KEB3	KEC4	IEB5	1
	ENG 7	FD2	KEA3	KEB4	KEC5	IEB1	2
	ENG 8	FD3	KEA4	KEB5	KEC1	IEB2	3
	ENG 9	FD4	KEA5	KEB1	KEC2	IEB3	4
	ENG 10	FD5	KEA1	KEB2	KEC3	IEB4	5
	ENG 11	FD1	KEA2	KEB3	KEC4	IEB5	1
	ENG 12	FD2	KEA3	KEB4	KEC5	IEB1	2
	ENG 13	FD3	KEA4	KEB5	KEC1	IEB2	3
Repair Case ID	32085-14	FD1	KEA1	KEB1	KEC1	IEB1	32085-14
	32107-14	FD2	KEA2	KEB2	KEC2	IEB2	32107-14
	32148-14	FD3	KEA3	KEB3	KEC3	IEB3	32148-14
	32149-14	FD4	KEA4	KEB4	KEC4	IEB4	32149-14
	32387-15	FD5	KEA5	KEB5	KEC5	IEB5	32387-15

Table 7.7: Evaluation Document Rotation and Preparation

The historic cases sample was retrieved from using a search in the current search tool for the design engineering team and based upon the work based scenario previously outlined. The shortlisted cases for the evaluation were selected from the retrieved list and the measurement of some tangible differences in the historic cases sample. The controlled sample was conducted to ensure the content complexity was appropriately similar but also presented enough media content variation to be a representative document sample. An original list of the document

sample retrieved is retained and available on request and below is listed the tangible control measures used to define an appropriate sample:

- Case selection rationale is combination of file size and number of pages.
- Number of Pages is Average (50 pages + or -30 pages).
- Size of files approximates 10000 KB, however this is not proportional to the length of the file and so may not a useful measure, it thus relates to the type of contents of the file.
- Sampling thus is files less than 3000 KB or above 13000KB (so as not are too large and complex in contents)
- Higher value could indicate rich image media which is expected and not to be justified out of test range but needs to be double checked for consistency.

It is necessary to be able to measure the understanding gleaned by each participant and these measures were elicited by devising a small list of questions with a senior design engineer prior to the evaluation preparation using other historic case documents as examples. This was deemed to be more accurate to measure understanding of design engineering content than using the researcher's own limited experience of the in-service repair historic case content and was developed iteratively with the design expert. These measures involved the preparation of short questionnaires to be filled out immediately after viewing each of the document information packs. The completion of the short number of questions was not time restricted as it was necessary for the design engineers not to feel that their own personal performance was being measured as this could alter task perception and performance. The only restriction imposed was that the questions were consistently answered (or applied) after the three minutes was over to ensure a similar approach was implicated in each experiment conducted.

The questions left room for only single text term entry to encourage recall and speed, although intentionally left open ended so as not to impede any response approach that a design engineer undertook. A sample questionnaire is provided in the appendices and measures used to determine question performance were devised iteratively with the senior design engineer and is discussed further in the results section of this chapter. A second task was requested of each participant to the evaluation interviews to both begin to evaluate their visual information behaviour preference and to engage them in thinking more about the design of document information support techniques. In this way the evaluation interviews were dual purpose in that they also encouraged design engineering users to actively engage in information supporting developments.

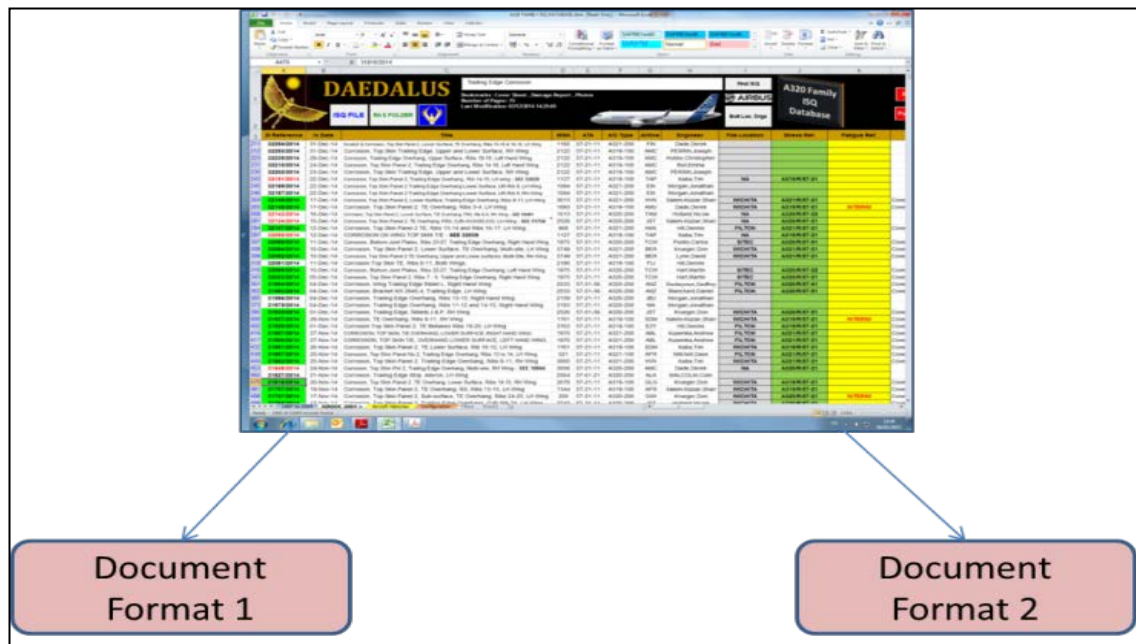


Figure 7.8: Secondary Information Behavioural Evaluation Scenario

7.1.4 Evaluation Supporting Interviews

The primary research aim of the second part of the interview evaluations was to scope the potential differences in personality upon information interaction behaviour of design engineers and thus elicit if information preference is likely to have an impact upon the development and utilisation of supporting tools (Shneiderman & Plaisant 2004). A secondary research aim was to actively engage the design engineering team in developing ideas for simple approaches to support their more efficient utilisation of historic case document contents and thus encourage any uptake of any support provision. Hence the second task focussed upon collecting qualitative data about design engineer practical information utilisation preferences. This second task involved the presentation of two new potential methods for presenting historic case document information. These two presentations were prepared by the researcher in advance and the same two presentations shown to each and every participant on the same computer during the interview. The outline work based scenario utilised was the same as for the first part of the experiment and thus the process provided to the design engineers for this part of the experiment uses the same document search criteria and information document samples. Both of the new document presentation examples had been previously utilised in the first part of the experiment and thus it was a historic case that would have been recently familiar to all the design engineer participants.

7.1.5 Evaluation – Industrial Constraints

The experimental studies were conducted in an industrial setting and thus the data collection approach needed to consider such things as the length of time the workload of the department could facilitate. Hence, the scheduling of interviews was constructed in advance and the design engineers scheduled into time slots that aimed to last no longer than 30 minutes. The participants were informed that the research was in no way a reflection of their ability and was not designed to measure this; they were also informed that all responses would be treated in the strictest of confidence and evaluated together not individually. This would allow time for a short introduction to the evaluation interview, 3 minutes to view each of the 5 reduced features documents and 1 minute to complete the short questions. The time schedule includes the confidential names of the participants and thus is not published with this thesis. The data collection for this experiment was designed to be mixed between quantitative and qualitative in analysis as previously described.

In the next section the strategy for capturing data from the tasks undertaken to enable different analysis approaches in the evaluation interviews is outlined.

7.2 Data Collection Strategy

Due to the different experimental approaches being conducted in the two part evaluation studies there are two data collection methods to outline in this section. The first part of the evaluation was intended to be directly comparable and thus a quantitative measurement approach was more appropriate. However, for the second part of the evaluation study the perceptions of the design engineers was paramount to be collected and thus a qualitative approach was a more feasible approach for any meaningful comparison.

The short survey questions shown in Figure 7.9, below, were intended to reflect the recall of the design engineer after viewing a document information features pack (described in the evaluation construction section of 7.1, above). Although a number of questions are labelled as open-end, participants were given only a short space to complete the answer and they were requested just to name as many points as they could recall from the information provided. This means the questions should only take approximately a minute to be able to complete and each point made can be analysed singularly as a textual term (or for each point made).

Questions 5 and 6a are closed questions to enable a direct comparison to make it possible to measure a cases presentation and performance. The measure of confidence is a subjective topic and thus a Likert scalar approach was deemed to be most appropriate. However, the actual response form scale provided was intentionally vague so as not to introduce bias by prompting responses as either end of the Likert scale. The scale measurements given were 0% confident up to 100% confident with only a half-way indicator provided. In practice this means that the estimation of confidence value unless expressly stated by the participant has to be evaluated by measuring the distance on the scale demarked. The survey approach means that the recording of data for this part of the experiment could be analysed after the experiments had been finalised.

	Question No	Question Text	Response Type	Question Type
Study 1	1	Describe as fully as you can, where is the damage located?	Free Format	Open
	2	Describe as fully as you can, what is the Aircraft Type?	Free Format	Open
	3	Describe as fully as you can, what materials are the parts affected?	Free Format	Open
	4	Describe as fully as you can, what part(s) of the aircraft are affected?	Free Format	Open
	5	Can you tell from the information shown if this is a complex or simple repair case?	Yes/No	Closed
	6a	Based upon the document format you have been shown, could you make a decision upon this cases relevance to the damage reported?	Yes/No	Closed
	6b	If No, what else would you have required?	Free Format	Open
	7	Based upon what you have seen, please mark on the scale to indicate how confident you would feel about making a decision upon this case's relevance?	Scalar	Semi- Closed

Figure 7.9: Evaluation Experiment 1 Data Collection Outline

For the second part of the evaluation interview, a different data capture approach was utilised. To reiterate, the second part of the evaluation was designed to capture the perception of design engineers in utilising document information in alternative formats. The participants were asked if they could give an opinion about the

alternative document formats as they perceived the “ease” of its use, it’s “understand ability” and the “decision making” capability it presented. The results were expected to be subjective as the information behaviour was expected to be highly variable due to the wide range of participant ages and experiences. Although the data capture appeared to be the scalar paper questions provided, the participants were asked to utilise the two presentations on the researcher’s personal computer and if it was possible to record the steps they made to interact during this time. Written notes of any participant comments were made by the researcher during this time and software was also utilised to record the steps and location of any computer actions made by the participant on the demonstration information presentations. The survey questions were completed after the participants had utilised both information presentations to capture a comparative view of the respective alternative views.

Study 2	Question No	Question Text	Response Type	Question type
	1	Ease of Understanding Information	Scalar	Semi-Closed
	2	Ease of Use of Information	Scalar	Semi-Closed
	3	Ease of Relevance Decision Making	Scalar	Semi-Closed
	Presentation Number	Presentation Type		
	1	Interactive Document Interface		
2	Static Document			

Figure 7.10: Evaluation Experiment 2 Data Collection Outline

Figure 7.10 above outlines the question types and response expectations for the second part of the evaluation interviews.

Due to the number of design engineers available (also excluding those that had participated in the previous workshop) in total there were 16 planned participant interviews over a two day period originally planned for the evaluation interviews. In practice there were 13 participants that took part over a period of three days. The conduct of these interviews is described in the next section (7.3) before the results are presented in section 7.4.

7.3 Conducting the Research

There were a number of practical considerations for conducting the evaluation experiments due to the industrial audience and the location for the interviews. The interviews were conducted on the industrial site so as to minimise any disruption to current working practice and to enable a maximum number of participants to be involved. A separate meeting room was booked for the entire period to enable the researcher to set up the experiment and conduct it repeatedly throughout without the need for the design engineers to have to travel far for the meeting. In practice this was incredibly useful as it also allowed for the dynamics of the industrial setting to be accommodated and reorganisation of interview timings and participants easily possible around working need. The evaluation interviews were extended over a three day period in the same meeting room to accommodate participants that needed to reorganise for unforeseeable reasons.

The need to eliminate any earlier designers that had participated in the storyboard workshops and the focus upon design engineering expertise means that the number of design engineers eligible to participate were small (16 in total). The total number of evaluation interviews conducted was 13 in total. Although this is a small number of participants the data collected represented a range of number of years’ experience, weekday and weekend working patterns and duty officer.

The preparation of the evaluations was iteratively designed with an expert design engineer that first answered the initial evaluation questions. The expert designer supported wording the questions with appropriate terminology, gave sample answers and agreed with the point marking approach for evaluating the responses. The analysis of the results in particular for the first part of the evaluation was by scoring points for each separate term recalled about each of the questions, with a tally for the number of responses being the final record. Hence the more recalled responses the higher ranking of the performance for each particular document information feature pack.

The secondary evaluation for capturing the perception of design engineers for alternative document presentations, the notations made recording the commentary from each participant, the interactive steps recorded in utilising the researcher's computer and the subjective question scales recorded for each presentation were all utilised to evaluate the perception of design engineers.

These results were analysed once all of the evaluation interviews had been conducted and the results are presented in the next section.

7.4 Results of the Studies

The results of the first part of this evaluation collate together the responses of the 13 participants and summate the number of textual terms reported as recalled about each document information reduced features presentation. An example of the data collected from the questions and its response summation is provided in Figure 7.11 to illustrate how the results have been recorded. In the illustration for each textual response recalled and recorded a point is given in the response column. For example in question one five textual terms are recalled and recorded and thus the response rating is 5.

<i>Pack 1</i>		
Question	Response	No of Responses
1	Corrosion, Riblet, Ribs 20, Trailing Edge, RH wing	5
2	A320	1
3	Metallic, Riblet, Trailing Edge	3
4	Metallic, Riblet, Trailing Edge	3
5	Yes	
6a	Yes	
6b	N/A	
7	67%	

Figure 7.11: Example of Question Responses for Participant 1

The total number of responses for each reduced features document is summated in Table 9.14 for each question. It is evident that it is possible for some of the questions such as question 2 it is possible to answer fully with less textual terms. However, due to the rotation of historic cases and comparison after summarisation it is possible for these values to be directly comparable for each document information features presentation.

The full document information presentation as previously described forms the baseline case measure for recording the performance of design engineers in a natural scenario using the historic case information documents. It must be understood that although the evaluation of the results in this evaluation may be applicable for the purpose of understanding historic document contents in full, the purpose of this evaluation was to evaluate the individual reduced feature document presentations with respect to the ability for the design engineers to be able make a

decision upon the relevance of a historic case document to be applied to a current task.

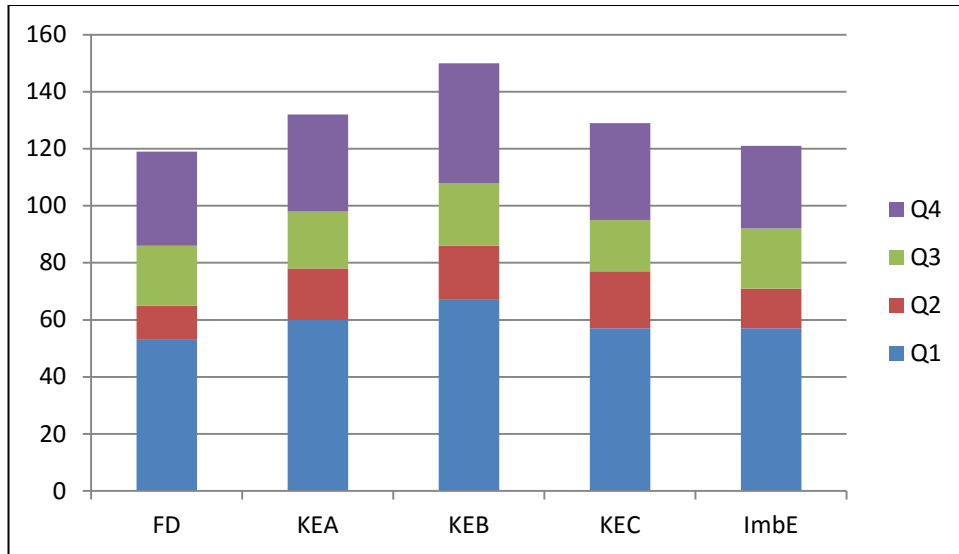


Figure 7.12: Summated Recall Responses per Document Representation

The total textual number of responses (or points awarded) collated for each of the document information features presentation types are illustrated in Figure 7.12. The informative content features for each reduced document presentation has been outlined previously in section 7.1. The acronyms in this illustration relate to each of these reduced document feature presentations and the acronyms defined in the list below:

- i) FD – Full Document (baseline case)
- ii) KEA - Key Elements A (minimal subdocument without images)
- iii) KEB – Key Elements B (minimal subdocument with images)
- iv) KEC – Key Elements C (alternative subdocument with images)
- v) ImbE – Imbued Elements (reorganised priority view)

7.4.1 Reduced Document Features Impact

From the results illustrated in Figure 7.12 it is evident that the participants were capable of eliciting more information content from some document presentations than others. The information elicitation performance of design engineers from much reduced information presentations was better than for those document presentations that were not reduced. This is evident when comparing the results of the full document presentation eliciting 119 responses and the 121 elicited responses from the imbued but complete information features document with the reduced features presentations in Key Elements A and in Key Elements C, eliciting 132 text terms and 129 text terms only. This is interesting due to the better response rate being achieved from less information content provision. The elicited responses then increases significantly to 150 responses for the Key Elements B presentation, an increase of 21% from the baseline Full Document presentation. The only variable change is the inclusion of the visual elements from the damage reporting subdocument to have instigated such a change in performance. This demonstrates the role of visual elements in supporting design engineers to elicit proportionally higher information content from the visual elements than from the textual contents.

It is surprising that for the final document presentation in Imbued Elements the effect of prioritising informative document content elements did not improve the performance of design engineer’s responses. This suggests that some cognitive

supporting techniques may be more applicable to the presentation of document contents and this is a point that should be explored further in future research.

	Question Number							Total
	1	2	3	4	5	6a	7	
FD	4.4	1.0	1.8	2.8	92.3	92.3	84.6	9.9
KEA	4.6	1.5	1.7	2.8	23.1	53.8	45.0	11.0
KEB	5.6	1.6	1.8	3.5	75.0	100.0	81.4	12.5
KEC	4.8	1.7	1.5	2.8	76.9	84.6	80.0	10.8
ImbE	4.8	1.2	1.8	2.4	84.6	76.9	77.3	10.1

Table 7.13: Results of Evaluation Experiment Part 1

7.4.2 Evaluation Survey

The Table 7.13 presents the collated findings of the average responses to each question for the evaluation survey. The findings of interest in this table are the in question 5 the imbued elements presentation enables a higher possibility of the participants to be able to determine the complexity of a historic repair from the prioritised view (84.6%) of information content provided. However this is still a lower figure than recorded for the baseline measure (92.3%). In comparing the capability of the information presented in facilitating participants to make informed decisions it is evident that for the reduced textual information contents provided in Key Elements A the capability drops to 53.8%, compared to the 92.3% of the baseline full document. This is a much reduced capability for decision making meaning that the prevalent subdocument utilisation patterns found in Chapter 8 (Coversheet and Damage Report importance) does not apply if the visual information elements are removed. This is even more apparent in the capability of design engineers to make informed relevance decisions 100% of the time for the Key Elements B information presentation that includes the damage reporting visual information elements. This illustrates again illustrates the informative role of visual elements in document information for improving the capability of decision making.

Another highly significant finding is in the results found for question 7 relate to a participants confidence in making decisions upon the relevance of the information they have viewed as a result of the differing information content presentations. In the full document presentation design engineers reported a confidence in decision making level of 84.6%, this confidence levels drop to an incredibly low 45% when only textual descriptions are included even from the most significant subdocuments from the findings of Chapter 6. However, if the reduced information content is supplemented by the visual information elements of these subdocuments the levels of confidence in decision making rises to almost the same level as the full document information (81.4%). This result needs to be understood completely, this means that it is possible to both reduce the capability and need to read information in detail by simply providing visual information elements. The development of document information support based upon this principle would save considerable information supported cognitive steps and thus potentially saves significant amounts of time in information utilisation for design engineers when using documents.

7.4.3 Descriptive Results Evaluation

The next results presented report qualitative findings from the second part of the evaluation studies. The conduct of this part of the experiment is described in 7.1.4 and reports the findings of the design engineer's interpretations of two different

methods for presenting document information contents. The first presentation was an interactive presentation shown below in Figure 7.14 and the second was a static reduced features document presentation in Figure 7.15. The experiment included collating information about the number and focus of any interactive actions of each participant. This was recorded using software and recorded the position of each action and the number of actions taken. However, the value of this recorded data is not possible to accurately analyse to contribute to this study due to the difficulty limiting the time each participant spent on each document representation, hence the qualitative results are reported only in this thesis. It would however be of value conducting more rigorous human computer interaction experiments to evaluate further in the future. These results are in the main taken from the descriptive perception reported from the design engineers about alternative document information presentations.



Figure 7.14: Interactive Alternative Document Presentation

In Figure 7.14 a snapshot of the document information presentation is given, although not possible to demonstrate in this illustration the document information presented was interactive and enabled the participants to retrieve more or less information or to view purely textual information from selected subdocuments. It was possible to navigate around the document information using information elements, subdocument categories and using links to acronyms relating to additional documents. Alternatively in Figure 7.15, below, a static presentation of the same historic case information was presented in a two page PDF document. Although small in size here, it illustrates the type of visual information being presented. This document information presentation was not an interactive presentation and further links to additional information or navigation possibilities were not available.

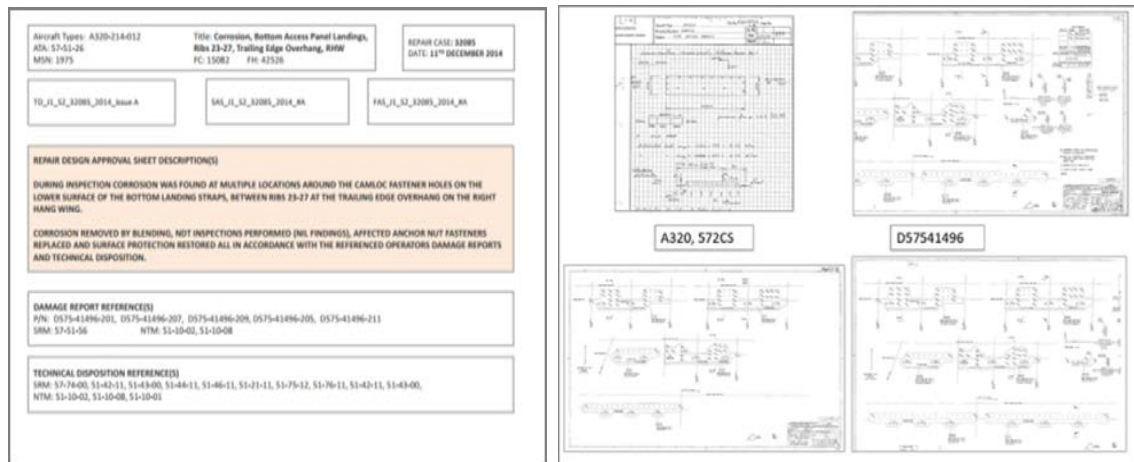


Figure 7.15: Static Alternative Document Presentation

The reported results of the two different document information presentations were qualitatively reported and it was possible to approximate from the scales utilised the perceptions of the participants. In all but one of the responses the preferred presentation of information was the first interactive document information presentation. The comments relating to this presentation suggest it was likely due to the additional links made between information element contents such as part numbers relating to further part drawings or standard repair manual references being able to link directly to retrieve the relevant standard repair chapter and drawings. In practice a system such as this is not yet available in part due to the limitations of historic document content technical capability and the sheer number of document resources that need to be interlinked. In respect of the reduced but traditional document view of information that was static and not interactive the responses suggest that utilising informative document content in this manner is not preferable and deemed to be more difficult to utilise. However, a number of reports suggest that the drawings and images were not clear and thus this could have resulted in the information content being more difficult to utilise.

The reliability of these findings are discussed in the next section for suggesting the validity of the method and results of this Chapter.

7.5 Considerations of Reliability of Results

The results of this experiment have been rigorously collected; considerable design effort went into the construction of the varying elements as detailed in section 7.1; however as with any experiment it is possible to make improvements to ensure the validity of the findings. The small number of participants could arguably be a weakness for the validity of the findings of this evaluation study. However, as ever the nature of industrial research means that the workload of the participants has to be considered paramount as without this the participants would be unlikely to be given management permission to engage, or inadvertently due to working pressures bias would be introduced into the results of the studies. For this reason it is accepted that this is a limitation of "real world" research. However, it must be considered positively to have been able to canvass the experience of those design engineers in current working practice or those already under significant "document overload" pressures and thus the results are considered highly appropriate and valid as representations of industrial design engineering in practice.

A secondary issue would be the evaluation of human information interaction from a theoretical perspective is much more complex than the simplistic approach taken for data capture in this evaluation and thus the results are representative of the opinions of the participants to this study. In practice the influences of age, sex, experience and personality are all reflected in human behaviour and thus making assumptions about the validity of any alternative document presentation

approaches would require much more rigorous extended experimentation that used principles from both the outcomes of this research and the theoretical principles from the domain of human information engineering. It is also evident that the quality of the demonstrated document information presentations has likely influenced the resulting findings. It is likely that the two presentations have in fact been compared and due to the difficulty in viewing some of the images have resulted in a negative view of the static but reduced document information. It is also possible that the suggestion that all of the document resources could be connected for navigation purposes in the interactive view of document presentations has resulted in an inflated view of this presentations value, when in fact this is not yet a realistic software application possibility without unreasonable manual effort and thus costly financial expenditure.

The next section summaries the findings from this evaluation and concludes the findings of the experiments in this thesis.

7.6 Discussion and Key Outcomes

At the beginning of this Chapter from the scoping studies in Appendix 6 and the work outlined in the experiments in Chapters 5 and 6, it has been possible to hypothesise that there are critical information content features (elements) in design engineering documents that have more importance in supporting them to make informed decisions.

The results of the evaluation experiments outlined in this chapter have sought to provide evidence for the utilisation of such reduced document feature patterns and sought to study the value of respective document information contents. It is evident from the results that there are recognisable patterns in the information utilisation for design engineers from historic case documents. The findings are thus as follows;

- The patterns from the results of the questionnaire studies in Chapter 5 and the Storyboard workshops in Chapter 6 are related to the importance of information elements, such as the importance of the damage report leads to a need for reading the document in detail due to the descriptive text present.
- Design Engineers *satisfice* when utilising document information content by gleaning information from textual terms and making a decision as quickly as possible, hence it is possible to reduce document information features to a minimum and note reduce the capability for information relevance decisions.
- The *omission of visual information elements reduces the design engineers confidence* informed making a decision significantly, suggesting the role of visual information is related to the confidence of design engineers in mental simulation processes.

The key findings of this Chapter are mapped in summary to the knowledge reuse process below in Figure 7.16 to illustrate how they fit into the overall design engineering need for support for knowledge reuse.

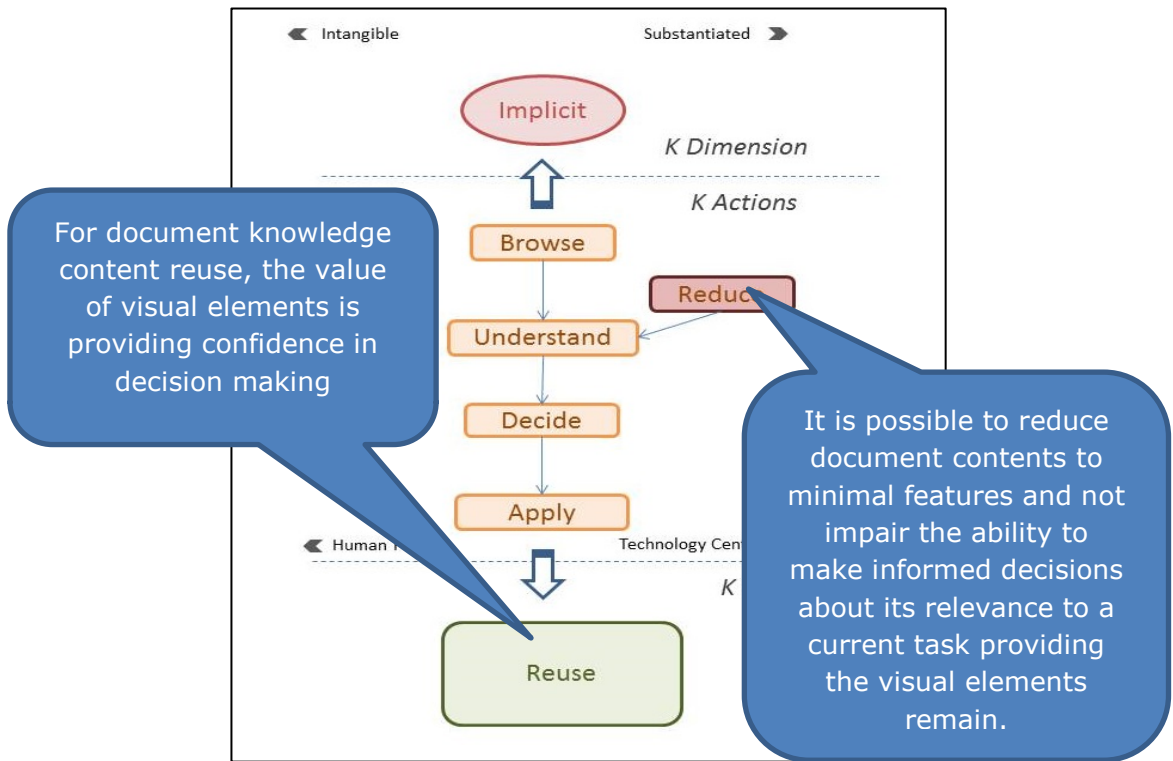


Figure 7.16: Knowledge Reuse Informed Decision Evaluation Outcomes

In the next chapter, the results and findings of this research thesis thus far are presented in conjunction with one another from the initial gap found in the literature together with the pressing industrial needs for support. The results of the scoping studies and from the experimentation described in Chapters 5-7 are all brought together and summarised in Chapter 8, where its application to design engineering document information and knowledge reuse are evaluated.

8. Information Requirements for Engineering Design Decisions

The overarching aim for this research has been to understand the role of visual information in documents for making informed decisions. In particular, there has been a need to focus upon the latter stages of design engineering when the reliance upon explicit document information resources becomes critical.

As a result of the research conducted, it is necessary to review what has been empirically established from the studies conducted, in light of the literature gaps, industrial challenges and the original objectives described for this thesis. This chapter seeks to establish a basis for understanding the relevance of the results and what this means to the future design if information support for design engineers. This is done by first reviewing empirically established findings for this work in the next section. These findings are then compared to the results of previous design engineering research to distinguish its importance in contributing to the design engineering body of knowledge. This contribution to knowledge is then mapped back to the original gaps found in the knowledge management literature to highlight how these findings can be used to realise further knowledge management support for the reuse of document information. The final part of this chapter embodies the findings of this research and suggests two potential industrial interventions that use the findings of this research to support document information reuse.

In the next section it is considered useful to revisit each chapter and its respective findings to collate and illustrate how they cascade to support each other and validate the findings that support original aims for this research.

8.1 Review of Key Research Outcomes

The approach for the work that has needed to be conducted for the aim of this thesis first outlined in Chapter 3, illustrating the work that needed to be undertaken to meet the objectives and achieve this aim. To arrive at the final outcomes for this research a number of smaller findings from the literature in Chapter 2, the industrial case in Chapter 4 and the scoping studies in Appendix 6 have been embodied and further investigated. The purpose of the investigations in Chapters 5, 6 & 7 have been synchronised to first establish a hypothesis about current utilisation and "reuse" need for design engineering document information content in Chapter 5. These information utilisation precedents and reuse hypothesis were characterised to combine the multi-stream human efforts of design engineering cognition and information strategies elicited in the Storyboards conducted in Chapter 6. Patterns of design engineering information content reuse have been elicited with suggestion of the relative importance of strategies and information elements and types, these combined empirical findings were further synthesised to hypothesise about the purpose of design engineering historic case document information content. This purposeful utilisation was evaluated in Chapter 7 eliciting the role and respective value of the visual and textual content of design engineering document information resources.

It is evident that the mixed methods nature of the empirical design for this research was particularly valuable when viewing the evolution of this research. The interlinked nature of its respective findings are displayed in the figures that follow; Primary and secondary research outcomes are identified that support the evolution of the research and develop the both the final hypothesis and the construction of the experiments that follow in sequence.

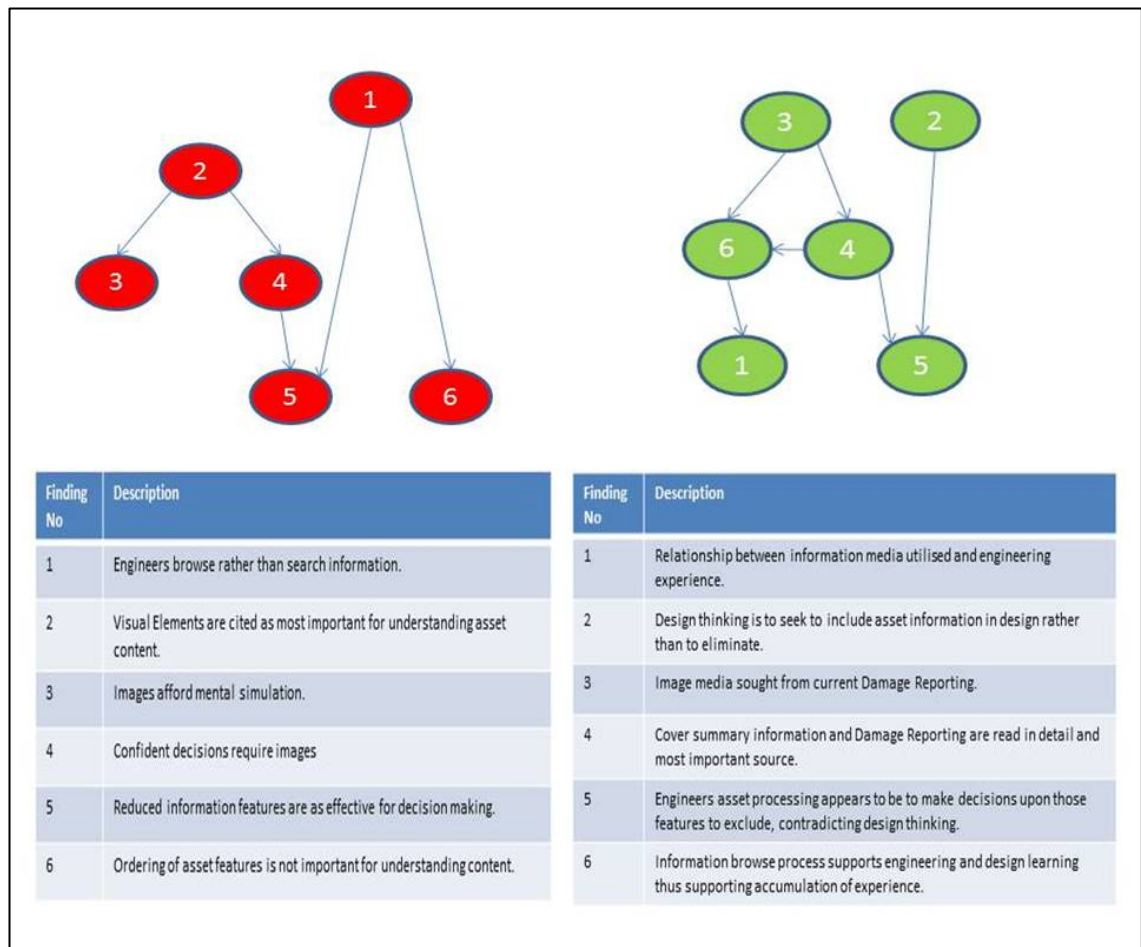


Figure 8.1: Evolution of Primary and Secondary Research Findings

Figure 8.1 shows the main research findings that have evolved throughout the discourse and experimentation of this work. In the *primary findings in red*, 1 & 2 are from results of the questionnaire conducted in Chapter 5. In the *secondary findings in green* numbers 1 & 2 are the result of the questionnaire study also from Chapter 5. These findings are then characterised further in the Storyboard workshop findings described in Chapter 6, where the primary findings 3 & 4 are as a direct outcome. In the secondary findings 3, 4, 5 & 6 are also outcomes from the Storyboard workshops in Chapter 6 adding further detail to the document information utilisation picture. Finally the evaluation study described in Chapter 7 elicits the primary findings 5 & 6.

If these outcomes are related directly to the sequence of research studies conducted the following two illustrations are representative of the stream of resulting findings, equally weighting the value of each study for its respective contributions to the primary design engineering research. The Figures 8.2 & 8.3 relate part of the thesis work conducted to each other in an overview and relates the results of each of the empirical studies and thus findings to the respective study.

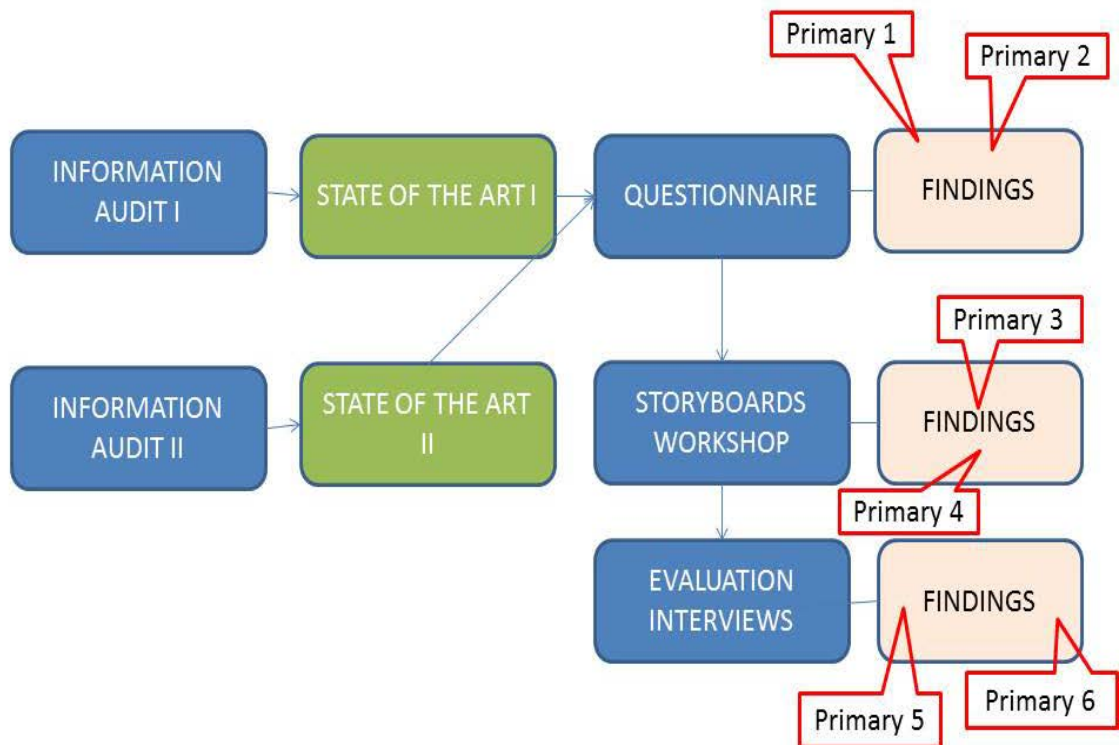


Figure 8.2: Primary Research Studies and Respective Outcomes

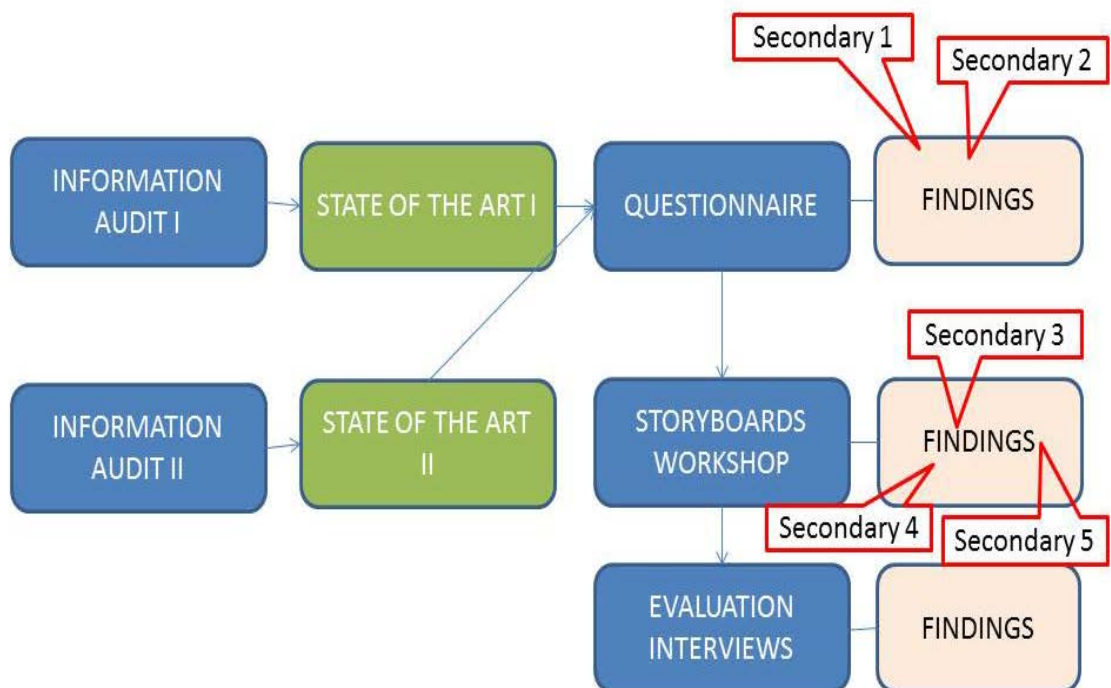


Figure 8.3: Secondary Research Studies and Respective Outcomes

In summary and in sequence the significant findings of the questionnaire study are;

1. Engineers need to browse information contrary to the perception that they seek specific information.

2. Visual elements of documents are ranked by far the most important informative content of such assets.

The findings of the Storyboard workshops are;

1. Images afford mental processing of information (mental simulation of RPD decision stages) required of design engineers when they are utilising document information contents.
2. Confident decisions about information relevance to task for design engineers is provided by the visual information media viewed.
3. Visual information or images are sought in the main from the damage reporting subdocument.
4. Most important information is read in detail and comes from the coversheet and damage reporting subdocuments.
5. Information processing appears to be to exclude irrelevant detail first, contradicting the perception of design engineers that they seek to include information gleaned. Hence they process much more than are necessary to find the information they require.

The findings of the evaluation experiment included:

1. Reducing the information features a design engineer processes does not compromise their ability to make decisions upon the information's relevance (providing visual information is included).
2. The order of information features is not influential to the decision making ability of design engineers.

8.1.1 Issues for Design Information Support

Bringing these findings together for the purposes of design engineering information support and needs it is evident that current information capture practices of design engineering are contributing to the information overload phenomena that are becoming suppressive in the latter stages of design engineering. The trend to capture as much knowledge and thus information about design engineering process and experience is leading to multipurpose and difficult to use collections of historic design documentation. It is these historic design document collections that the latter stages of product design become ever more reliant upon especially as product lifecycles lengthen and experience is lost. Current reuse of the valuable knowledge within these document information repositories is incredibly time consuming (up to 4 hours of a design engineers day is spent upon historic document information) and requires the interactions and understandings of human design engineers. Thus understanding and supporting design engineers to faster assimilate the information they require to determine the relevance of such historic documents is a critical part of making the design process more efficient and thus sustainable.

The supporting techniques for industry although required on an quantitative scale for the documentation reuse problem must involve part human methods due to the current limitations of image recognition and lack of "off the shelf" products for document media content extraction and recognition. Hence the focus must be upon the respective value of the information content of documents to focus research efforts upon supporting the reuse of critical elements. These efforts do not include the more recent trends to visualise the data content of these documents as (Humphrey 2013; McMullen 2011; Hunter 2010) more recent scoping research has suggested that this is not useful for understanding the entire historic repair content.

In the experimental research conducted in this thesis it was first found that design engineers are spending significant amounts of time seeking information from, understanding the content of and utilising document information content. Any support for reusing the knowledge content of these document assets must thus

focus on “how” best to reduce this time expenditure to improve human efficiency. There are also clearly more significantly ranked informative elements and viewing strategies that warranted further investigation. Upon deeper more detailed inspection it has become apparent that there are certain information elements that are critical to the understanding of document information, such as the coversheet and damage report subdocuments. However, due to current practice and thus viewing strategy it is the contents of these documents that are being read in full and taking considerable effort and time. Any time thus that reduces the reading need for this document content will improve the efficiency of document reuse. The second significant outcome is that the visual information elements of documents afford the mental simulation that is required by design engineers to facilitate the information relevance decision making process. These principles when evaluated demonstrate that it is possible to considerably reduce the amount of document information content that design engineers are required to view in order to discriminate its relevance to their current task and that visual information provides considerable informative value. However, the omission of the visual information elements means that the design engineer is almost half as confident in making this decision. This thus leads to further information seeking for recognising the relevance of such documents and thus less efficient use of their time.

8.1.2 Overview

It is concluded thus that to make the knowledge reuse process more efficient, in particular for the reuse of historic document information in design engineering, the patterns in document content utilisation should be used to create reduced document features. These reduced document features are the critical informative content that should be captured for the purpose of document knowledge reuse. To enable confident and hence much faster decisions upon the relevance of the reduced document features the visual information elements should be included in any such representations that are used to support these decisions. Further the future of design engineering research should consider the decision making sub-processing and cognition of design engineers as a valuable understanding resource within information experimentation to produce rich insight into the design engineering process.

These findings are further validated in the next section when attention is paid to the findings of previous design engineering research to consider the validity and position of this research within design engineering information contributions.

8.2 Establishing Value for Design Engineering Research

In Chapter 2.3, the experimental basis for knowledge and information reuse from the literature was presented. In particular this focussed upon the work that has already sought to characterise aspects of the design engineering information need. Although much empirical study has claimed to elicit the needs of design engineers it is evident that they focus their efforts upon broad participant samples and upon the needs of front end design engineers. This makes it difficult to establish a reliable basis for understanding specific design engineering needs for the duration or stages of the product lifecycle process. There is also a gap evident in the research into decision making for information relevance in particular for design engineering information utilisation as there is little literature surrounding this subject from the design engineering research.

The challenges this presents for design engineers is becoming ever more pressing as the latter stages of the lifecycle process become more competitive and a much larger part of the product offering due to product and service package trends are increasing. Exacerbating this even further is the lengthening product lifecycles that contribute to amassment of product data and learnings and the attrition of expertise that increasingly tip the information reliance and thus overload balance for latter stage design engineers. Upon closer inspection when comparing the

findings and approaches taken in this research to the design engineering literature we find a number of interesting points highlighted below;

1. Vianello & Ahmed (2012) find that knowledge transfer is complicated by the transfer for a multiplicity of purposes and Markus (2001) suggests that knowledge capture has been driven to be multipurpose. *Addressing this research in this thesis has been highly specific to purpose for the reuse of historic case document information for its reuse in latter stage design repair.*
2. Jagtap & Johnson (2011) state they haven't looked at the "how" of information utilisation and Vianello and Ahmed (2012) have referred to the lack of research at the data end of the knowledge pyramid. *Both of these aspects or gaps have been addressed by using the actual document data content utilisation patterns and studying "how" design engineers interface with such information resources.*
3. Mancilla-Amaya et al. (2012) suggest that the reuse of high quality knowledge is crucial to an organisations success. They also suggest due to intangibility of experiential knowledge (Nonaka 1994) it is only possible to measure the quality of explicit knowledge resources. Although difficult to measure examples metrics for knowledge quality can be derived from the work of Mancilla-Amaya et al. (2012), Lee & Lai (2007), Garvin (1987), Yoo et al. (2011) and Rao & Osei-Bryson (2007). Given the importance of knowledge quality, the complexity of explicit knowledge resources and the need for efficient reuse of documented knowledge more effort is needed to focus upon the measure of the quality of knowledge being reused from explicit knowledge resources. *Thus it also follows that the formatting and representation of knowledge in explicit assets present significant potential for evaluating the knowledge metrics being developed the knowledge representations required to efficiently transfer that to knowledge users. Hence the use of document information utilisation patterns elicited and principle role of visual information elements are critical to the development of this research field.*
4. Marsh (1997) finds that only 24% of a design engineers time is spent seeking, utilising and disseminating information, *comparing this to the questionnaire results (Chapter 5) suggests there are significant differences in the stages of design we focussed upon in latter stages or that design engineering has evolved significantly in this time lapse.*
5. The difficulties Wasiak et al. (2010) finds with protocol analysis in the reluctance in participation and inherent difficulties experts have in "telling what they know" (Carey et al. 2012; Laudon & Laudon 2000). *This is overcome if the Storyboarding method utilised in Chapter 6, where design engineers were captured unobtrusively communicating with one another in conjunction annotating their story unidentifiably. However, significant qualitative and multi-stream data analysis challenge introduced.*
6. Harsh (2014) suggests that in design engineering 20% of the efforts are technical and the other 80% is human. Khadilkar & Stauffer (1996) also suggest that 70% of design is utilising previous design hence the reliance upon documented design detail. *The findings in this research agree with this in the huge amounts of time spent in human information synthesis of documents (Chapter 5, up to 4 hours each day spent viewing document information).*
7. A limitation of the research is the level of document information decomposition possible. An example is visual media in these experiments includes non-textual patterns in data such as tables, results, graphs and photographs leading to the assumption that all images or visual elements have the same purpose and role. Research by Guthrie (1988) suggests that searching document information is a goal oriented exercise unlike the browsing we identify in this thesis. *Hence deeper investigation that focusses upon further decomposed information types could yield further significant utilisation patterns or results about the role of specific media information.*

8.2.1 Summary

In summary, it is evident that the design engineering information need is as complex as the products it develops and supports, thus it becomes apparent that the information requirements evolve as does the product lifecycle. Hence it is necessary to establish the product and lifecycle stage needs as independent entities and thus research them in isolation appropriately, before drawing conclusions about design engineering information needs. It is also evident that the research approaches employed for this body of research are required to be entrenched within the information systems methods more appropriate for understanding the complex nature of human information interaction for supporting decision making and the cognition that underpins such interactions.

The work conducted in this thesis in particular establishes the highly information reuse driven needs of latter stage design engineers and hence it is proposed that the framework of information support and provision for the latter stages of design need to be ever more focussed to the specific demands of the complexities of latter stage product design. In the next section the findings of the research in this thesis are mapped to the original knowledge reuse gap in the literature that was established in Chapter 2.2. This further establishes the position of this research within the knowledge management domain.

8.3 Mapping Key Outcomes to Knowledge Reuse

In Chapter 2, the discussion of literature for design engineering requirements for knowledge management was framed. In light of this it was established that the most pressing needs for design engineers was for information utilisation support to facilitate effective reuse of design engineering knowledge. The work that has already been under taken in this area was outlined to highlight the shortcomings of the research thus far and the lack of significance placed upon the *purpose* of knowledge capture processes to facilitate efficient knowledge reuse. Hence the sub knowledge flows and human knowledge processing was established to map the focus of the research studies onto the human knowledge processing need. Chapter 3 explicitly outlined the objectives for this research, characterised the research approach that would be needed to begin to fill the gaps established and highlighted the appropriate methods to conduct studies within industry were outlined. This section seeks to establish in light of the knowledge reuse need for engineering design the achievements of this thesis. This section describes the findings and achievements of respective chapters and maps them to the original knowledge reuse illustration in Figure 8.4 below.

The industrial case study in Chapter 4 has further understood and embodied the current industrial challenges for knowledge management and design engineering information support, in particular for the amassed historic documents that represent valuable design engineering knowledge already captured. Some of the significant findings of the industrial case are the scale and the complexity of the document information reuse issue and the challenge that presents both for industry and to design engineering teams. The scoping research studies outlined in Appendix 6 further establish the technical challenges in supporting efficient document information utilisation (or reuse) and the potential for research given the current state of the art. The findings of the empirical research have collected evidence to suggest that unsustainable amounts of time are needed to keep using valuable document information content (Chapter 5), there are significant patterns in design engineer document information element utilisation (Chapter 6) and visual elements are most valuable for supporting mental simulation and thus decision making (Chapter 6) and they give confidence to design engineering decisions that mean information can be efficiently reused (Chapter 7).

From the above summary a number of gaps arise that correlated to steps in knowledge reuse in the illustration Figure 8.4 below. The points when mapped to explicit knowledge reuse steps embody the difficulties design engineers have in

efficiently reusing explicit knowledge resources. These points in the knowledge reuse illustration also offer insight into constructive human media utilisation steps that have been studied in this thesis to collect data about the understanding, the thinking and cognitive elements required of design engineers to reuse the prevalent difficult to manage document resources they collect.

These findings in turn should be utilised to develop supporting techniques and methods that better present document information content to design engineering users to capitalise upon the visual elements that support both mental simulation for decision making and give confidence to the design engineers making complex decisions. In the next section two such examples of support for in-service document information content are outlined to embody the notion of visually informed design engineering decisions.

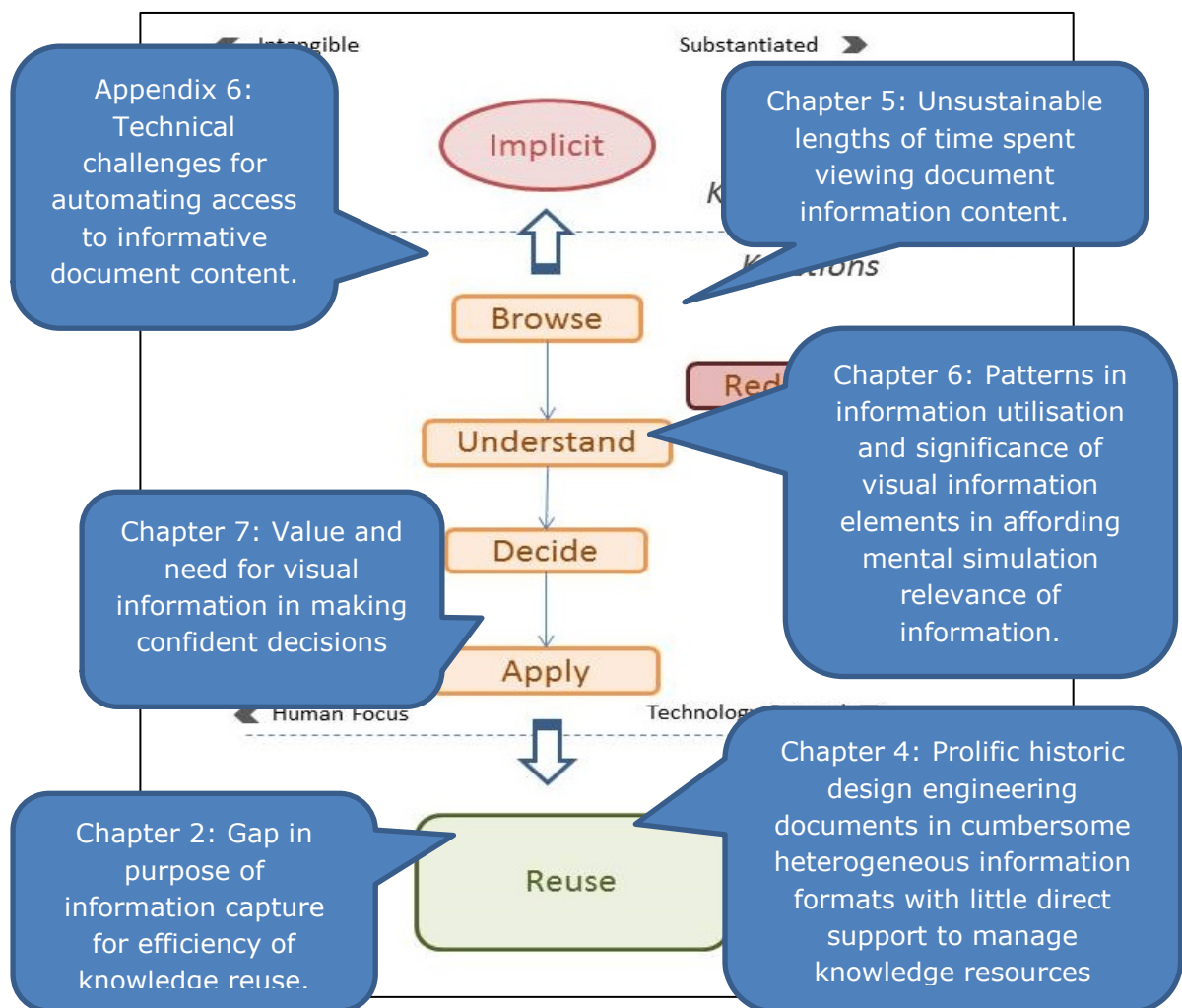


Figure 8.4: Knowledge Reuse Map of Research Outcomes

8.4 Industrial Implications and Potential Impact

The focus of this research has been upon the use of images in information handling and decision making. This has been undertaken in conjunction with a strong, supportive and forward looking industrial partner. Thus the utilisation of the findings of this research for industry is a key concern. In Chapter 4, section 4.3.3 the industrial workflow scenarios for design engineering repair are outlined. This is the work and task based scenario upon which the experiments in Chapter 5, 7 & 7

have all focused on to elicit the information reuse requirement for historic case information. This section summarises that process and explains how the findings can be utilised to create more efficient document content information techniques and tools for the design engineering users. This is a practical example of potential knowledge reuse intervention for the efficient utilisation of document content information. Whilst both of these implementations are possible with varying amounts of manual and automated intervention neither of these methods are currently being utilised in industry but are posed as potential interventions.

A model for implementing knowledge interventions for the reuse of document information in in-service design repair is illustrated in Figure 8.5 below. This illustration is a deconstruction of the “search historic case Daedalus” search step shown in Chapter 4, Figure 4.4 and in Chapter 7, Figure 7.4. This shows the process used by the design engineers when seeking a supporting historic case for a current repair task. It involves using a key text term (see Chapter 6, section 6.1, Figure 6.3 & Chapter 7, section 7.1, Figure 7.4 for the work based simulation detail) in an enhanced excel spreadsheet to retrieve a shortlist of potentially matching historic case documents that can then be viewed/browsed to determine their relevance to the current repair task.

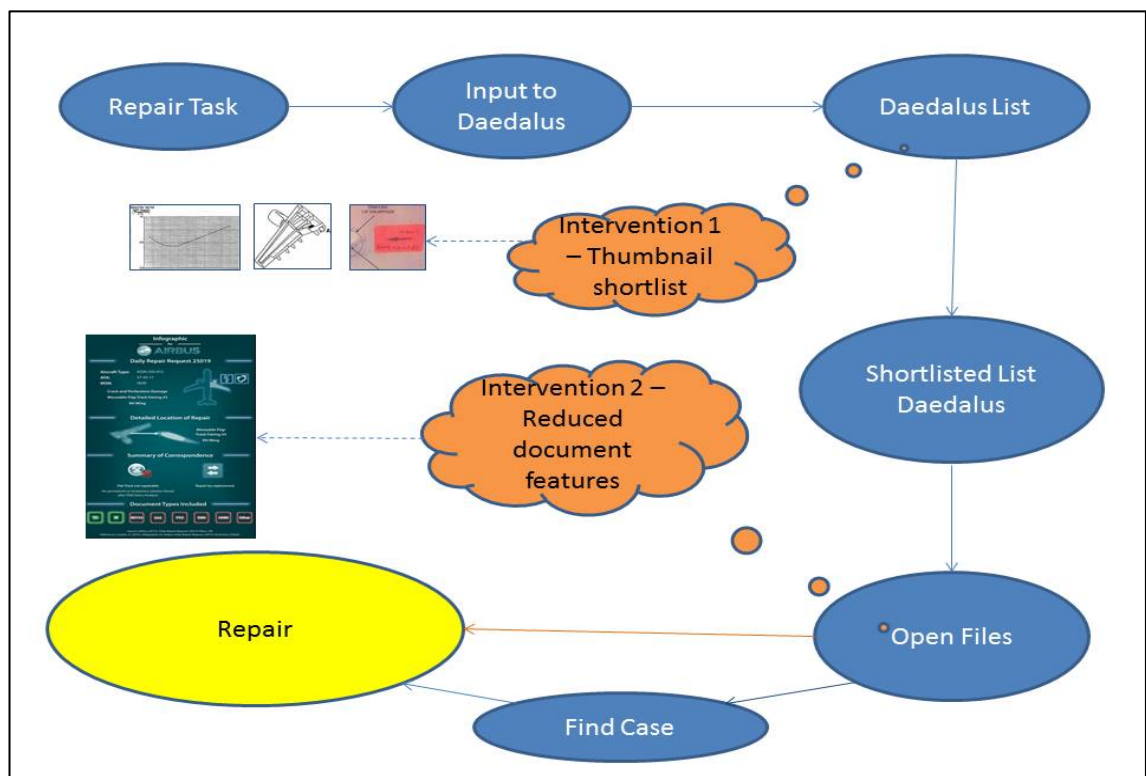


Figure 8.5: Information Search and Retrieval Document Intervention

The scenario depicted illustrates two points in the current document retrieval process that could be utilised to present document information in novel formats capitalising upon the utilisation pattern findings of this research and the importance of visual information elements in supporting confident information decisions. Both of these support needs are derived directly from the outcomes of this research summarised in section 8.1, Figure 8.1. There are two points identified in this current process that present potential for presenting document information content to reduce the need to open as many historic case documents and reduce the time spent reading the documents in full, both of these aspects are identified from the questionnaire research in Chapter 5 as important to make the reuse of document information more efficient.

In practice both of the interventions in conjunction with each other would be highly applicable; however they are each addressed in turn in the following subsections.

8.4.1 Knowledge Reuse Intervention 1 in In-Service

The earlier opportunity to intervene and present document information content to design engineers in their current practice is when the results of the text based search utility are shortlisted in the excel spreadsheet view shown below in Figure 8.6. The current tool allows a textual list to be filtered using a single text field such as the "MSN" aircraft identifier or the "ISQ Number" the historic repair case unique identifier. In the current system it is possible to filter these results by a single text field only.

As is illustrated in Figure 8.6 the visual features of a document are not available until individual documents are selected and retrieved to be viewed more comprehensively and there are currently over 90,000 documents that are available to be retrieved in this manner.

ISQ No.	In Date	Title	MSN	ATA	A/C Type	A/I	Engineer	Location	Stress Ref.	Fatigue Ref.
97	10-Dec-10	LH Spoiler No.6 Upper Surface - Dents	649	57-76-11	A310-300	KAC				
98	09-Dec-10	RH Inboard Flap Upper Skin - Several Dents	649		A310-300	KAC				
99	06-Dec-10	RAS REVIEW TO COVER ESG	783		A300B400	JAL				
100	06-Dec-10	RAS REVIEW TO COVER ESG	770		A300B400	JAL				
101	07-Dec-10	RAS REVIEW TO COVER ESG	753		A300B400	JAL				
102	06-Dec-10	RAS REVIEW TO COVER ESG	730		A300B400	JAL				
103	06-Dec-10	RAS REVIEW TO COVER ESG	683		A300B400	JAL				
104	06-Dec-10	RAS REVIEW TO COVER ESG	679		A300B400	JAL				
105	06-Dec-10	LH SPOILER No.5 - UPPER SKIN DELAMINATION	782	57-72-11	A300B400	THA				
106	06-Dec-10	RH SPOILER No.5 - UPPER SKIN DELAMINATION	782		A300B400	THA				
107	03-Dec-10	LH Spoiler No.5 Top Skin - Delamination	785		A300B400	THA				
108	15-Nov-10	RH SPOILER No.4 - DELAMINATION AT CENTER HINGE ARM	641		A300B400	JAL				
109	15-Nov-10	LH Spoiler No.4 - BROKEN CENTER HINGE AND DELAMINATION	626		A300B400	AAL				
110	10-Nov-10	LH Flap Track Beam No. 2 - Multiple Damages	345		A310-200	FOX				
111	09-Nov-10	LH OUTBD. FLAP END RIB No.12 - MIS-LOCATED FASTENER HOLES AND EXISTING DOI	362	57-53-00	A310-200	FOX				
112	19-Oct-10	RH OUTBD. FLAP T.E. - LOWER SKIN EXISTING SRM REPAIR	318		A310-200	FOX				
113	28-Sep-10	LH Inboard Flap Lower Skin - Existing Repairs	318	57-52-12	A310-200	FOX				
114	27-Sep-10	LH Inboard Flap Roller Guide Support Surface - Cracks	634	57-52-11	A310-300	FOX				
115	16-Sep-10	RH OUTBD. FLAP T.E. - LOWER SKIN DEBONDING	318	57-53-00	A310-200	FOX				
116	03-Sep-10	LH OUTBD. FLAP - UPPER SKIN GOUGE AT RIB No.1	264	57-53-00	A310-200	FOX				
117	12-Aug-10	LH INBD. FLAP - EXISTING REPAIR BTW. RIB No. 10 & 11	264	57-52-00	A310-200	FOX				
118	12-Aug-10	LH Outbd. Flap, upper side - Existing skin repair at Track 3 between main and rear	264		A310-200	FOX				
119	12-Aug-10	RH INBD. FLAP VANE TRACK No. 4 - CRACK AT VERTICAL WEB	333	57-52-00	A310-200	FOX				
120	02-Aug-10	LH Inboard Flap Trailing Edge Reinforcing Crack	480	57-52-00	A310-300	THY				
121	12-Jul-10	RH Inboard Flap Trailing Edge - Delamination on Karman Fence.	345		A310-200	FOX				
122	12-Jul-10	RH Inboard Flap Trailing Edge - Delamination	481	57-52-12	A310-300	JAV				
123	09-Jul-10	RH Inboard Flap Trailing Edge - Debonding	480	57-52-12	A310-300	THY				
124	09-Jul-10	RAS REVIEW TO COVER ESG	670		A300B400	JAL				
125	09-Jul-10	RAS REVIEW TO COVER ESG	641		A300B400	JAL				
126	09-Jul-10	RAS REVIEW TO COVER ESG	637		A300B400	JAL				
127	08-Jul-10	RAS REVIEW TO COVER ESG	711		A300B400	JAL				
128	08-Jul-10	RAS REVIEW TO COVER ESG	703		A300B400	JAL				
129	08-Jul-10	RAS REVIEW TO COVER ESG	729		A300B400	JAL				
130	08-Jul-10	RAS REVIEW TO COVER ESG	737		A300B400	JAL				
131	12-Jun-10	RH Spoiler 687 - Trailing Edge Ribs at Spoiler 687 Area Cracked	531		A310-300	RJA				
132	12-Jun-10	LH OUTBD. FLAP LOWER SKIN - DENT DAMAGE TO OUTER SKIN AND CORE BTW. RIB	476	57-53-00	A310-300	THY				
133	12-Jun-10	LH Spoiler No.6 Gouge at Actuator Hinge Lug Inner Face	806	57-73-11	A300F400	UPS				
134	12-Jun-10	RH Outboard Flap Upper Skin - Gouge Marks	251		A310-200	FOX				
135	12-Jun-10	LH SPOILER No.5 - GOUGE AT ACTUATOR HINGE LUG INNER FACE	806	57-72-11	A300F400	UPS				
136	12-Jun-10	LH Outboard Flap Upper Skin - Gouge Marks	251		A310-200	FOX				

Figure 8.6: Document Information Retrieval Shortlist

Hence it makes sense that from the findings of this research and understanding the value of the visual informative elements for making more confident decisions and the patterns in subdocument information utilisation, that at this stage of the retrieval process a design engineer could faster discriminate those repair cases that were not applicable to the current task if thumbnail images from the damage report subdocument information content were presented. This would mean that it was necessary to open less historic case documents. An example of the visual elements that could be presented as thumbnails is illustrated from one of the historic repair case documents and shown below in Figure 8.7.

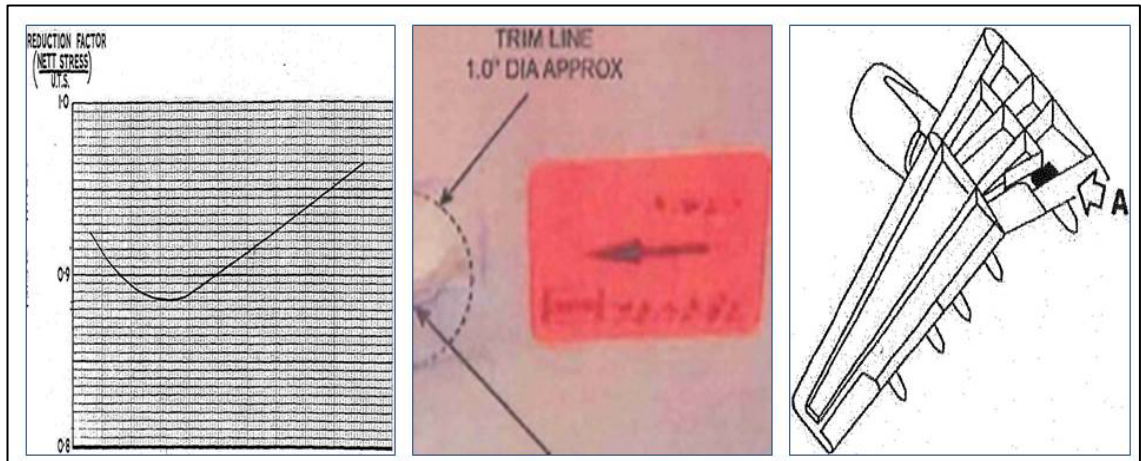


Figure 8.7: Example Thumbnail Images from One Historic Case Document

Although this principle has not yet been employed within the in-service team, one of the senior design team has been observed utilising the thumbnail patterns presented by the Adobe software application when a document is opened to view and open selected pages that contained visual elements such as tables of results. This facility is also available in some windows based applications and enables previews of document thumbnails suggestive of file contents. The principle observed in the experienced design engineers working practice is illustrated in the PDF document snapshot shown below in Figure 8.8;

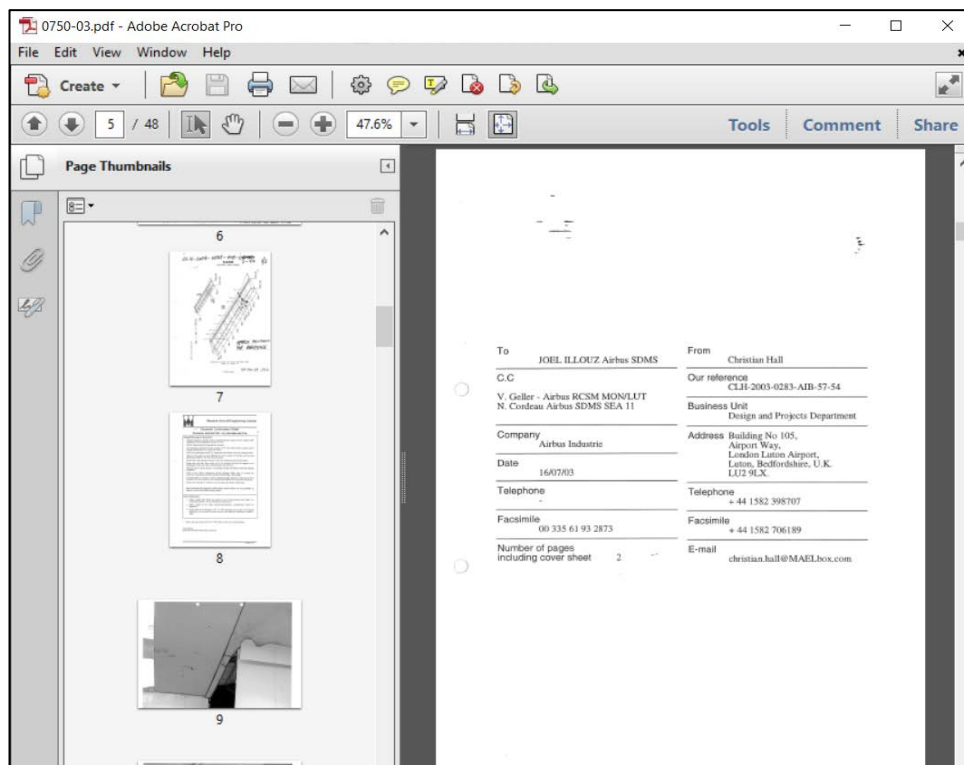


Figure 8.8: PDF Thumbnail Document Information Patterns

This could be combined with the next suggested intervention to considerably improve the efficiency of document information content reuse for design engineering.

8.4.2 Knowledge Reuse Intervention 2 in In-Service

The second such intervention involves utilising the informative contents of design engineering documents and repurposing the critical contents. The intention of the

repurposed contents of the documents is to assimilate from the critical information utilisation patterns found in Chapter 6 & Chapter 7 to present them in highly visual forms.

The work reported in this section has utilised the findings from this research summarised in section 8.1 and the critical textual terminology elicited from the Storyboard workshops, see Chapter 8, section 8.5, , to create single page infographic representations of the historic design repair case documents. This section reports on the work of Lockett (2015) that aimed investigate the potential role of infographics for design engineering document utilisation.

Examples of the infographics prepared from design engineering documents are provided in the Figure 8.9 shown below.

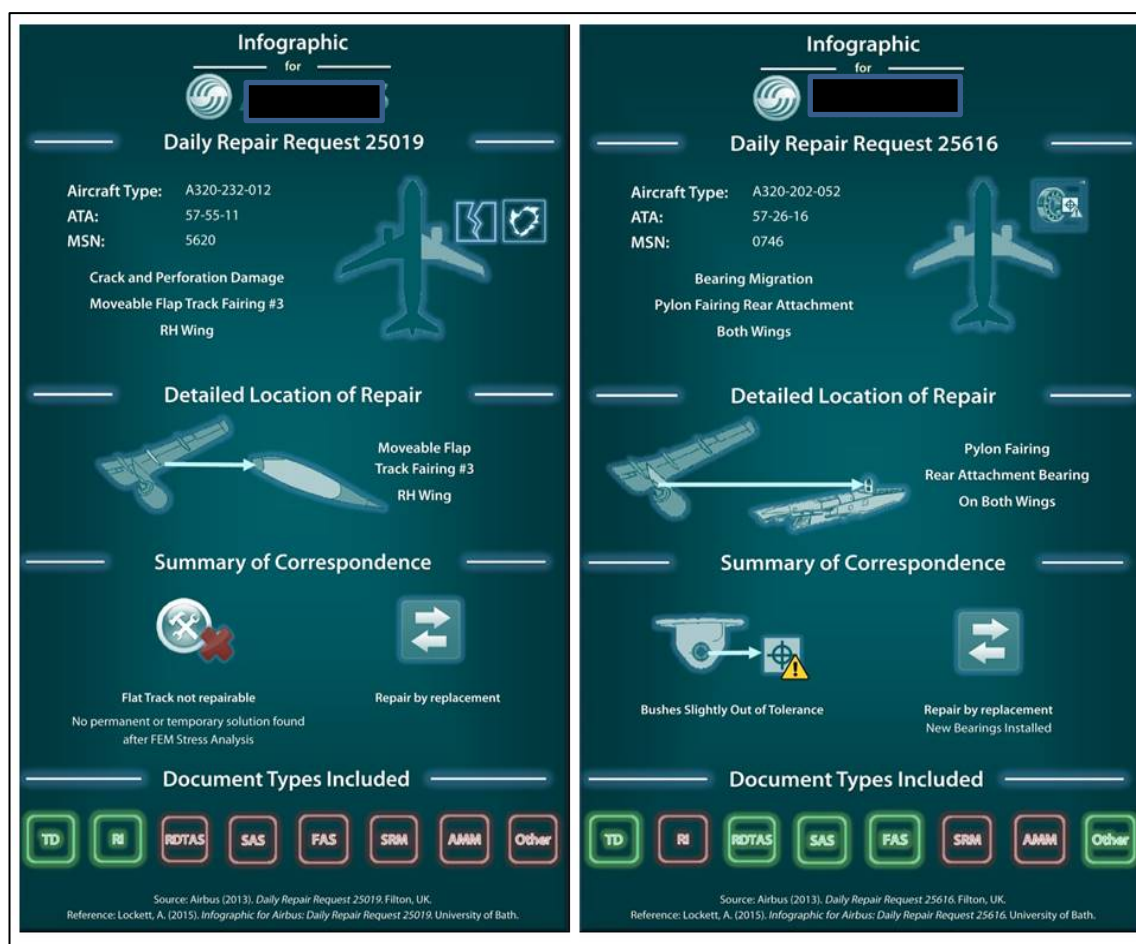


Figure 8.9: Example Design Engineering Document Infographics

The purpose of this research project was to evaluate the potential benefit of infographic representations for design engineering documents. It involved the creation of infographic representations from a number of different design engineering documents including the historic case documents were the focus of this research that were further evaluated with both an industrial audience and a student audience against a number of informative criteria. The example infographic document presentations shown in Figure 8.9 are created from the document information content of example historic cases. The utilisation patterns elicited from the design engineers in the experiments in Chapter 5 & 6 were used to prioritise the information presented in the infographics. The reuse of the original historic case document visual information elements were not utilised in these presentations as one of the purposes of the experiment is to create standardised visual elements

that are further useful in communication of information from document resources, in particular to extended industrial audiences.

Lockett (2015) describes that the experimentation first required the application of a variety of principles from the human computer interaction fields to create the infographic documents. This included heuristics and principles for the clear presentation of information, amongst those used was the (Smiciklas 2012) questions to identify with the infographic audience, the logical segmentation of the information using introduction, middle and end subtitles (Smiciklas 2012), the simplification of complex concepts (Lal 2013) and the use of text sparingly (Lal 2013). Additional image principles were identified such as the use of the rapid, serial and visual presentation developed by (Spence & Witkowski 2013) to capitalise upon the brains ability to recall larger images.

These infographics once created were evaluated with a student audience surveying the recall of students about the content of the infographics to evaluate the infographic ability to transfer design engineering information rapidly and within industry using an interview method to evaluate both their ability to communicate information rapidly and for their value within a business. Lockett (2015) finds for the business evaluation that the infographic presentation summaries are in fact not useful as much of the information has already been gathered by the design engineer in the initial information gathering process (outlined in Figure 10.5 of this Chapter). However, there is much value attributed to the visual portrayal of the "location" information, the additional visual icons that replace the textual elements, the decision-making time is perceived to be much reduced and the potential it presents for increasing design engineer information productivity.

However, one of the main perceived limitations is that the preparation of such infographics for the 90,000 current historic documents being searched would not yet be possible and thus this is a tool for the future. In practical terms however, with the extraction of text and automated interpretation illustrated in Appendix 6, it would already be possible to automatically evaluate and potentially substitute graphical representation for the informative content of much of the historic case documents. This application holds much potential but is yet to be investigated further.

The sequence of information interactions presented in this section for the novel retrieval, presentation and reuse of design engineering utilisation capitalises upon the value of visual informative element contents. This is an application specific example of how the findings of this research could be applied within current industrial process. The principles presented here could be extended with further research to understand patterns in the utilisation of other wider document information collections and used to create supporting knowledge reuse intervention in wider domains.

8.5 Information Decision Making in Design Engineering

In the assimilation of key literature domains for design engineering from Chapter 2, section 2.4 the importance of decision making for design engineers was derived. The importance of decision making theory to information systems has long since been recognised with knowledge based decision making tools being developed as an organisational supporting standard (Laudon & Laudon 2000; Easterby-Smith & Lyles 2003). In the fields of information science the need for decision support has been developed now incorporating expertise from psychology and cognitive sciences for further investigating the effects of macro-cognitive steps and subdivision of information processing requirements and its relation to decision making practices, human information interaction and information optimisation. Such methods developed for studying these aspects are cognitive task or work analysis (Schraagen et al. 2000).

The importance of information and knowledge to support design engineering projects has long since been valued and has highlighted in Chapter 2, section 2.2 e.g. Hicks et al. (2002). Knowledge management research is evolving into organisational research (Easterby-Smith & Lyles 2003) as there becomes more attention paid to the social nature of knowledge and thus evolving support needs (Gopsill et al. 2013; Wasiak et al. 2010).

However, although the information needs of Design Engineers has long since been the topic of research the literature investigating *its relative purpose* during the design processing of the such information and its utilisation little understood.

It is now time for design engineering research to capitalise upon the methods developed in wider fields of human information interaction and naturalistic decision making to deeper understand the cognition and information processing that is undertaken by design engineers in information utilisation. This is particularly significant to understand in a wider product lifecycle context the micro-decision making that relates to information relevance to design task. Although intuitively the aspects being researched may seem obvious, without the empirical evidence it is not possible for the science of information support to progress. The deeper understanding of the underlying decisions being carried out will elicit also the information detail that supports this process and thus drive the development of more effective methods for information discrimination and provision.

8.6 Reiterating the Wider Importance of Imagery

As discussed in the previous section, the intuitive importance of images may appear self-evident, however as also stated the scientific evidence for the role and thus value of visual information elements in design engineering documentation had until now not yet been collected, this has been an important and critical aspect of this research. The empirical evidence collated as part of the experimentation for this research has now provided scientific basis for this intuition in design engineering documentation and information.

It is evident from wider domains there is much interest in the human propensity for visual cognition and thus capability (Cavanagh 2011; Wood 2011). As long ago as 1982 (Mackinder & Marvin) suggested that decisions were much easier using illustrations and this has progressed into how humans synthesise information much faster using visualisations rather than textual or numerical data (Kohlhammer et al. 2011).

There are also many further human visual information propensities described such as the use of colour coding for semantic enhancement (Kauppinen 2004) or the special significance of spatially arranged data investigated by Andrienko et al. (2007). This human senses research and our inherent information processing capability is harnessed further in the pedagogical principles employed by Collison & Parcell (2005) and memory and recall (Davoli et al. 2012; Karpicke & Roediger 2007). In Kumpulainen (2014) derivation of information "berrypicking" trails for molecular scientists has been used to study information behaviour, this is clearly an important and developing area and scientists are one example of information reliant workers. These information trails are important as they represent the information seeking patterns for not only differing users but also for solving different types of information purpose or answering questions. The berries represent the information utilisation or selection whilst the trails are the routes and access mechanisms and thus information utilisation patterns are collected. These information utilisation patterns provide answers to the question about both the importance of certain information resources and clues as to the information access requirements of user types and is clearly applicable much further afield than for molecular scientists.

The research reported in this thesis has sought to understand this at a macro-cognitive level for informative document contents. The utilisation of such

“berrypicking” trails in information preferences and utilisation for document information may contribute to understanding the information seeking needs of different users and to better present information from documents. Harnessing such information preferences and information utilisation patterns is critical for improving the efficiency utilising documents and information in the wider research context. In particular as technologies and communication advance and our lives are becoming ever more persuaded by the historic information in documents that governs our organisations. Applying the visual principles to documents in a wider context is thus important to improve the efficiency and ease of our working lives.

This section concludes the presentation of the experimental research of this thesis and the final Chapter that follows concludes the overarching contribution to knowledge that this thesis has achieved.

9. Conclusions, Limitations and Further Work

The overall aim for this research has been to investigate the role of visual document information contents in supporting design engineers to make informed decisions. In this Chapter the overall rationale for this work is reviewed and how the objectives have been met by the research carried out throughout. The achievements of this research are further summarised in the main knowledge contributions made by the work in this thesis.

The second contribution of this Chapter is to consider the extension of work to this thesis presented in the latter sections to further develop research for design engineering and wider domains, in particular for the reuse of document information for knowledge support. Firstly to understand how the work in this thesis has contributed to its aim we must review the objectives for this thesis and how this research has achieved each of those objectives.

9.1 Summary of Research Objective Contributions

In Chapter 3 of this thesis the overall aim for this work was broken down into a number of tangible objectives that contributed to achieving the overall. These are repeated below for ease of reference;

- i) Identify current theoretical and industrial challenges for design engineering information reuse.
- ii) Define an industrial case study that includes a typical large heterogeneous collection of data and information resource for design engineering.
- iii) Characterise the current difficulties facing design engineering practitioners in the case study.
- iv) Identify key document content (information elements) and, in particular, the role of visual representations in design engineering decisions.
- v) Describe information strategies, patterns of use and thinking processes used by design engineers in the case study.
- vi) Recommend and evaluate approaches for improving practice.

The earlier objectives for this research have sought to characterise further the theoretical and industrial limitations and challenges for the reuse of document information contents, with particular focus upon the industrial design engineering concerns. The background for this problems addressed by this research being the prolific nature of historical document collection that is prevalent across design engineering for storing and collating important historical design knowledge.

Objective 1, is achieved by the literature reviewed in Chapter 2 and the outlined industrial case described in Chapter 4, contributing the industrial document content utilisation challenges and the current industrial limitations.

For **Objective 2**, has been provided in Chapter 4 with a comprehensive description of the industrial case. This has provided detail of the current industrial challenges for in-service design engineering, outlined any industrial research limitations and elicited typical document information content detail. This has also provided the work based scenarios required to conduct the empirical investigations for this thesis. This industrial case and the literature describing strategies from the to overcome these issues from theoretical decision making and cognitive science research methods have built upon this to achieve **Objective 3** Appendix 6 outlining the state of the art challenges and the feasibility studies for industrial document re-use has further characterised objective 3. The additional detail provided in the in-service questionnaire has characterised the time constrained problem further for design engineering document information re-use.

Each of the empirical research studies has contributed to **Objective 4** including the development of the original document re-use issues to the importance of the visual

information elements and later eliciting the “confidence” need of design engineers for utilising visual information types.

Objective 5 has been addressed by the first two empirical studies in the questionnaire that described the initial outline of informative elements in document information and then in the storyboard workshops where rich detail is added to be able to elicit common document information utilisation patterns and their importance in document reuse strategies.

The significant value of design engineering visual information elements of documents and validation of its importance in the evaluations in Chapter 7 & 8 have illustrated the broader applicability of the visual information element utilisation premise in a wider context for document information reuse and hence contributing to the final **Objective 6**. This and the visual propensity of human users to support cognitive processing discussed in Chapter 2, section 2.3.7 suggests that the respective value of visual information content for explicit knowledge assets are concluded.

9.1.1 Summary

In summary, the combined efforts of the literature reviewed was to create both an understanding of the challenges and the potential for decision theory to further understand the cognitive processing underpinning design engineering information relevance decisions. Chapter 4 illustrates how these principles are embodied in the industrial case and for real world concerns; this also forms the basis for the research method in enabling enough understanding of the working practice to enable the researcher to create a working simulation for the basis of designing empirical studies. The data collected in Chapters 5 & 6 contribute to eliciting the patterns in document information utilisation and prioritising the decision stages and information needs of design engineers when discriminating between information sources. Chapter 7 has provided experimental validation for the important role of visual information content of design engineering resources and in Chapter 8 this is then compared to work that has already been conducted This has substantiated the hypothesis about the importance of visual information content of documents and substantiated its wider applicability to document information content in other domains.

Each of these objectives that have been met have contributed towards the overarching aim for this research and its achievements, thus the next section outlines the main contributions of this thesis to research literature and thus knowledge.

9.2 Contributions to Knowledge

The main contributions of this thesis to knowledge is the empirical evidence for the intuitive but important role that images have in making informed engineering design decisions and thus their respective high value in document information content.

This research has further identified the key challenges for design engineering information research is the rapid growth of resources and the complexity of the media formats that constitute information. It has also established that contributing to these issues is the current knowledge management trend to capture information without clear “reuse” purpose is significantly contributing to this unwieldy information growth. Other contributing factors are the trends raising pressure upon design engineering productivity, the heterogeneous nature of design engineering information resources and the technological difficulties in facilitating its automatic extraction for reuse.

In summary the main contributions of this thesis are:

- *Multi-stream data collection method for efficient industrial research for design engineering information interaction and practice.*
- *Conducted innovative and scientific data collection method for studying engineering design information processing to observe cognitive activity.*
- *Framework for developing design engineering information systems to expedite crucial decisions.*
- *Additional rich evidence for engineering design document information element utilisation patterns and critical need for visual information to facilitate informed decision making.*
- *Important role of visual information elements to mentally stimulate users and support "confident" information relevance discrimination from documents for design engineering tasks.*

The creation of a data collection method for the industrial experimentation in this thesis using Storyboards and multi-stream data capture is a novel research method that can be replicated in further design engineering cognitive research. The analysis and coding model developed in Chapter 6 presents an innovative approach for analysing design engineering information and decision process to be applied to future research. This framework for the capture of rich data and its analysis can be reused in its entirety as a valuable contribution to industrial design research methods.

9.3 Thesis Reflections

There are strengths and weaknesses for each and every research project and this section reflects upon the overall research approach and the strengths and weaknesses of the work in this thesis. These have emerged throughout the research process and although warrant discussion do not alter the validity of the findings of this thesis but contribute to the progression of rigorous scientific approaches for industrial research going forward.

In the literature for knowledge reuse it is evident that one of the challenges is the nature of knowledge capture and a need for the focus upon a specific reuse purpose. Adhering to this specific purpose for the collection of data about the latter stages of design engineering document utilisation means that the findings may be deemed highly specific to the domain for which they have been collected. Mitigating this is the body of evidence from the literature surrounding the propensity of human users for visual information thus supporting its wider applicability to document information.

In Chapter 8, section 8.1, the work of other theorists in the utilisation of document content are highlighted. The strength of this work is that the content audits were collected in industrial situ, hence their validity is maintained. However, the decomposition of such documents has been shown to be possible in a multitude of schemas and illustrates further complexity and heterogeneity of the information composition. Further, we highlight that the findings are based upon one such decomposition of information or media; the outcomes of this research potentially could be reliant upon the decomposition schemas and reliant upon the sub categories as in the audits conducted in Chapter 4. However, a simplistic approach has been taken to mitigate for this in evaluation by comparing textual elements to the visual information elements, this means that any sub decomposition should not be influential to any result. Such limitations to the experimental findings of this research are also in the limitations of applying decision making theory, hence the representative value of one approach is illustrated in this work, potential benefit could be sought from further psychology principles applied for encoding the data collected.

Conducting industrial research presents challenges such as the sampling issues identified in Chapter 6 and these naturally influence the research results. Reflecting upon the results of the questionnaire, the perspectives of off-site or contracted

design engineers was not possible, this is a limitation. Similarly the international nature of the teams canvassed also introduces different working practices and potential process interpretation issues. However, the value of collecting data in a real world scenario speaks for itself as it presents realistic findings that are directly applicable to the industries being supported. It also means that similar to the cognitive study methods the work is very extensive and based on very full and rich data sources.

The methods utilised for the experiments presented in this thesis included multi-stream data collection producing highly qualitative and incredibly rich results. To capitalise upon this type of data collection more qualitative approaches to data analysis could be employed. However research projects of this type would need much more time than is available for mixed methods research and future research could focus upon this aspect, using similar approaches to the cognitive work analysis. This is particularly important if design research is to capitalise upon the human information interaction knowledge base.

Finally it is important to mention the rapidly changing environment of organisations particularly for design engineering that maintains its competitive edge by staying at the forefront of technological developments. Technologies are ever rapidly changing and for the findings outlined in Appendix 6, rapid advancements mean that this needs to be regularly reviewed to ensure that document utilisation capability also stays at the forefront of technical capability.

9.4 Future Work for Design Engineering Research

The findings of this research are a valuable basis for the development of further design engineering research. There are a number of ways in which this research could potentially be extended to design support for the utilisation of document information more efficiently and effectively. It is also possible that the principles elicited are of real benefit for the application to wider design engineering research such as the development of knowledge reuse.

Two areas in particular stand out as critical research avenues for using the findings of this research in the engineering design domain; these are discussed in the subsections that follow.

9.4.1 Decision Utilisation Patterns and Visual Elements for Reuse Efficiency

Distinct document information element patterns are elicited in the findings of Chapter 6 of this work and in Chapter 7, evidence of the capability of visual elements is provided. Developing applications that capitalise upon these aspects of document information for more efficient reuse of information and knowledge are critical for design engineering industries to remain competitive in providing products and services. An example of the possibilities within in-service design document information search and utilising visual elements of documents and the content usage patterns is demonstrated in Chapter 8.

As previously stated, one of the visions for this research is the theoretical basis for providing more effective document information support for design engineering teams. Notwithstanding the current technical limitations for automated document content applications the design of tools and technologies that use information usage patterns and the historic visual contents should be a priority for developing knowledge support. Technical artificial intelligence methods present potential for the development of push technologies that use the patterns in document information utilisation to efficiently push or prioritise the critical information that is needed for making decisions (such as subdocument contents) and thus results from information search and retrieval technologies need to present this to human users. This combined with the reuse of the visual information elements in any summarised

document presentations are important aspects to include in design engineering information interventions.

It is also possible that investigating extended patterns in information utilisation or the information “berrypicking” trails that we can collect from across the design engineering lifecycle stages could offer insight into a much wider information provision and need for product development.. This would require similar Storyboarding research methods to be employed to research the differing stages of the product lifecycle, the information and decision making and the cognitive underpinning process. This could contribute considerably to a bigger information provision picture for the entire product lifecycle.

9.4.2 Visual Document Representations for Improved Transfer and Quality

The second application would be the creation of methods to enable the presentation of graphical or visual information standards such as the infographic document presentations suggested in chapter 8. The value of the development and creation of such standardised document information is already evaluated within industry as described hence its implementations are a current priority for in-service design method and tools. This presents an approach to document information utilisation that overcomes current technical challenges..

The evaluation of such infographics and the potential for developing standards of quality for knowledge representation and its respective transfer are illustrated in point Chapter 8. This extension of information presentation and quality of the transfer of knowledge could benefit the study of both accumulation of experience and the transfer of expertise between design engineering teams and for the capture of expert team members. This presents potential for reduced time for information viewing from reduced document information and the better quality of knowledge to be captured and transferred for experiential learning. There is further application of the principles for document information in a much broader sense for research and technical application. This is the topic of the final section presented in this thesis.

9.5 Wider Research Opportunity

Finally it remains to discuss the application of the methods in this thesis for repeating and comparing the studies for other document information resources.

Similarity between the complex domains of design engineering information processing has been made to other domains that also rely on comprehensive information collection and utilisation such as medical information need or the use of document collections for library services. These domains could benefit from the application of the visual principles for decision making found in this thesis and the elicitation of document information utilisation patterns specific to the users of such complex information resources.

Repeating the Storyboarding data collection methods employed in this research for wider cognitive work analysis would be valuable to elicit the rich information utilisation patterns of medical teams or library service users. The repeatability of these methods in wider research presents opportunity to compare the information utilisation patterns and to evaluate the visual information value in decision making further afield to create standard frameworks for the presentation of historic document information content for wider audiences.

In Chapter 8, the comparable benefits of the method for wider domains is presented as also discussed above. The potential for further industrial and practical investigation should be combined with the technical efforts in a wider context such as outlined in Appendix 6, to develop similar technical approaches from any information frameworks. There capitalisation of further pattern identification and use of further human information interaction research methods could be used to

develop cognitive systems analysis techniques for the storyboard workshop method.

In summary, this thesis has found evidence that is applicable not only to design engineering document information collections, but also wider afield. Finally it is important to note that keeping abreast of technological capability in the rapidly changing design engineering environments is critical for the evolution of information systems for design engineering. The technical challenges for organisational researchers to continue to capitalise upon document information content remains. Thus, the value and use of this research for developing document information reuse support is critical.

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Table of Appendices

Appendix Number	Appendix Name
Appendix 1	Engineer Information Audits
Appendix 2	Sample Questionnaire
Appendix 3	Preliminary Questionnaire Amendments
Appendix 4	Questionnaire Results
Appendix 5	Multi-Stream Storyboard Results
Appendix 6	Technological Review and Feasibility Studies

Appendix 1 - Engineer Information Audits (2012)

Information Source	Information Type
A380 Checkstress Folders	Checkstress
SFS: System	MRB/ESG - Justifications
P:Drive	Design Standards (material types)
Todon server in France	Fastener Standards (thickness)
AIRDOC	Aircraft Details
Shared Storage Drives	Previous Cases
Repair Workfiles	Policies
Copy of Justification	Guidelines
Technical Description	Test Lives
Previous Repair Cases	EF2
SRM/MPD/AMM	Safe Life Certification
ALS Part 1 & Part 2	Damage Description
EDS (SIR)	Repair Description
ZAMIZ	Digital Photos
FESPS	Damage Reports
Local Tools (GEnSF GenINFO)	Telephone Calls
ICARUS	Direct Visual Via Video Link
DAEDALUS	Teleconference
Test Findings	Checkstress
CPD Documents/Spreadsheets	Methods and Tools Used for Stress
Repair Instructions	Technical Reports
(Specs) DOCMASTER	Material Data
Formal Methods (SIMs, AM, M, P)	Faster Data
Technical Reports	Processes
Generics	Text Reference to Identify Checkstress Document
Generic Repair Instructions	ICARUS Document Reference Numbers
Loads Data	Repair Instruction Reference Numbers
FEM Models and Results/FESPS	Hyper Linked Documents to access directly from store
ACD's	Previous Cases
SRM - Weight Variants by MSN	Expertise from Chief Engineers
Distributed Email from Expert - Checkstress spreadsheet	CAD Data
Applicable MOD (Data Pack) from Design	Photograph
Data Packs (Design Collated Data)	
Damage Reports (Airline Email)	
Drawings from Historic Cases	
Drawings of Damage Location (from ZAMIZ & Other)	
People Portal	
Standard Fastener Data	
DocMaster	
Rock - Fatigue Document Hyperlinks re References	
Expert Team Member - Re Long Range Stress and Fatigue Questions	
Technical Report Ref LR57RP1023904	
Static Strength Justification	
Weight Variants	
Modifications (MODS by Aircraft)	
Long Range Aircraft info A340/A330 for stress/repair	
Help Guide LR57RP1023904	
Superdome>Fatigue and Static Info	

Unix Based Server	
Stress Methods and Tools	
Chief Engineers	
CPP's S/A W/B L/R A380	
Experts i.e Bearings, M & P	
M & P for material process	
EASA AD via Google	
I-share	
E-Mail	
Google	
Airbus Portal	
Daculas	
DPDS	
Primes	
ACC	
AMM	
CMM	
AIRTAC/Emails	
Airbus World/AOLS	
CDL	
RMT Communication Trace Emails and References	
ACD - Aircraft Certification Document for Checkstress Reference>x:drive ACD Folder	
SIR - stress Information respository	
My Doc "Microfilms"	
CAD Model or 3D Xml if cannot access drawings	
EDS	
Validated Documents	
EDMS	
Airdoc	
Technical Records Facility	
Technical Library	
Certified Documents	
Technical Manuals - IPC/SRM/DRM/PMS	
Air Nav	
Copedoc	
ICC	
ZAMIZ/Windchill drawings	
Primes	
IXOS Archive	
Catia/CADDS 5	
ICY codes/Trevor Pierpont ICY info	
Composites (inc FPQ & 20 A1)	
Fasteners Inc Alts	
Plastic Injection Mouldling AP2020	
SAP/PEGS Raw Matl Catalogue	
Docmaster & Standards Department	
Alternative Materials	
Concessions	
S80 Procedures Scamp	
SAP Worklist	
Casting and Forgings	
Aircraft Information Spreadsheet	

Pre Defined Solutions	
SAP(Sari etc)	
DQN & approval	
Welding	
Madame	
Production Procurement Work Packages	
Reading Drawings	
Tooling Engineer (see separate matrix)	
S80 stores nationwide	
STS System	
Material Masters	
S80 SAP planning	
Quality Inc Class Parts	
Supplier Instructions ASI	
DPDS	
Harmonisation	
CCLE	
TRS	
Data Exchange	
Loft Scanning	
Suffixs	
Repair Planning	
Supe@airworld	
DMS	
SAP A400M process plannings	
Training courses attended	
Suppliers Visits	
Titanium Forming	
Broughton Visit	
Toulouse Visit	
Hamburg Visit	
GKN Filton	
PMS System	
Aircraft MSN numbers	
S80 SAP BOMs	
A300/A310 eWQN System/Tracker	
CARS	
DG System	
Design Product Handbooks	
Standards Department	
M & P materials and processes	
DMU	
PEGS via SAP	
Pegs (B&F)	

Appendix 2 - Sample Questionnaire

Research & Questionnaire Introduction

First I must introduce myself, my name is Emily Carey and I am a researcher conducting a project in conjunction with Airbus and the University of Bath. The work I have been undertaking is jointly funded by the EPSRC (Engineering & Physical Sciences Research Council), University of Bath and Airbus.

What am I doing?

The work you undertake requires the use of a multitude of complex information from differing sources. My research aims to create new tools and techniques to help you access and use the information you require.

My current focus is on the reuse of learnings from the historic document collections relating to in-service repairs. As part of this, I'd like to gain a better understanding of how you might view or understand their content when undertaking new repairs.

How can you help?

I've designed a short questionnaire, which shouldn't take more than 15-20 minutes to complete. The questionnaire broadly follows the process you follow to find and use supporting design repair information. It is designed to help me understand what strategies you use to find and assess information, and what types of information are most useful to you. It is not an assessment of your work and there are no 'right' answers. Please be assured that any responses collected from you as part of this research will be treated in the strictest confidence, in alignment with the confidentiality agreement and framework contract between Airbus and the University of Bath. Any responses to this questionnaire will be made anonymous and any identifying email will be deleted from my inbox upon receipt. If results are published (for example, in an academic journal), they will be aggregated and anonymised in such a way that individuals or teams are not identifiable. Further, the results will be vetted by Airbus before publication.



General:

1. Please indicate your location?	Filton	Wichita
	Offsite	
2. Please indicate if you are?	Weekday Team	Weekend Team
3. Please indicate what you consider to be your main expertise?	Design	Stress
	Fatigue	Other (Please state)
4. Please indicate the number of years' experience you have in In-Service?	0-2 years	2-5 years
	5-10 years	10+ years
5. Please indicate the number of years' prior experience you have in engineering or design?	0-2 years	2-5 years
	5-10 years	10+ years
6. In the main would you most frequently search or browse for information to support your In-service work?	Search <i>(predominantly enter keywords)</i>	Browse <i>(view a number of pages)</i>
7. Why do you open a historic repair PDF case(s) to find? <i>(Please tick all that apply)</i>	Supporting or similar design case	Additional repairs on an aircraft
	Other (Please state)	
8. Thinking of historic repair case information, does the time taken to find and access it limit its use?	Yes	No
9. Do you have additional reasons for not using historic repair case information?	(If yes please state)	
10. How could In-Service information systems be improved?	(Please state)	

Current Practice:

1. Thinking of each daily repair you undertake, how much time do you spend searching for a case in Daedalus?	0-2 minutes	2-5 minutes	
	5-10 minutes	10+ minutes	
2. Thinking only of the Daedalus results list presented to you			
a) How long does it take you to shortlist which cases might be most suitable?	0-2 minutes	2-5 minutes	
	5-10 minutes	10+ minutes	
b) What Daedalus text fields would you use to make the decision that a case is relevant or irrelevant to your current repair?	Case Relevance	<u>Relevant</u>	<u>Irrelevant</u>
	ATA Number		
	Airline		
	Repair In-Date		
	Title Description		
	MSN Number		
	Engineer		
	Aircraft Type		
Other (Please state)			

c) Do you predominantly seek to find a similar case by eliminating those that are irrelevant first?	Yes	No
3. Thinking again only of one Daedalus search result list		
a) On average how many historic cases would you open before finding the information you require?	0 cases	1 case
	2-5 cases	5-10 cases
b) For each historic case opened, on average how much time would you spend browsing it?	0-2 minutes	2-5 minutes
	5-10 minutes	10+ minutes
4. For each repair case you open, how quickly can you determine that it is not relevant to support your current task?	0-2 minutes	2-5 minutes
	5-10 minutes	10+ minutes
5. For each repair case opened, how quickly can you identify that it is relevant to support your current task?	0-2 minutes	2-5 minutes
	5-10 minutes	10+ minutes
6. For each repair case you undertake		
a) How many times do you need to refer to a historic case to make a decision upon its relevance ?	Never	Once
	Twice	More Often
b) On average, how many times might you refer to it to complete your current repair task?	Never	Once
	Twice	More Often
7. Thinking about a specific historic repair case, (that may or may not be relevant), do you seek information elsewhere to consider its relevance to your current task?	Yes	No
	(If yes please state)	
8. Thinking about the Daedalus results list only, before you have opened a historic case please briefly describe what you might understand about the repair task?		

PDF Files & Contents:

	<i>Importance Rank</i>	<i>High</i>	<i>Medium</i>	<i>Low</i>
1. Thinking about when you first open a PDF case what strategies might you use to aid you?	Scrolling through a number of pages			
	Estimate location of detail and jump to page			
	View page thumbnails to determine contents			
	Utilise bookmarks to jump Images			
	Utilise bookmarks to jump to Sub-Document			
	View Cover Sheet Text Details Only			
	Other (Please state)			
	2. Thinking about when you first open a PDF case, if it does not contain the information you require, what might you do next?	<i>Importance Rank</i>	<i>High</i>	<i>Medium</i>
Question a colleague				
View another PDF from Daedalus repair case list				
Search Daedalus using alternative text term				
Search using another internal Airbus system				
Search using an external system				
Design without using similar supporting case				
Other (Please state)				

<p>3. Thinking about when you first open a PDF case, what might you use to</p> <p>a) Make a decision if it is suitable as a supporting repair case?</p>	Importance Rank		<u>High</u>	<u>Medium</u>	<u>Low</u>
	Airdocs Title Description				
	Damage Images				
	Repair Drawings				
	Engineers Name				
	Sub-Document Names				
	Authorising Signatures				
	Repair Location Sketch				
	Repair Location CAD Drawing				
	Images with Annotations				
	Evidence of Testing or Measurements				
	Approval Summary				
	Supporting Calculations				
Other (Please state)					
<p>b) Most useful to understand a repair fully E.g. to apply it to your current repair task?</p>	Importance Rank		<u>High</u>	<u>Medium</u>	<u>Low</u>
	Airdocs Title Description				
	Damage Images				
	Repair Drawings				
	Engineers Name				
	Sub-Document Names				
	Authorising Signatures				
	Repair Location Sketch				
	Repair Location CAD Drawing				
	Images with Annotations				
	Evidence of Testing or Measurements				
	Approval Summary				
	Supporting Calculations				
Other (Please state)					
<p>c) How long might you view/read a document for to be able to understand a historic PDF's repair detail fully?</p>	0-2 minutes		2-5 minutes		
	5-10 minutes		10+ minutes		
<p>4. When viewing a PDF case do you,</p> <p>a) Make a decision upon its relevance?</p> <p>b) Defer the decision and view another case?</p> <p>c) Defer the decision and view multiple cases to compare?</p> <p>d) Other (please state)?</p>					
<p>5. It has been indicated that PDF cases are categorised into large or small. What would you consider to be (Please state a number of pages)</p> <p>a) A large case?</p> <p>b) A small case?</p>					
<p>6. Thinking about a large PDF case, on average, how many pages of a repair case might you need to read/view to understand it fully? (Please state a number of pages)</p>					
<p>7. Thinking about a small PDF case, on average, how many pages of a repair case might you need to read/view to understand it fully? (Please state a number of pages)</p>					

8. Thinking about when you first view a PDF case, a) Which document types are most important to you for understanding a historic repair case fully?	Importance Rank	<u>High</u>	<u>Medium</u>	<u>Low</u>
	Airdocs Cover Sheet			
	Damage Report			
	Corresponding Emails			
	Technical Disposition(s)			
	Repair Instruction(s)			
	Repair Approval Document(s)			
	Service Item Summary Sheet(s)			
	Technical Approval Sheet(s)			
	Stress & Fatigue Approval Sheet(s)			
	Supporting Document(s) or Calculation(s)			
	Other (Please state)			
b) Which elements contained in a document are most important to you to support understanding a historic repair case fully?	Importance Rank	<u>High</u>	<u>Medium</u>	<u>Low</u>
	Photographs			
	Images			
	Correspondence Text (Email/Fax)			
	Calculations			
	Handwritten note(s) or Sketch			
	Diagrams			
	Tables (of measurements)			
	Text			
	Signature(s)			
	Formal CAD Drawing			
	Other (Please state)			
9. Thinking about the strategies that are available to you to navigate and view the contents of documents, please indicate from the list those that are most useful?	Importance Rank	<u>High</u>	<u>Medium</u>	<u>Low</u>
	Print entire document			
	Print sub-documents/Parts of document			
	Use hyperlinks to sub-documents by name			
	Use hyperlinks to elements e.g. photographs			
	Read more of the document			
	Skim document for similar information			
	Skim document for dissimilar information			
Other (Please state)				
10. Thinking about the future use of historic PDF cases, please list three suggestions to improve how you understand them?	1.			
	2.			
	3.			
11. If you would consider participating in future research studies please add an email contact address here.				

Please send your responses to this questionnaire by Friday 14th February 2014 using the "submit" button below. A confirmation box will appear requesting confirmation to use your current e-mail account. Alternatively you can save this questionnaire and attach it to an e-mail, sending it to emcc20@bath.ac.uk (alternative e-mail emily.carey@airbus.com). If you have any queries please e-mail Emily Carey at either address shown above.

Pilot Study Collated Comments

1. Search & Browse definitions not that clear – so makes it difficult to answer the questions
2. Weekend & Weekday question might need to be added to classify responses more accurately
3. It has become apparent that the two uses cases or scenarios effected for this questionnaire as “When determining if a case is irrelevant” & “When determining a case is relevant” need also be extended to include a four matrix scenario of “In the event of accessing a large PDF case” & “In the event of accessing a shorter PDF case”. Need to consider the effect this has upon our questions & results.
4. Wording for Question 1 & 2 needs to be a collated question, if querying in Wichita also then response might be better placed as “Offsite”, “Filton” & “Wichita”. This will not give the contract worked upon but will split for working practices – Those Sitec in Filton will work the same as those Airbus employees so will not separate the abstract between working conduct & site practices effectively
5. Part 1: Question 3: Need to clarify and identify if 0 cases makes sense as an option.
6. Part 1: Question 6: Would state average range as purely because there is a possible case dependent. Cases that are smaller naturally require less reading & larger cases are often more detailed requiring more in depth analysis.
7. Part 1: Question 6: Potentially could alternatively split into two questions.
8. Part 1: Question 9: Might be a similar scenario to Question 6 and thus last two points may apply. Suggestion was that “Never” might be removed as is irrelevant.
9. Part 3: Question 11: Re wording might be required for the strategies list as “Add Link” is unclear in meaning.
10. Part 3: Question 4: It was suggested that strategies listed do not include the option for “print off” case which is a common alternative, or to “print off a number of pages”.
11. Part 3: Question 7: This could also be subject to the case & size dependency issue raised for Part 1: Questions 6 & 9. Could overcome by rewording as, “On average”, how many pages are read? Results might not reflect what we want to record.
12. Part 3: Question 8: The difference between question 8 & 6 needs to be clear and for the results to be kept differently.
13. Part 3: Question 6: Needs to be clearer as currently is ambiguous due to similarity to other questions. Should read “Upon first accessing a case file...”
14. Part 3: Question 3 & 6: Current ambiguity is between purposes of question scenario. Need t create clarity when questioning between file discrimination & understanding complete content of file. The idea of browsing or searching for content becomes apparent.
15. Potential for adding in initial opening paragraph to lead difference in browse & search within their department as there is currently little understanding within the engineer cohort.
16. Part 1: Question 6: Definition of terms location was not prominent enough – a glossary would have been better. Setting the scene with these definitions clarified much of the latter questions also.
17. Part 2: Question 1: Answer to this question depends upon the occasion. (This comment was a little unclear).
18. Part 2: Question 8 & latter ranked questions: The ranking system forces there to be hierarchical ordering to the value of the terms. It makes more sense to order the items using

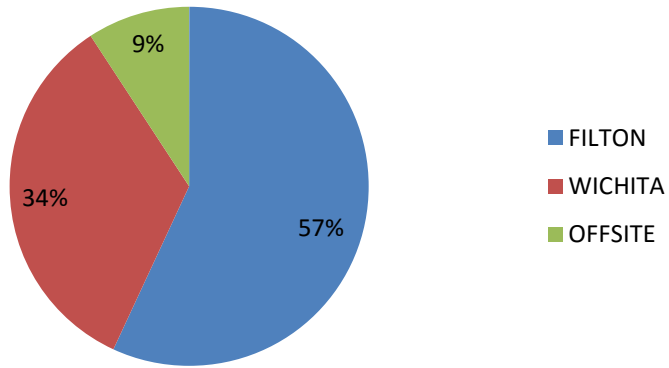
categories as in most cases the value of the items is the same and they are used in conjunction with one another.

19. Part 3: Question 3: Ranking system could look somewhat different and use the categorical selection of “All Important”, “Nice to Have” & “Not Important”.
20. Part 3: Question 3: Was deemed to be complex to complete due to not having required categories.
21. Part 3: Question 3 & 5: Need to be clear with engineers and state that they are inverse situations from each other to make it clear how to complete them.
22. Part 3: Question 7: Possible to rank a %age of use rather than no of pages as often this is relative to the size of the file being accessed. For example if it is a 10 page file then only 3 may be required. If it is a 150 page file then 50+ may be required to be read.
23. Part 3: Question 10: Category for emails doesn’t make sense as there is more formal correspondence than emailed correspondence; otherwise the files are reduced down.
24. Part 3: Question 3 & 5, 5 & 10: Wording between these needs to be distinguishable & consistent for questioned to understand them.

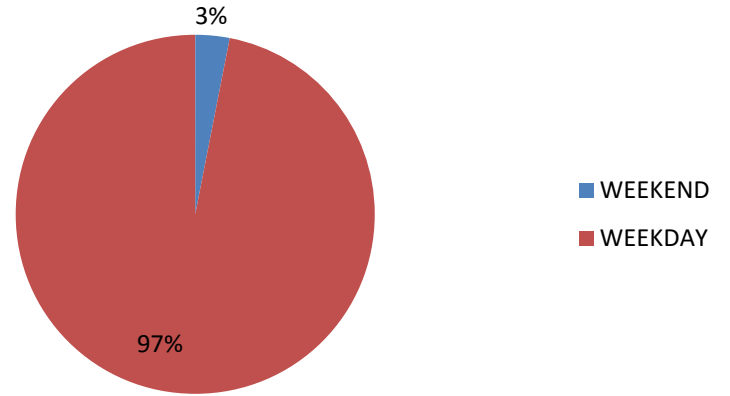
In-Service Questionnaire Analysis

Emily Carey April 2014

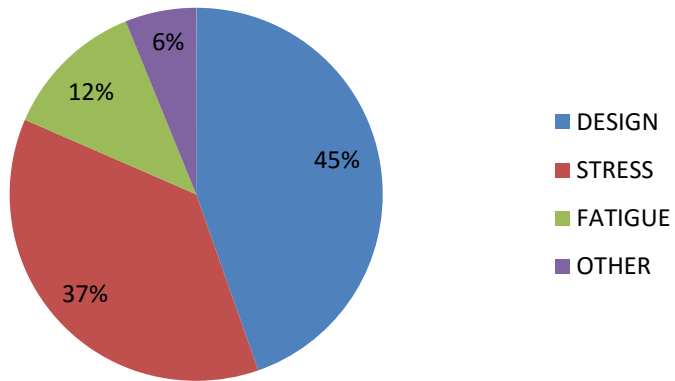
Respondent Location



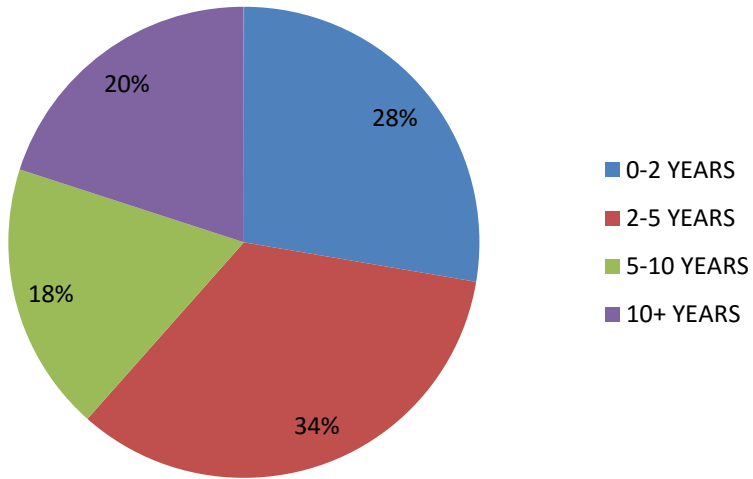
Respondent Working Pattern



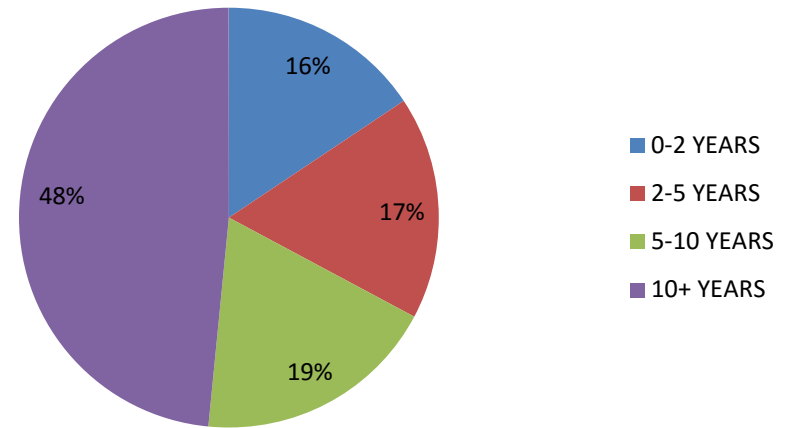
Respondent Expertise



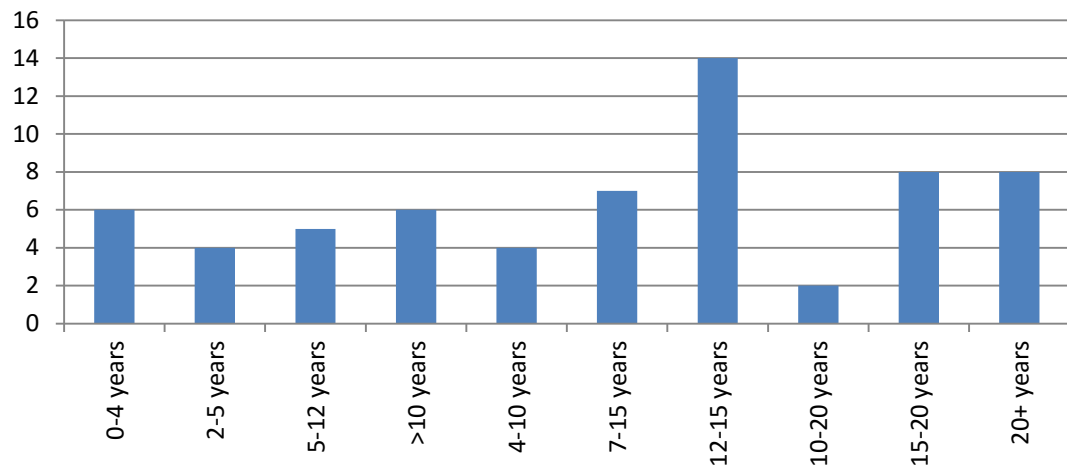
In-Service Experience



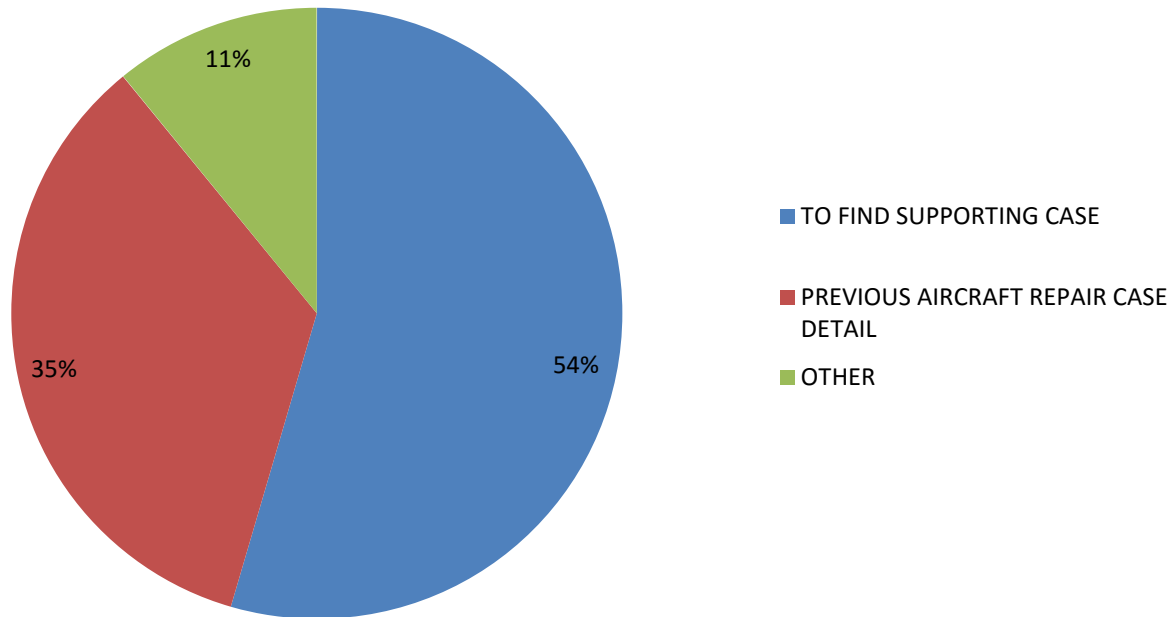
Prior Design or Engineering Experience



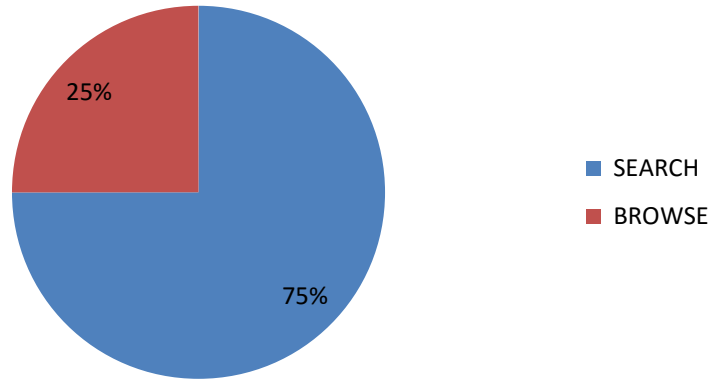
Number of Respondents Experience



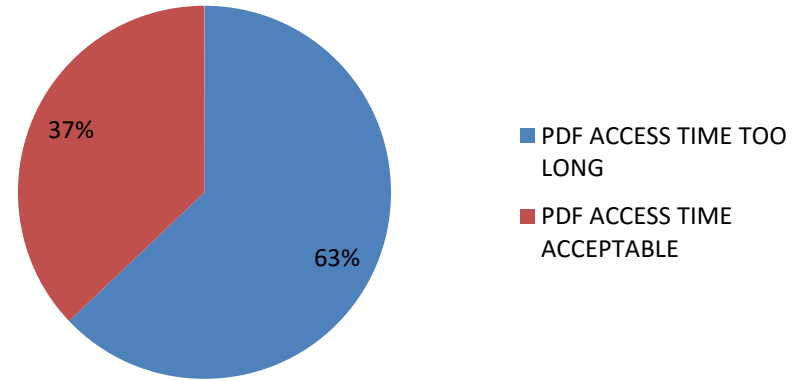
Purpose for Reuse of Historic Repair



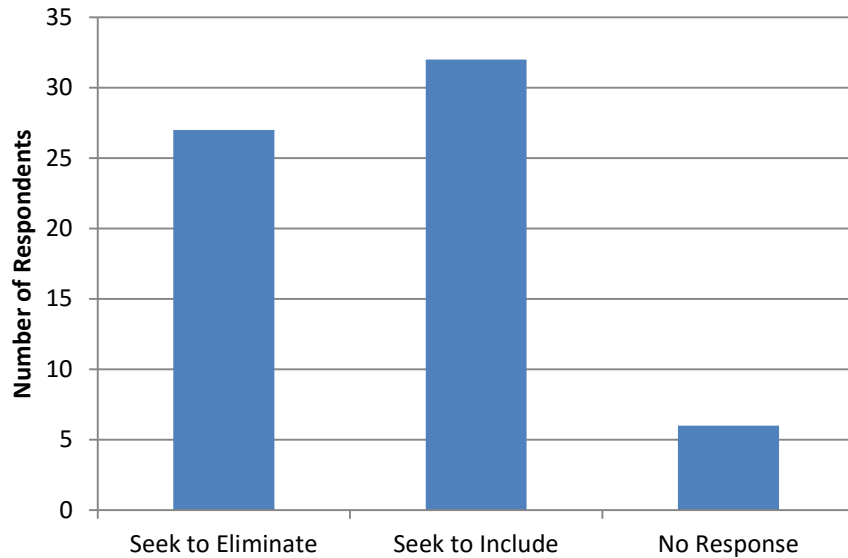
Percieved Information Practices



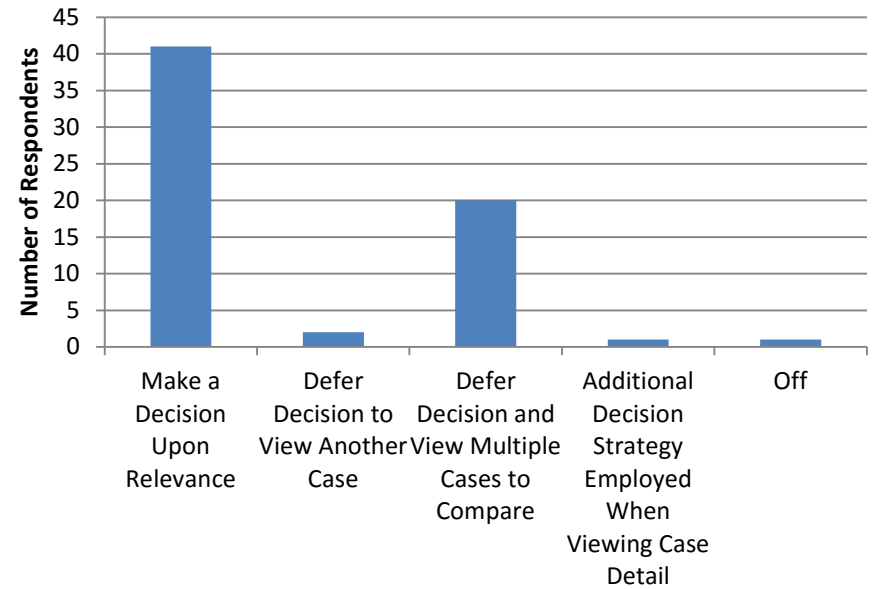
PDF Access Perception



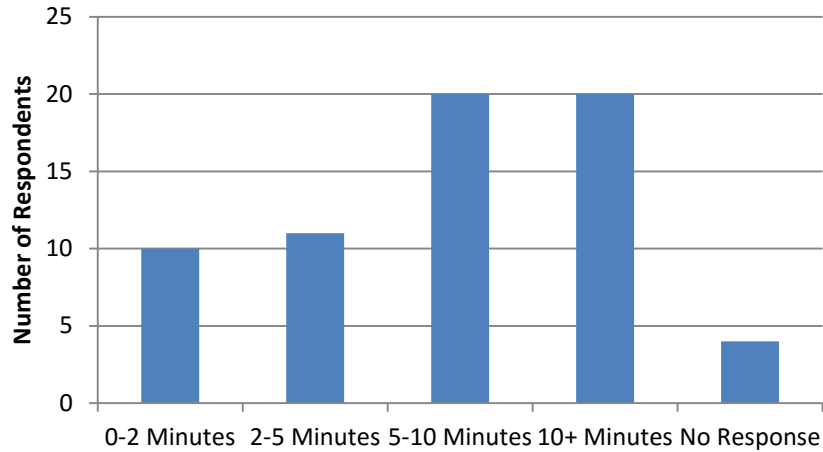
Search Perception



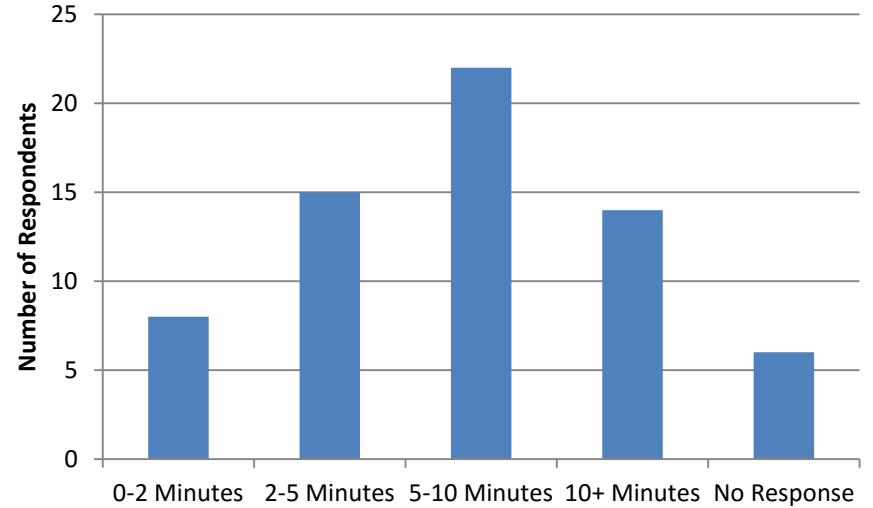
Strategy for PDF Decision Making



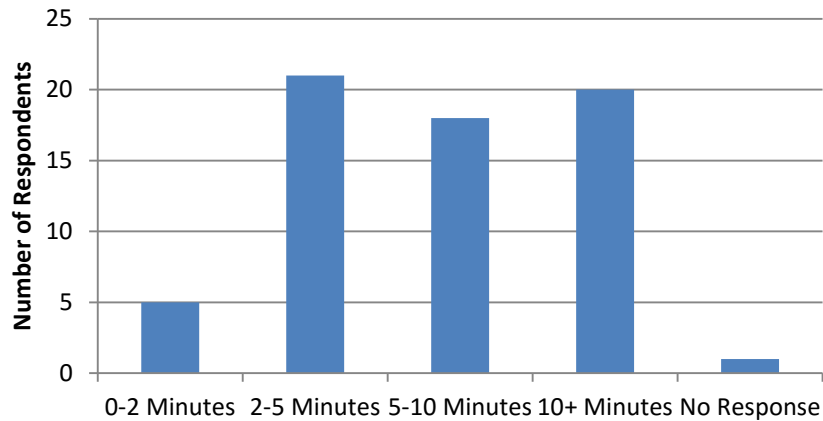
Time Spent Per Case Searching Daedalus



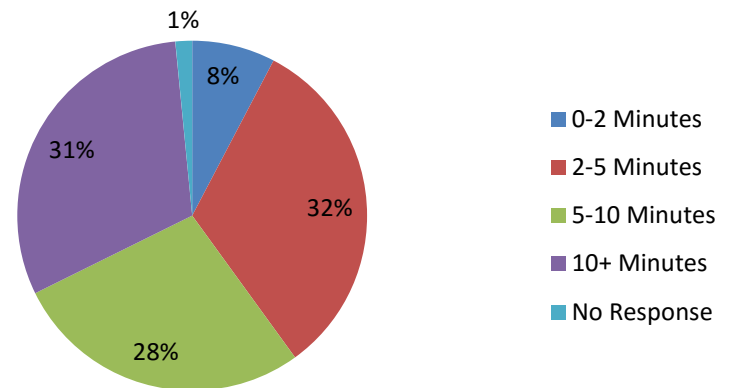
Time Spent Shortlisting in Daedalus



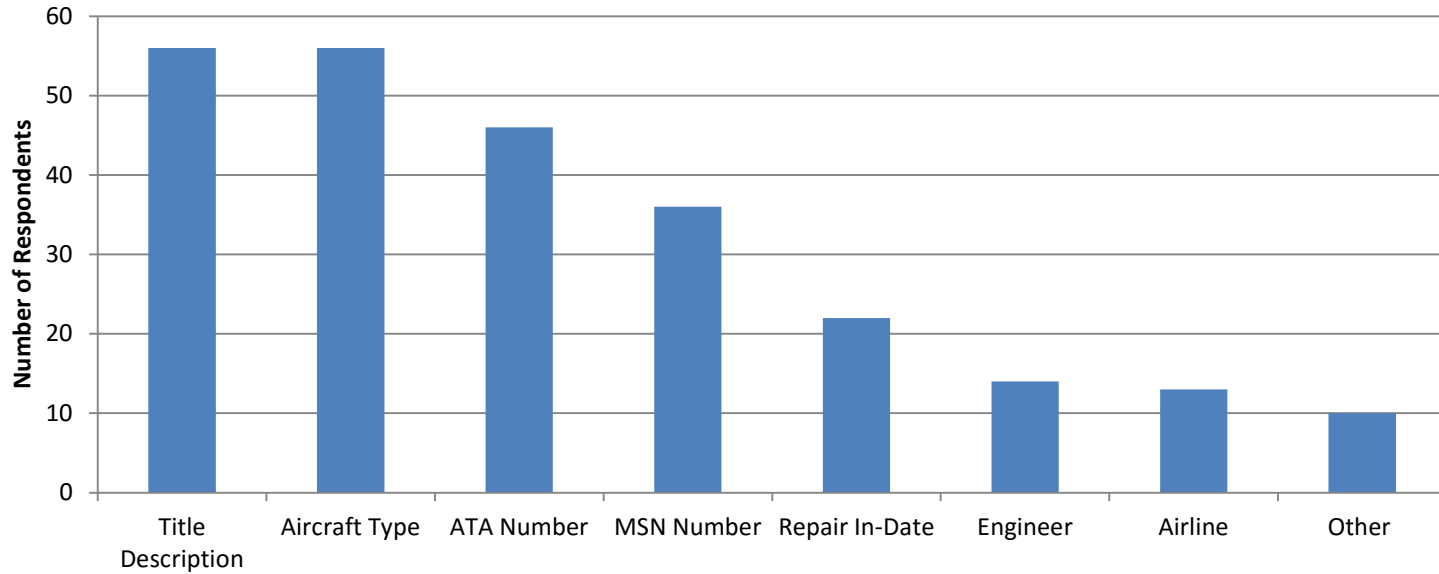
Time Taken to Understand Repair PDF Fully



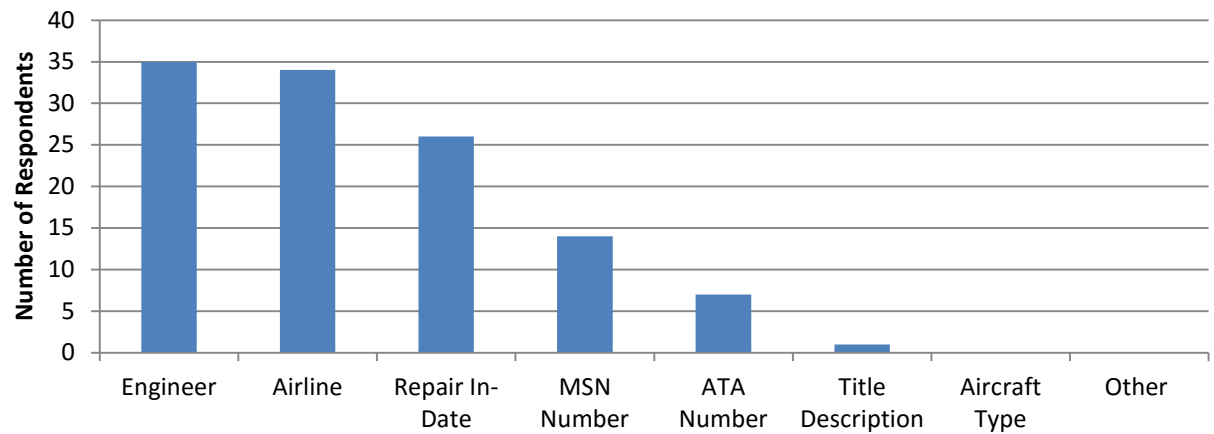
Time Taken to Understand PDF Repair Fully



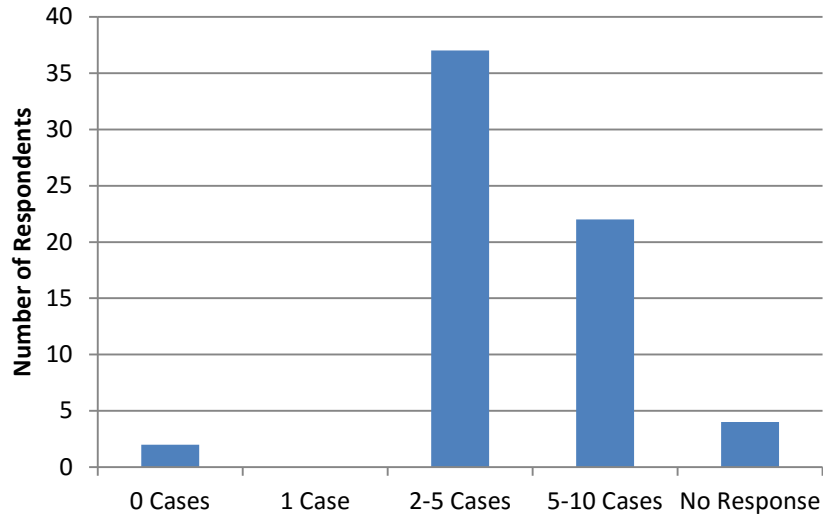
Daedalus Fields Indicative of Relevance



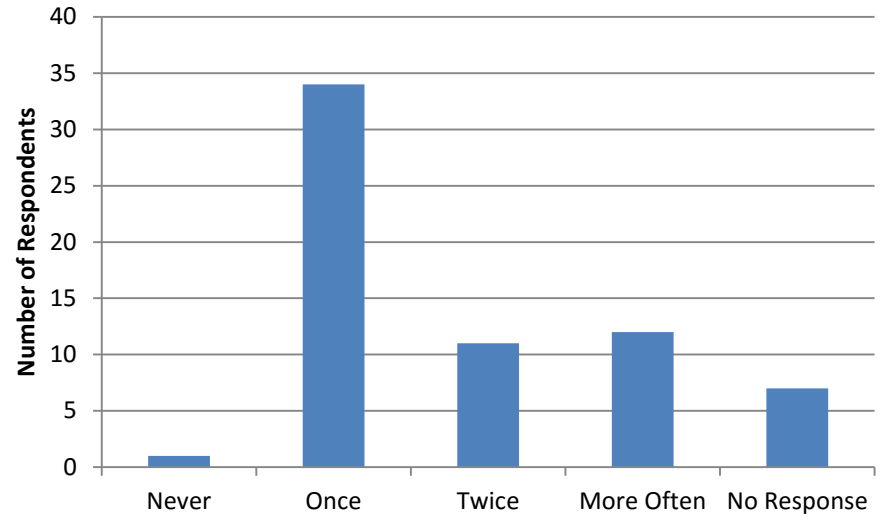
Daedalus Fields Indicative of Irrelevance



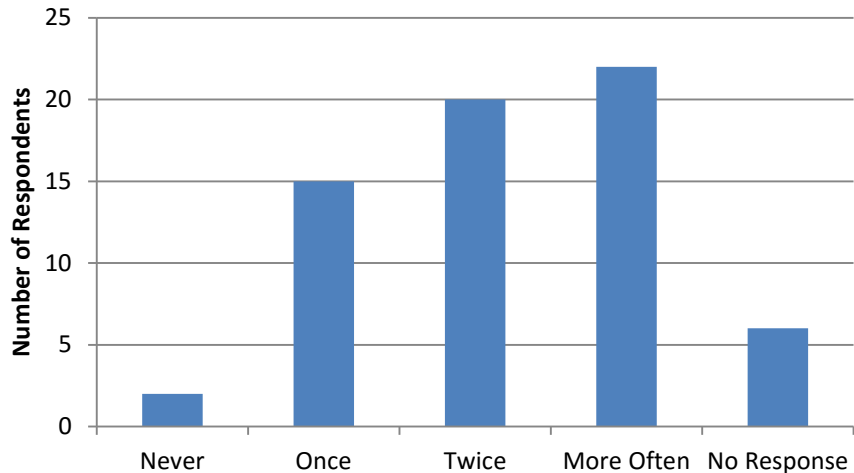
Average Number of Cases Opened Per Repair



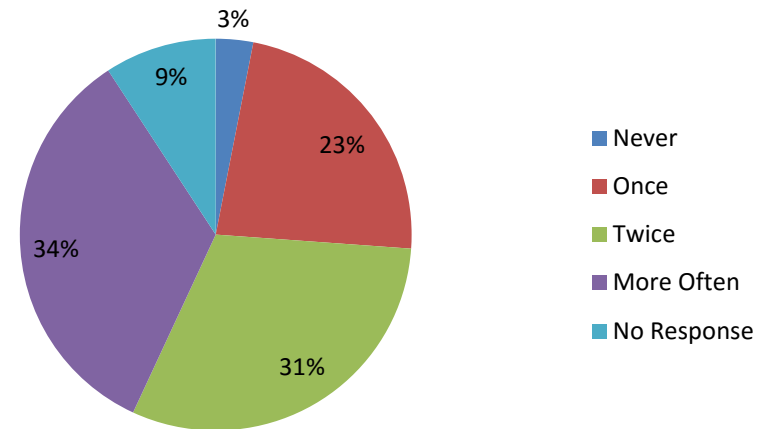
No of Times PDF Viewed to Determine Relevance



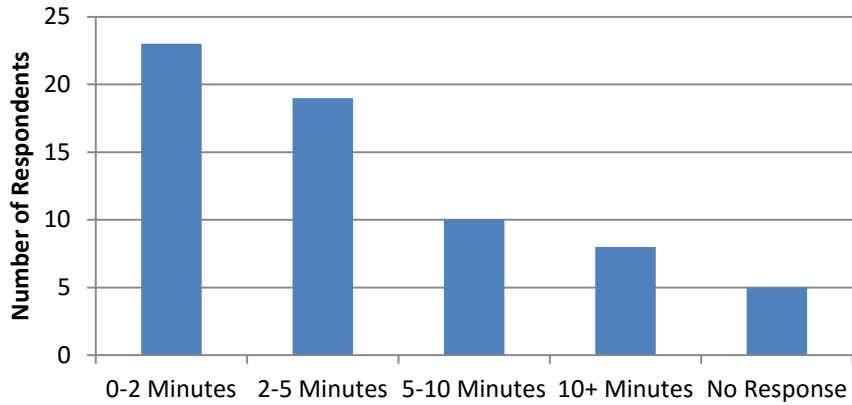
No of Times PDF Viewed to Complete Repair



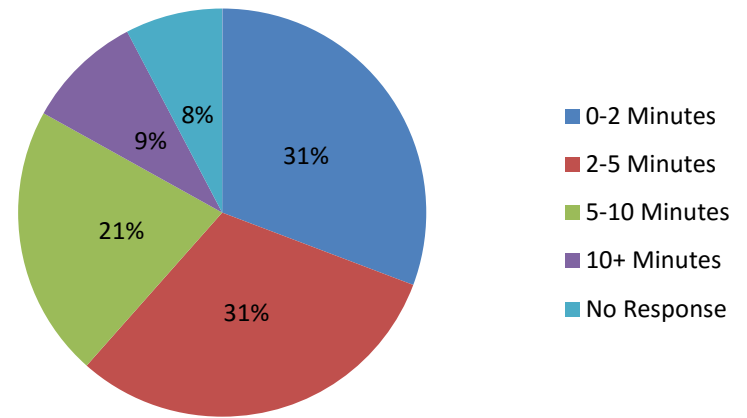
Number of Times PDF Viewed Per Repair



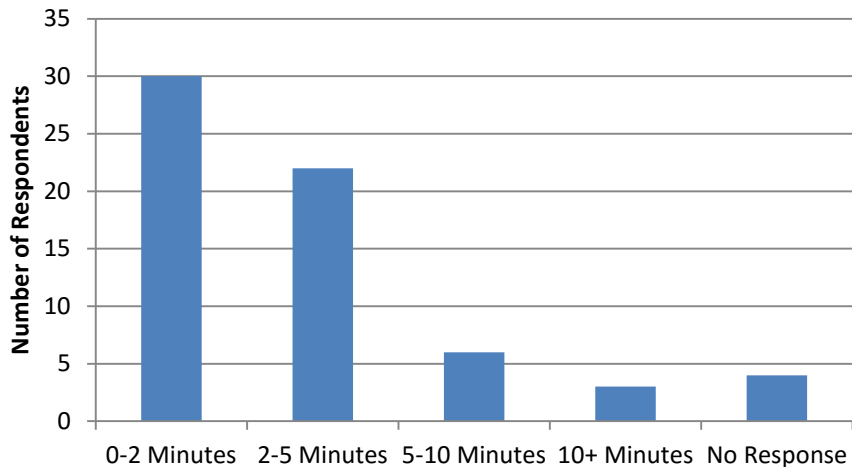
Average Time Spent Viewing Each Case Opened



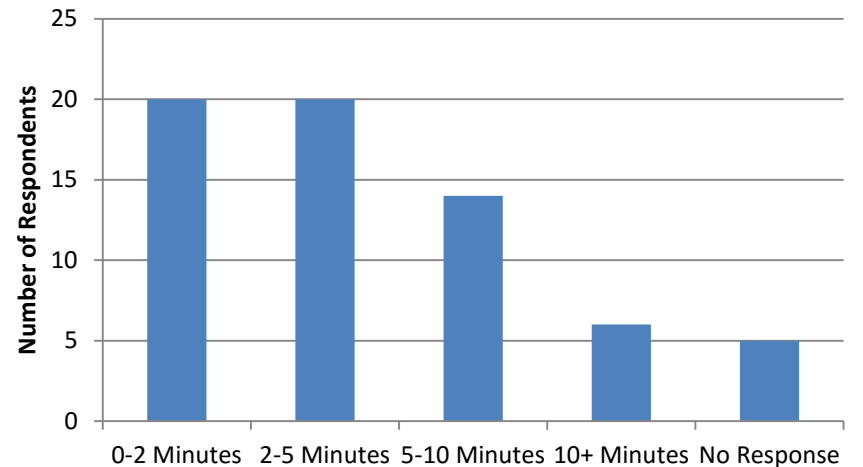
Time Spent Viewing to Determine PDF Relevance



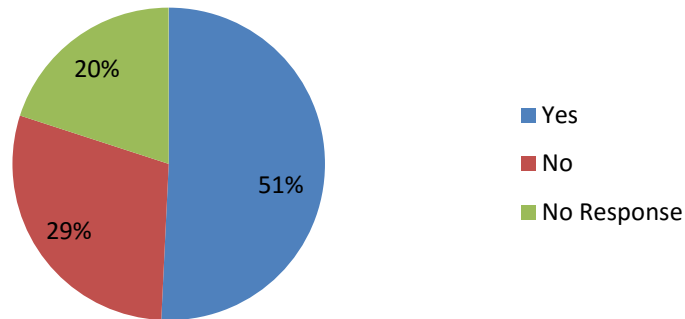
Time Spent Viewing to Determine PDF Irrelevance



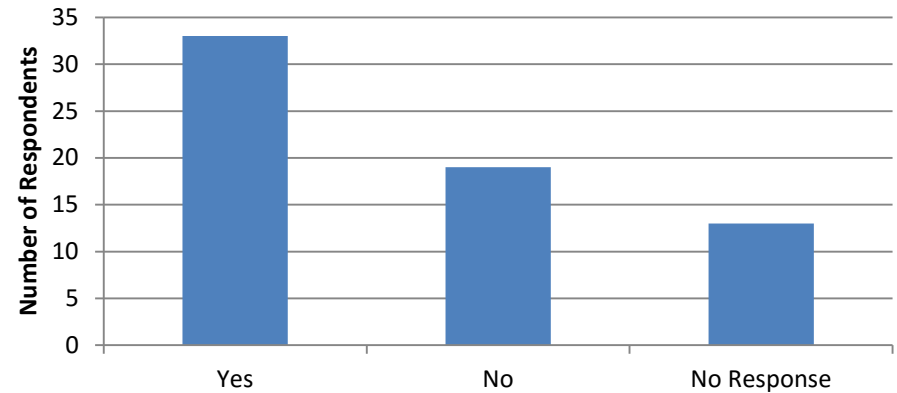
Time Spent Viewing to Determine PDF Relevance



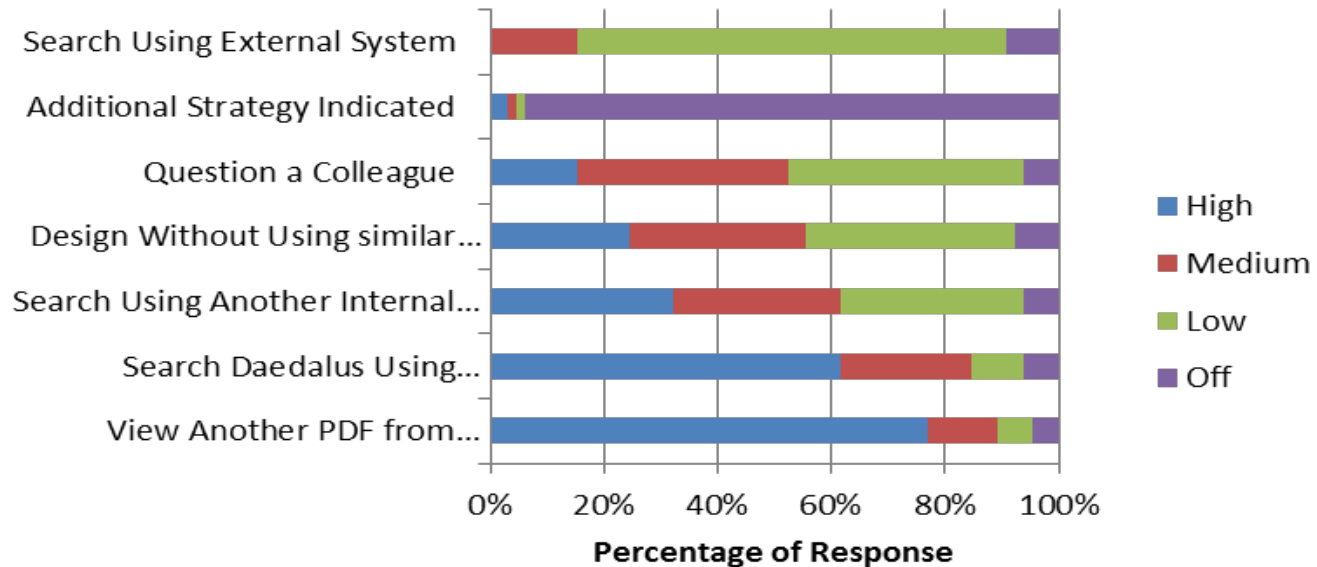
Supporting Information Sought Elsewhere to Make Decision Upon Relevance



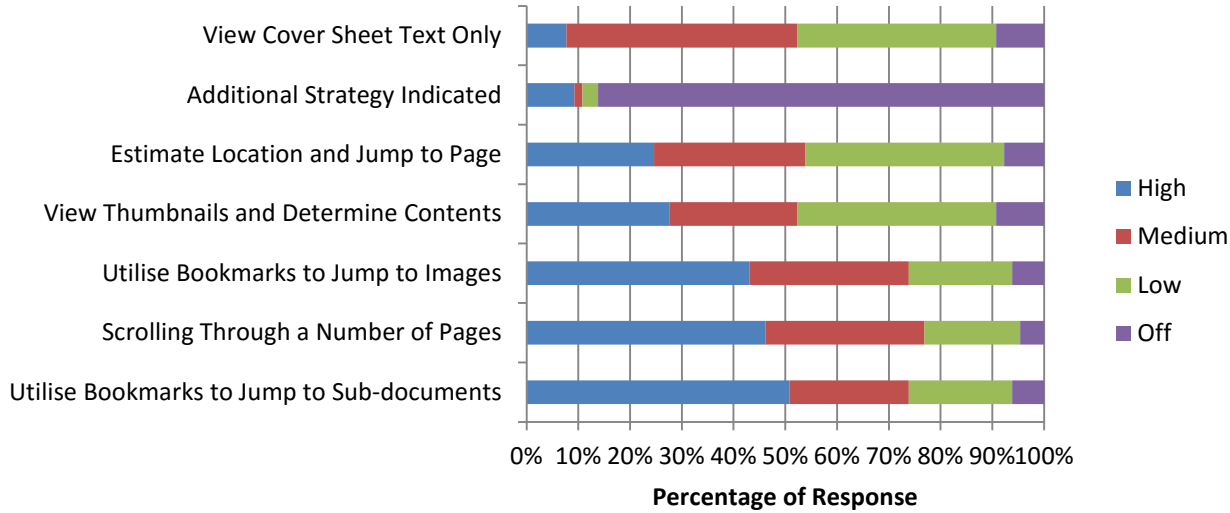
Supporting Information Sought Elsewhere to Make Relevance Decision



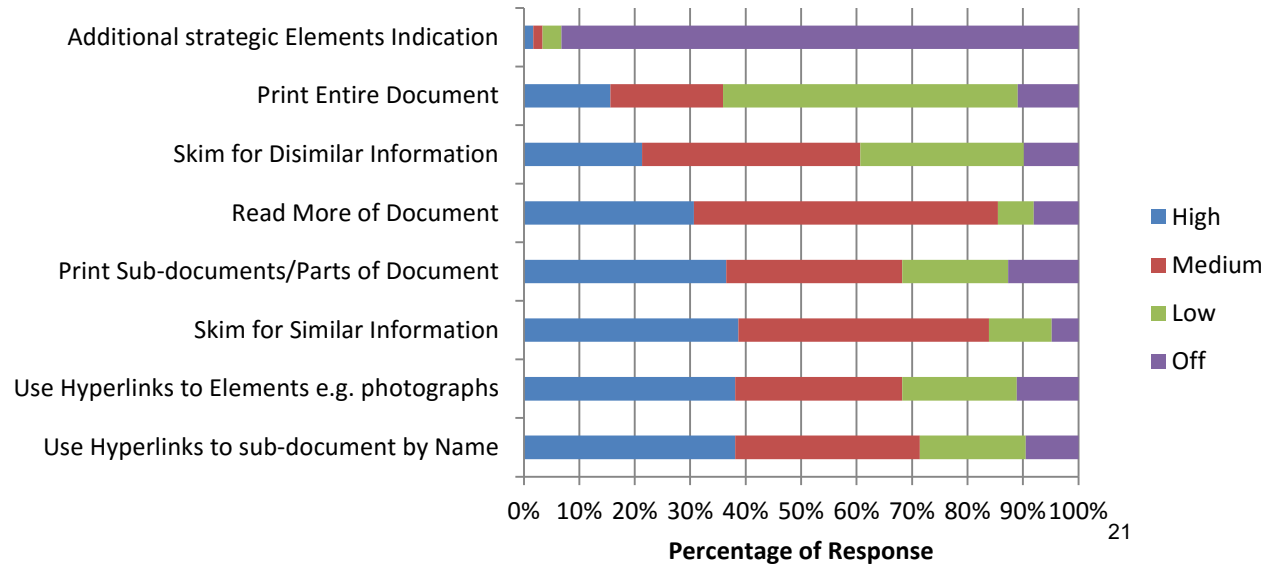
Post PDF Information Seeking



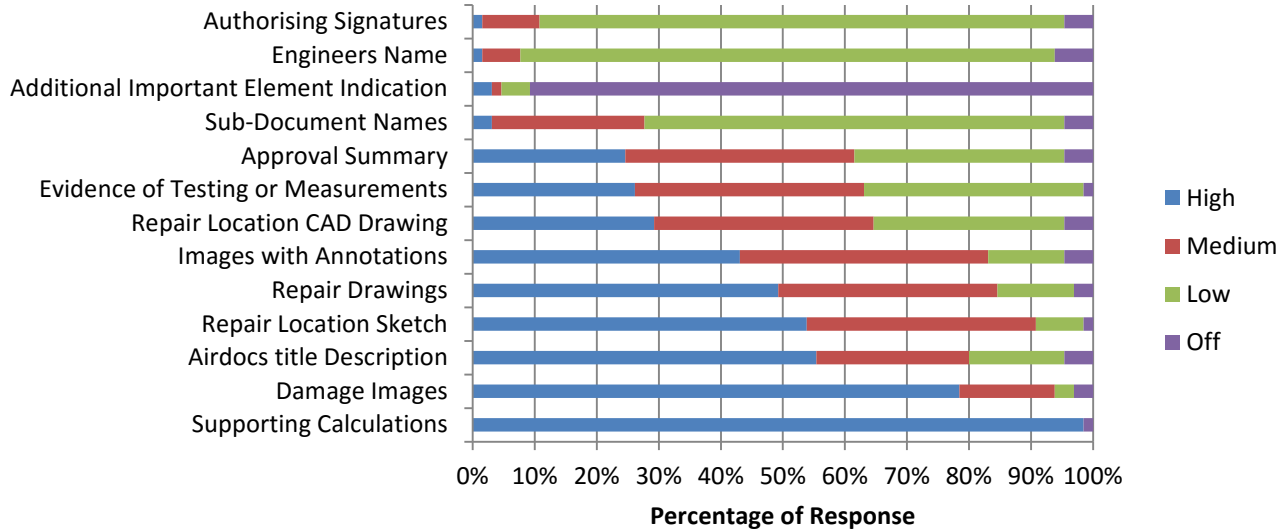
PDF Viewing Strategy



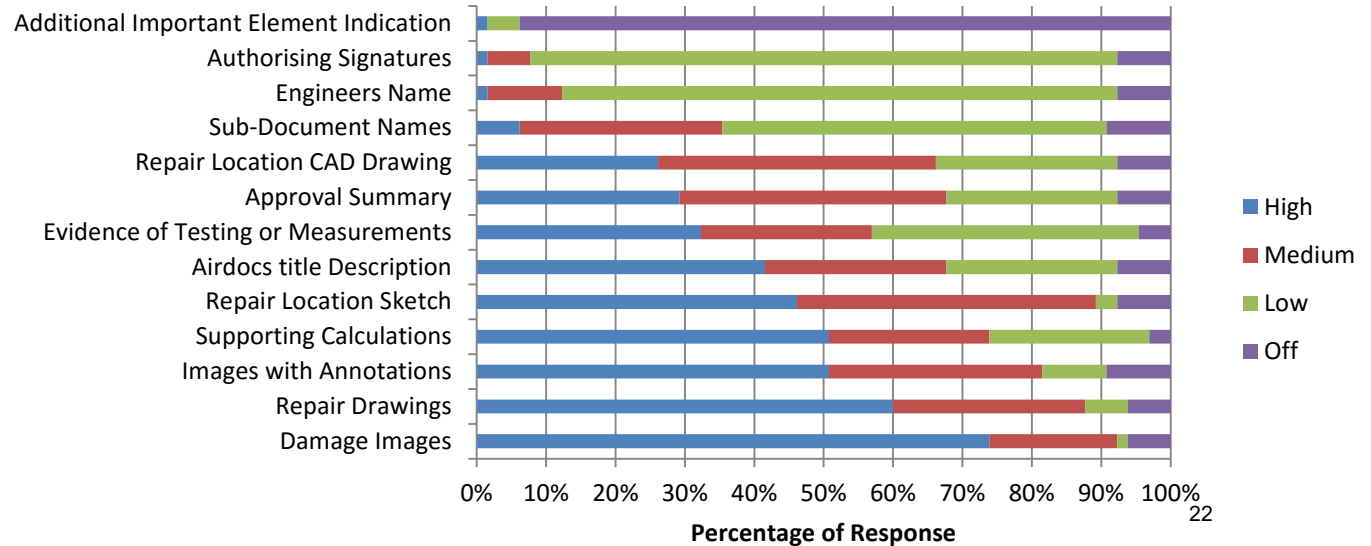
Strategies Employed to View PDF



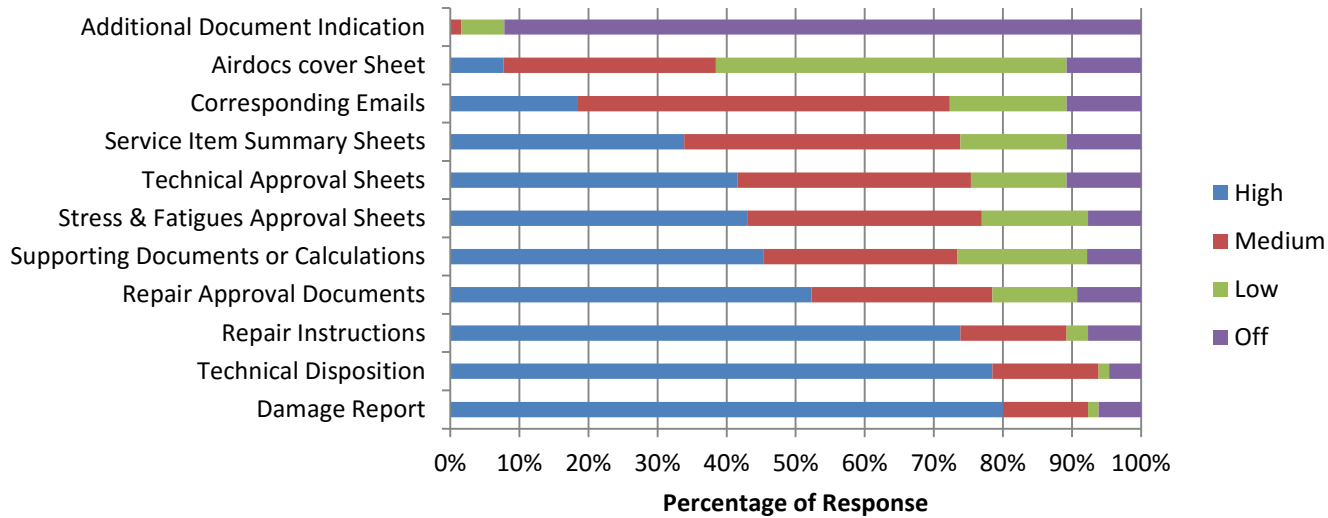
Elements Supporting Making Relevance Decision



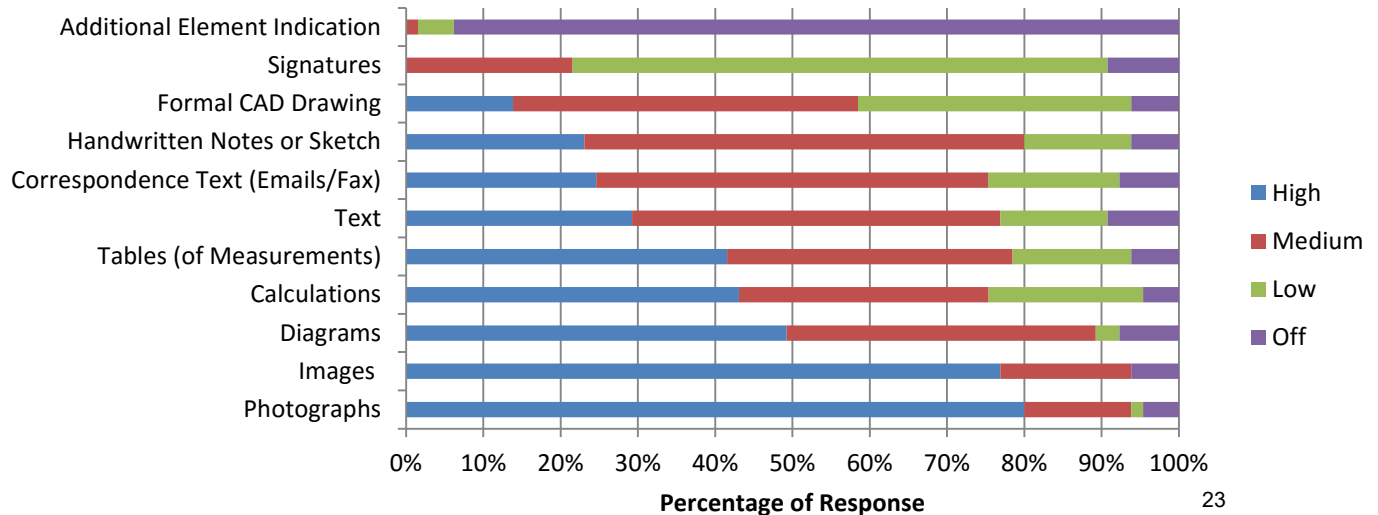
Elements Supporting Understanding Repair Case Fully

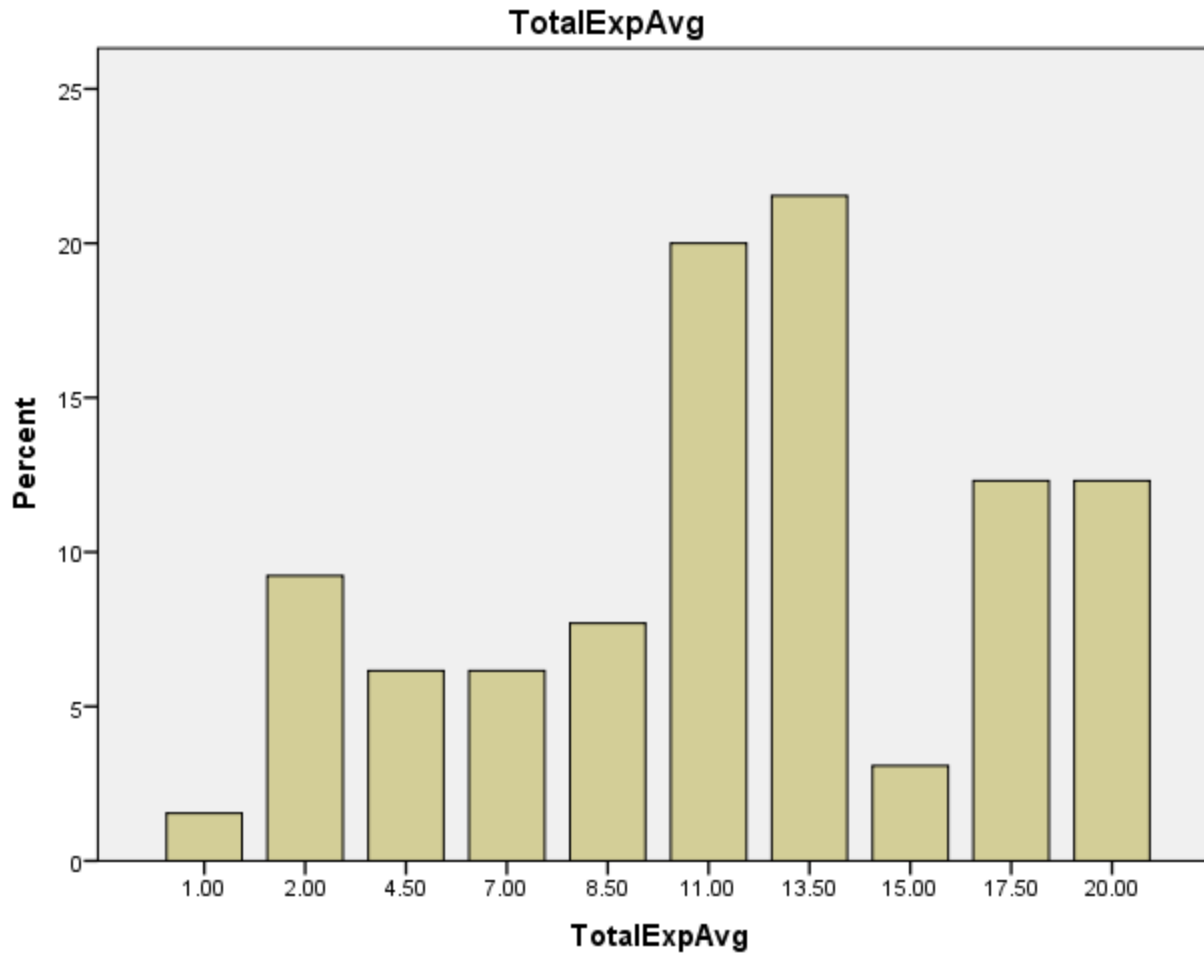


Sub-Document Type Informative Importance



Informative Document Elements

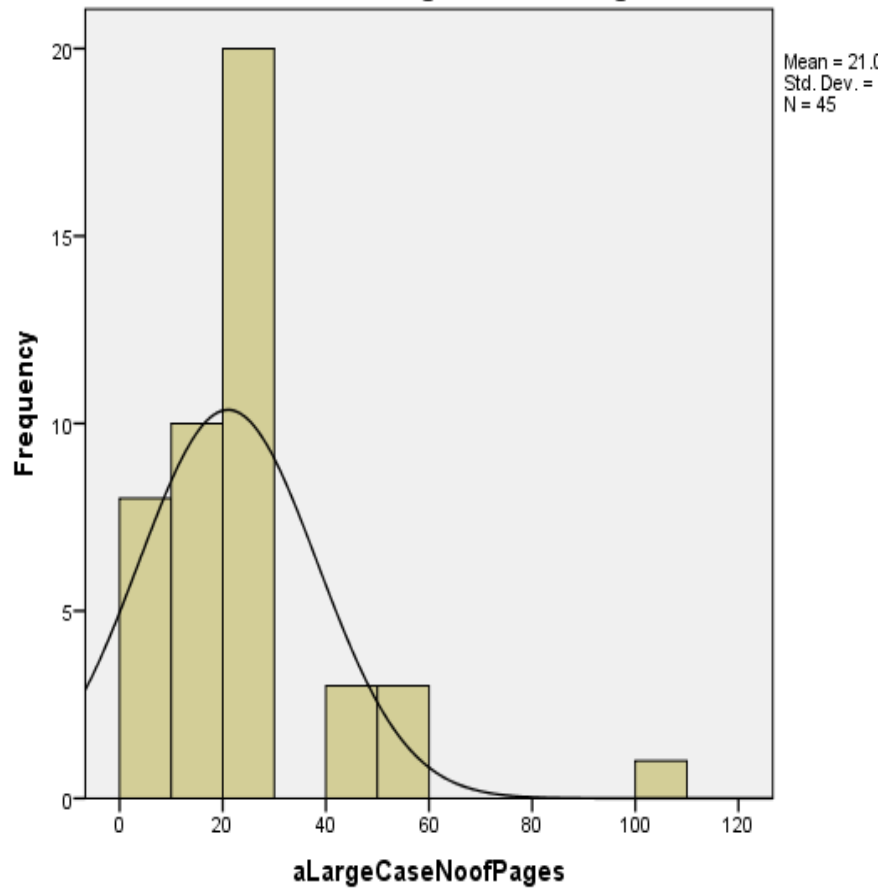




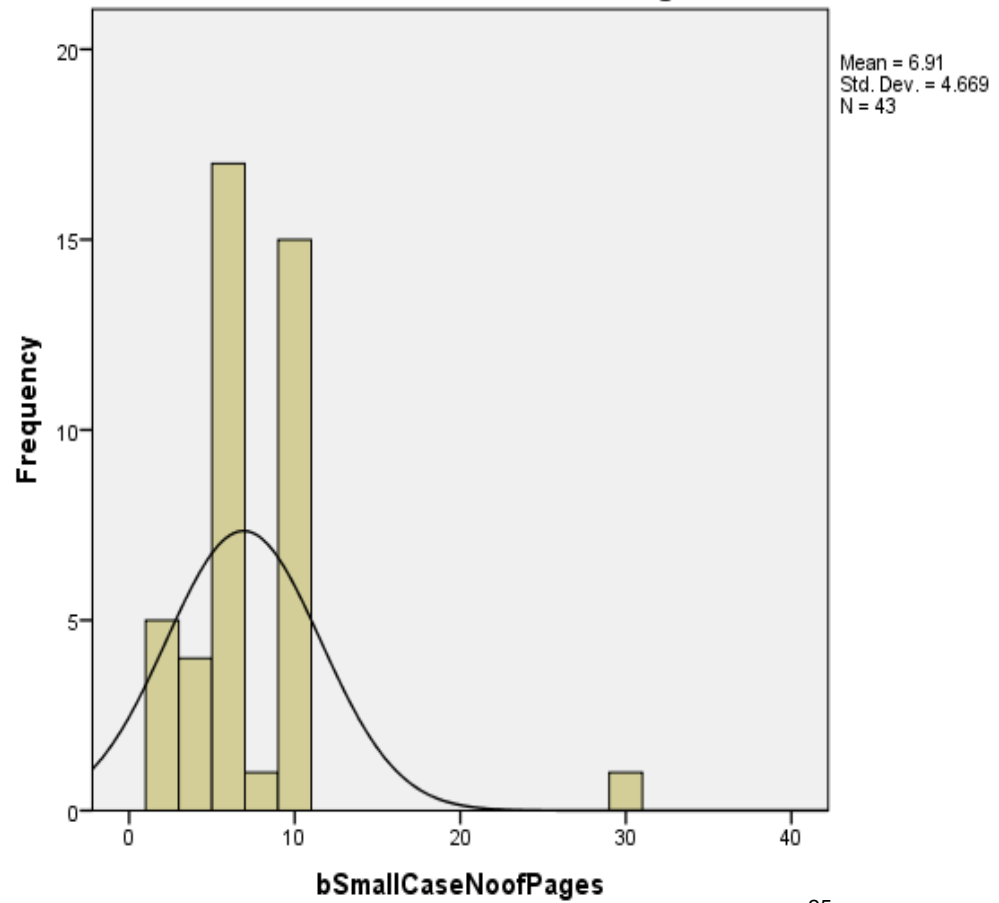
Total Average Respondent Experience

Large & Small Case Page Distribution

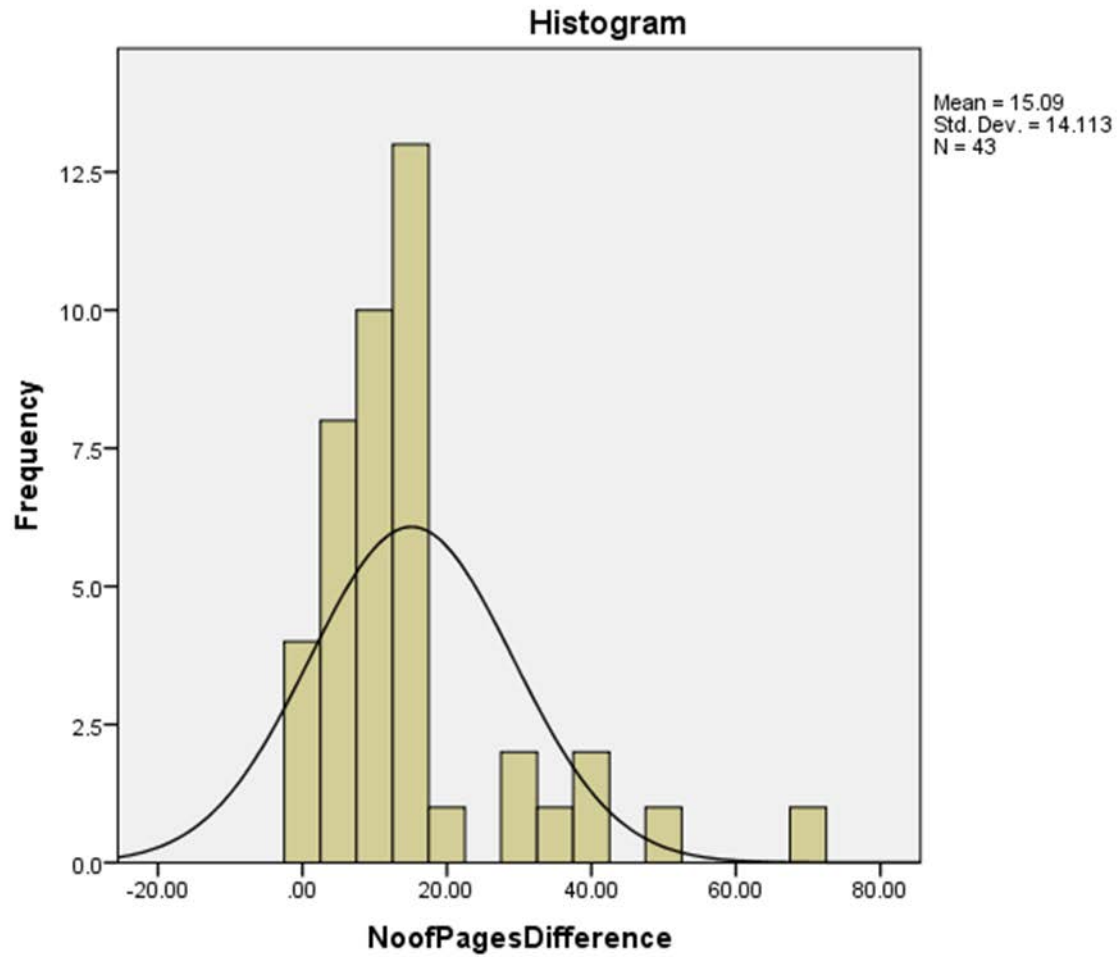
aLargeCaseNoofPages



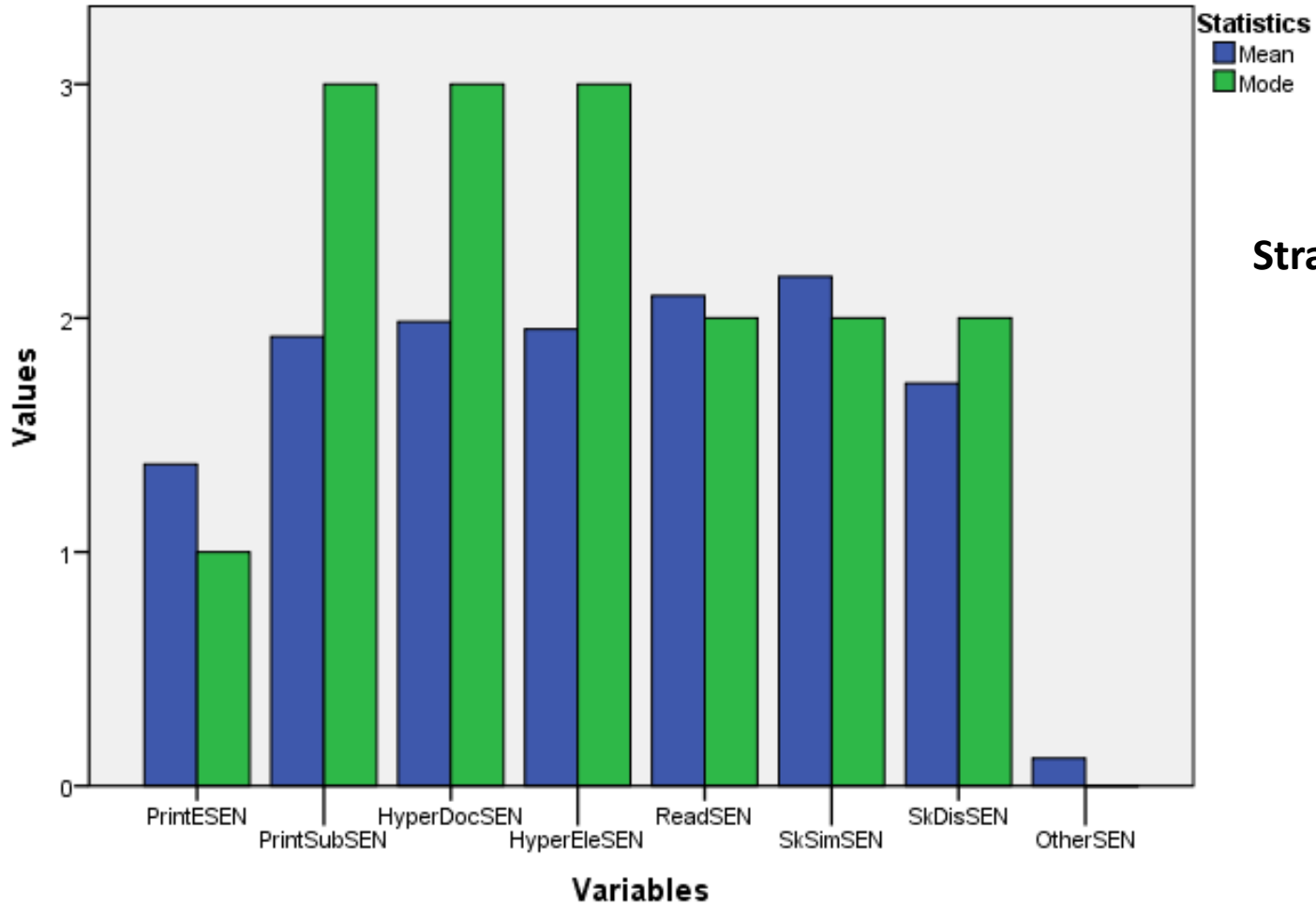
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Large & Small Case Page Difference Distribution



Statistics

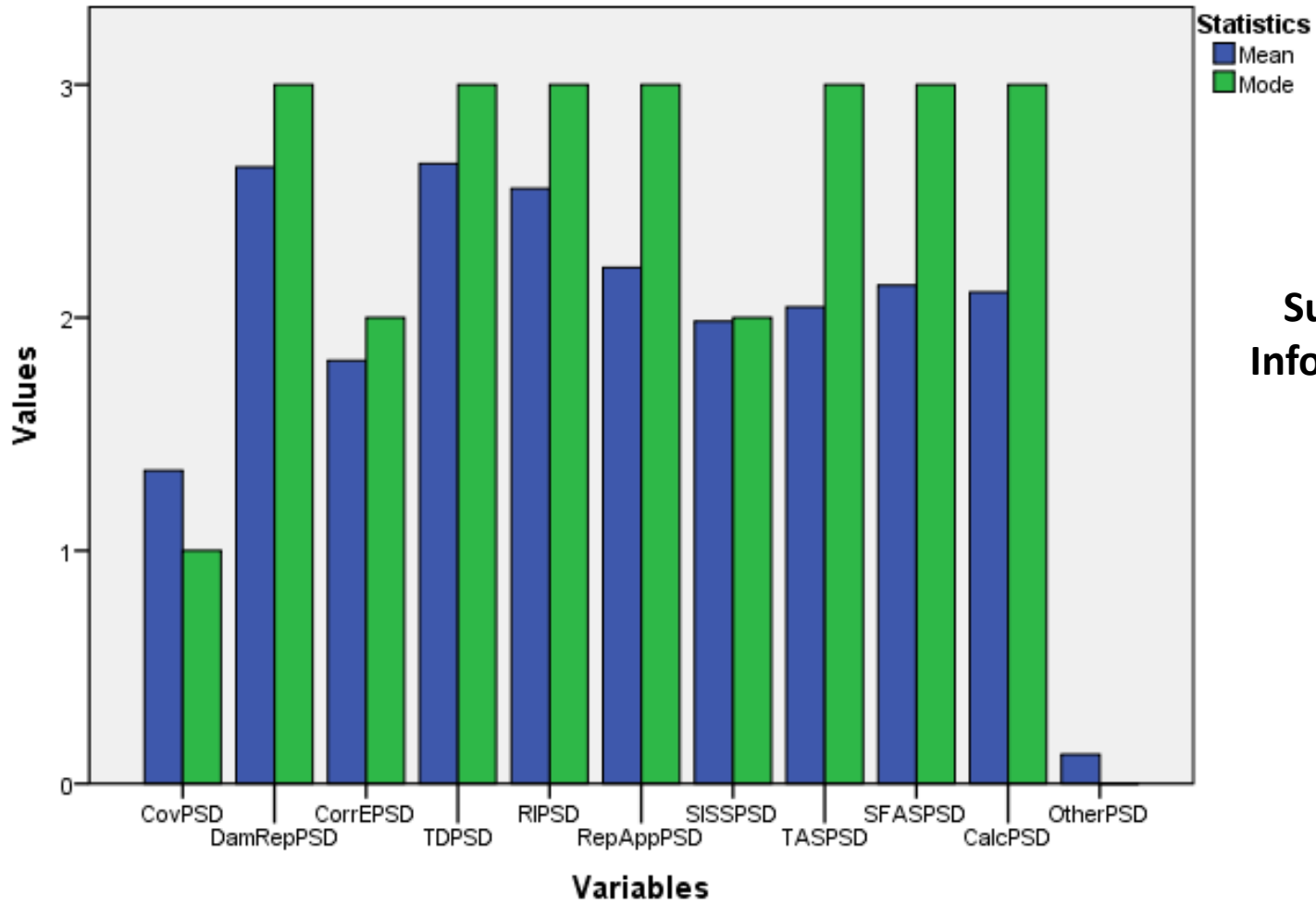


Strategies Employed to View PDF

Statistics

	PrintESEN	PrintSubSEN	HyperDocSEN	HyperEleSEN	ReadSEN	SkSimSEN	SkDisSEN	OtherSEN
Mean	1.3750	1.9206	1.9841	1.9524	2.0952	2.1774	1.7213	.1186
Mode	1.00	3.00	3.00	3.00	2.00	2.00	2.00	2.00

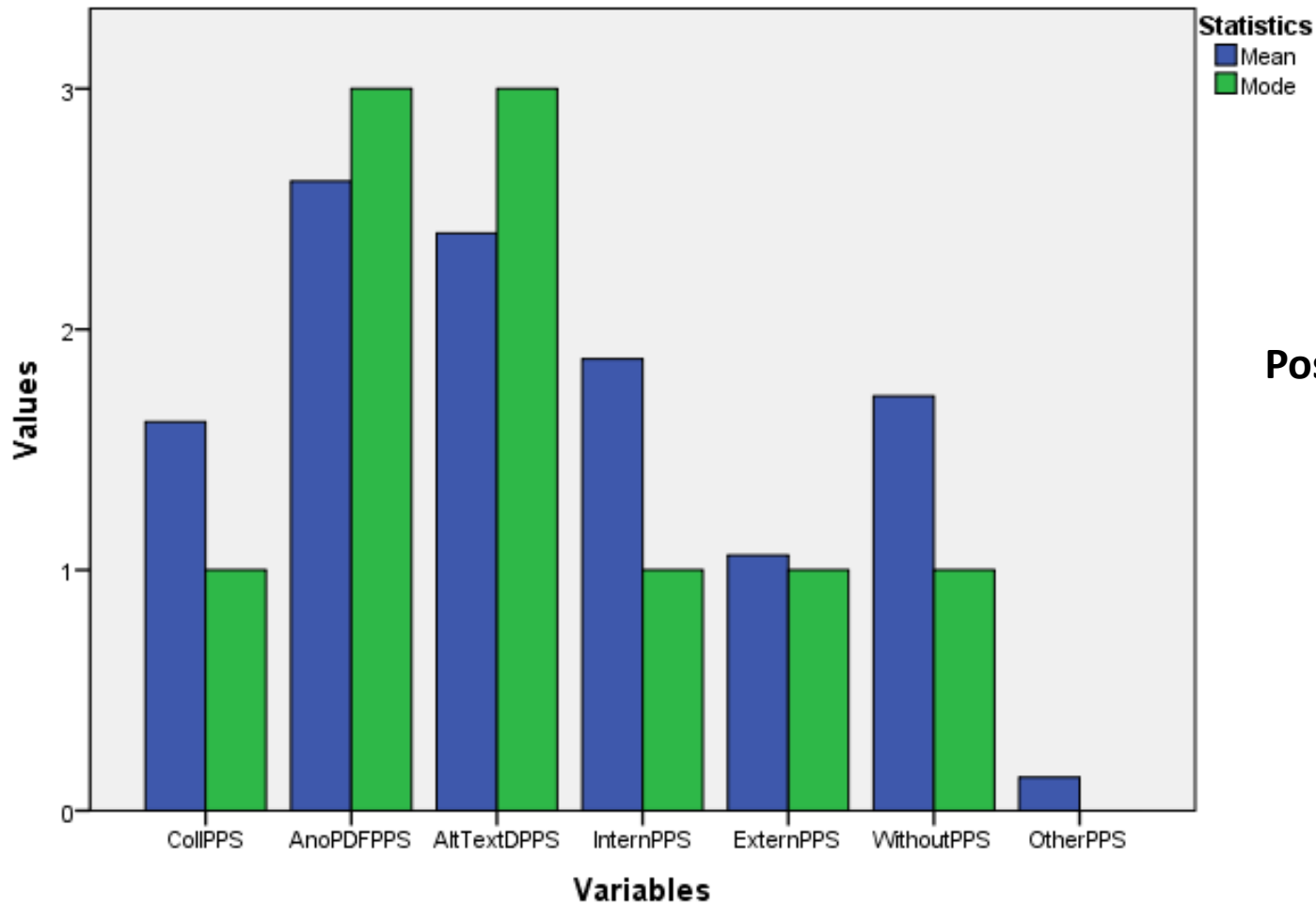
Statistics



Statistics

	CovPSD	DamRepPSD	CorrEPSD	TDPSPD	RIPSPD	RepAppPSD	SISSPSD	TASPSD	SFASPSD	CalcPSD	OtherPSD
Mean	1.3438	2.6462	1.8154	2.6615	2.5538	2.2154	1.9846	2.0462	2.1385	2.1094	.1250
Mode	1.00	3.00	2.00	3.00	3.00	3.00	2.00	3.00	3.00	3.00	.00

Statistics

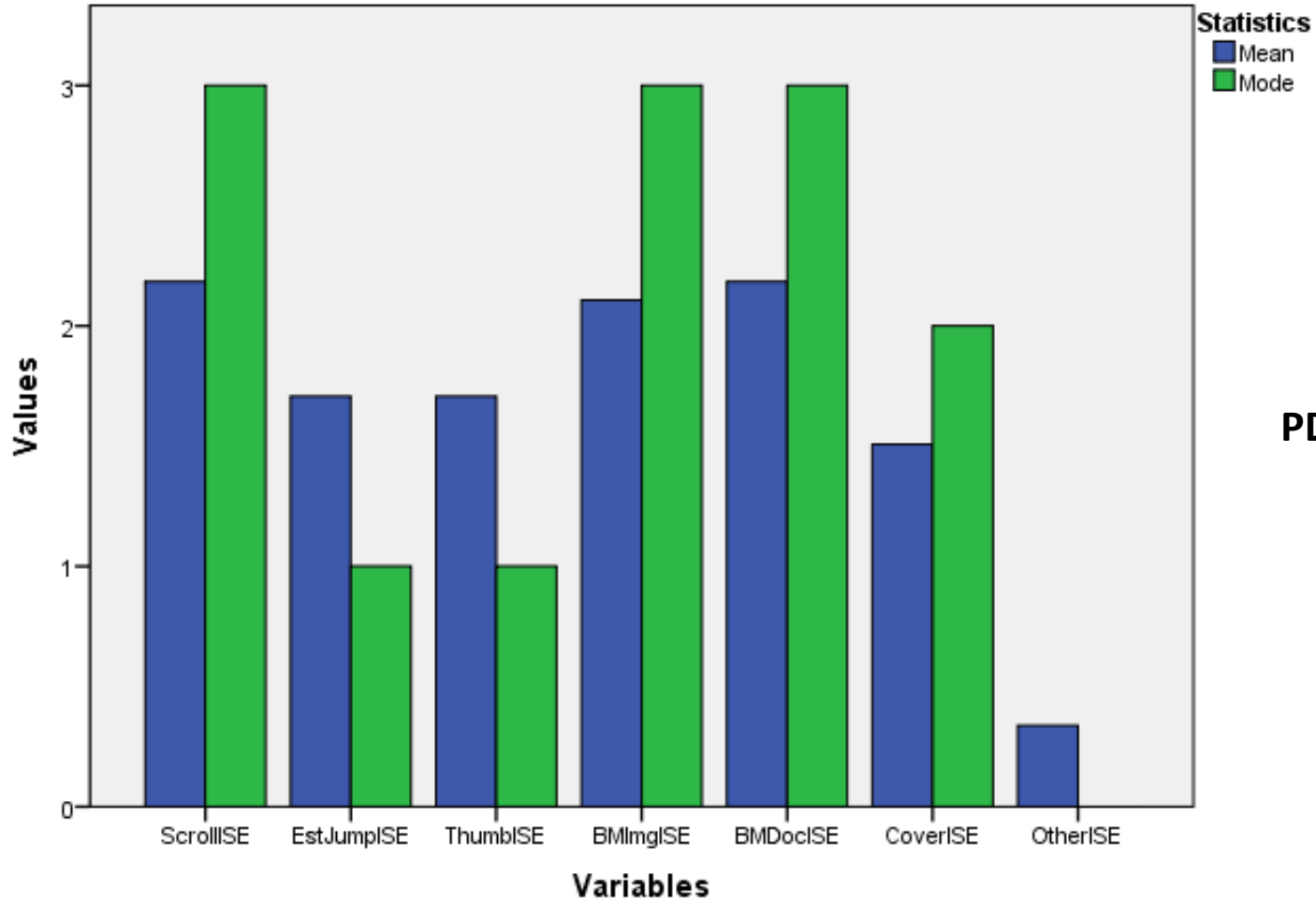


Statistics

	CollPPS	AnoPDFPPS	AltTextDPPS	InternPPS	ExternPPS	WithoutPPS	OtherPPS
Mean	1.6154	2.6154	2.4000	1.8769	1.0615	1.7231	.1385
Mode	1.00	3.00	3.00	1.00 ^a	1.00	1.00	.00

a. Multiple modes exist. The smallest value is shown

Statistics

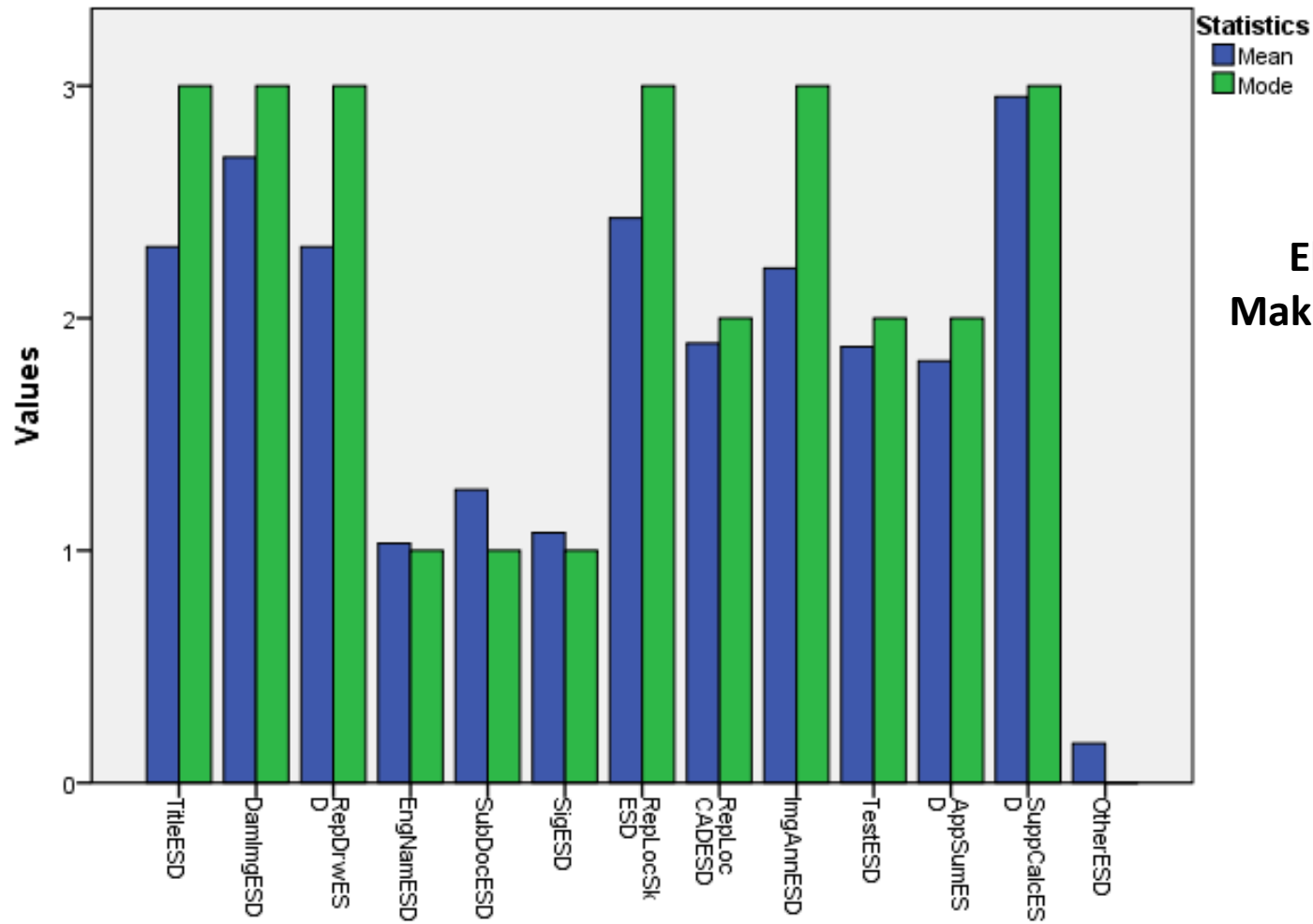


PDF Viewing Strategy

Statistics

	ScrollISE	EstJumpISE	ThumbISE	BMImgISE	BMDocISE	CoverISE	OtherISE
Mean	2.1846	1.7077	1.7077	2.1077	2.1846	1.5077	.3385
Mode	3.00	1.00	1.00	3.00	3.00	2.00	.00

Statistics

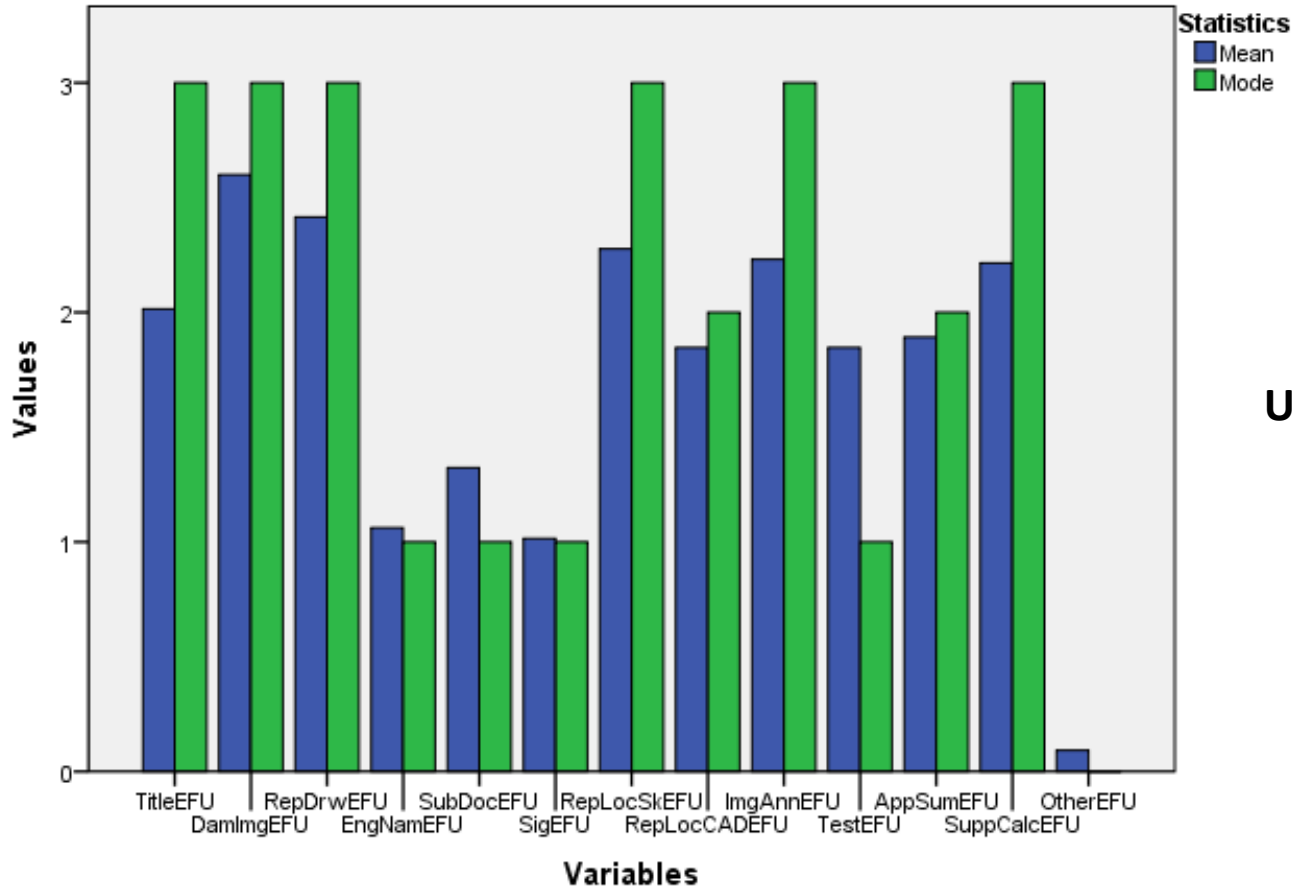


**Elements Supporting
Making Relevance Decision**

Statistics

	TitleESD	DamImgESD	RepDrwESD	EngNameESD	SubDocESD	SigESD	RepLocSkESD	RepLocCADESD	ImgAnnESD	TestESD	AppSumESD	SuppCalcESD	OtherESD
Mean	2.3077	2.6923	2.3077	1.0308	1.2615	1.0769	2.4308	1.8923	2.2154	1.8769	1.8154	2.9538	.1692
Mode	3.00	3.00	3.00	1.00	1.00	1.00	3.00	2.00	3.00	2.00	2.00	3.00	.00

Statistics

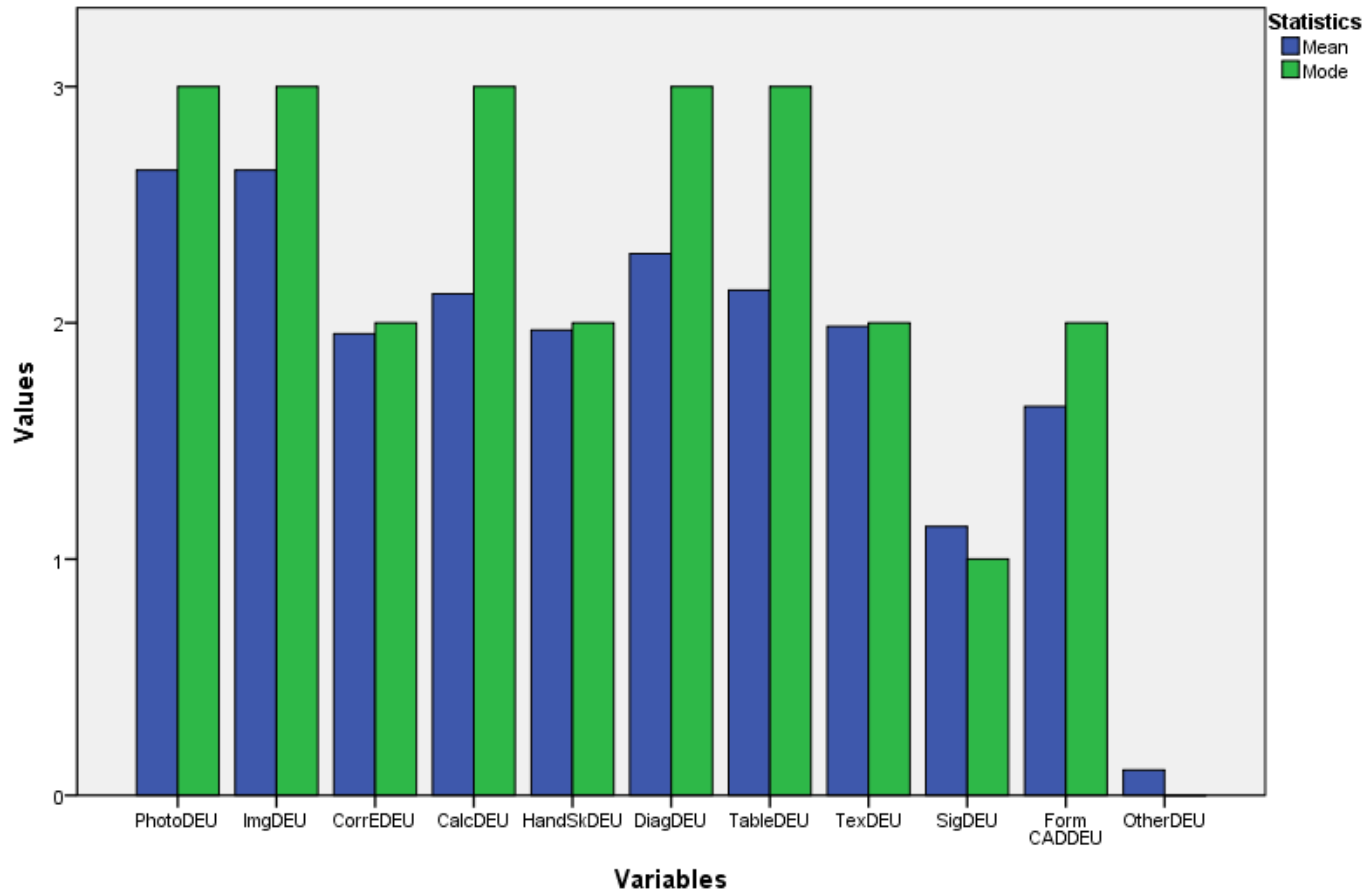


**Elements Supporting
Understanding Repair Case
Fully**

Statistics

	TitleEFU	DamImgEFU	RepDrwEFU	EngNameEFU	SubDocEFU	SigEFU	RepLocSkEFU	RepLocCADEFU	ImgAnneFU	TestEFU	AppSumEFU	SuppCalcEFU	OtherEFU
Mean	2.0154	2.6000	2.4154	1.0615	1.3231	1.0154	2.2769	1.8462	2.2308	1.8462	1.8923	2.2154	.0923
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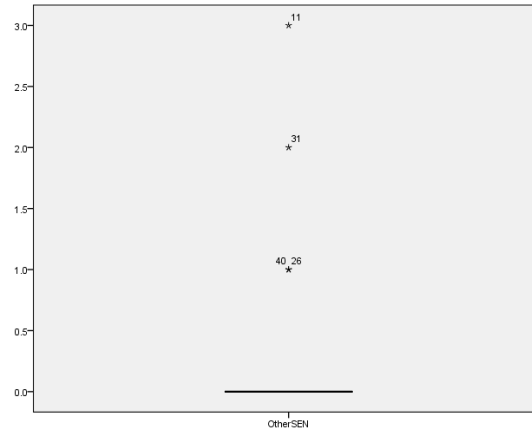
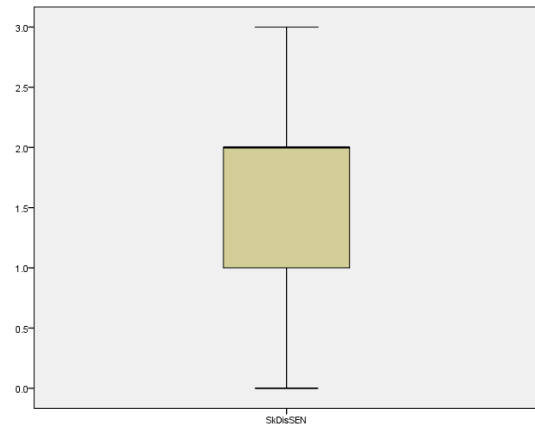
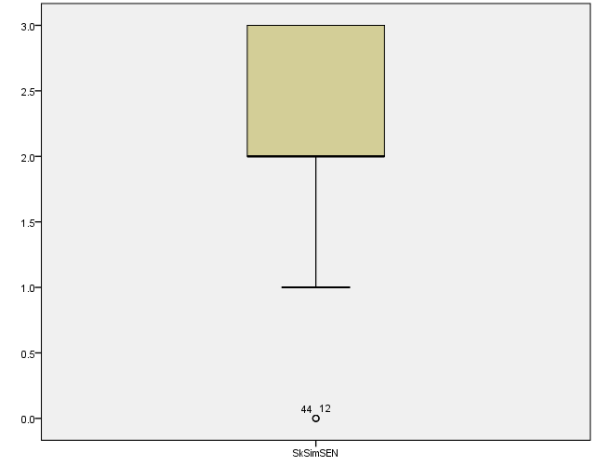
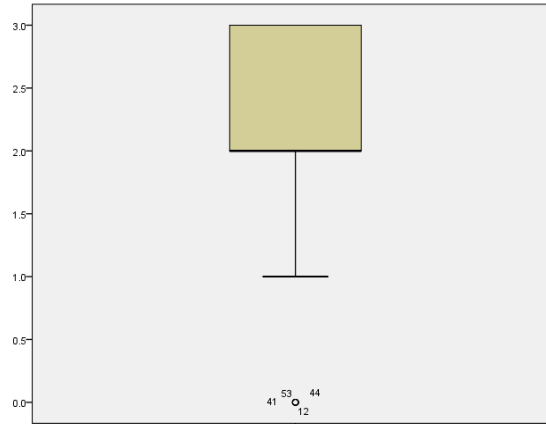
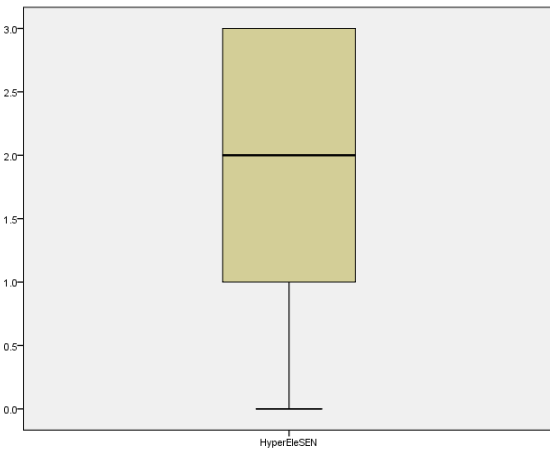
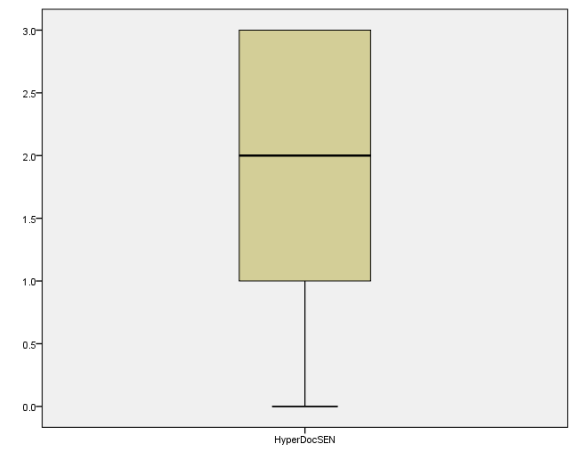
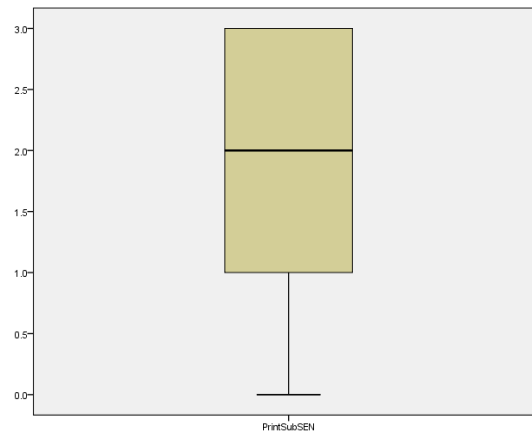
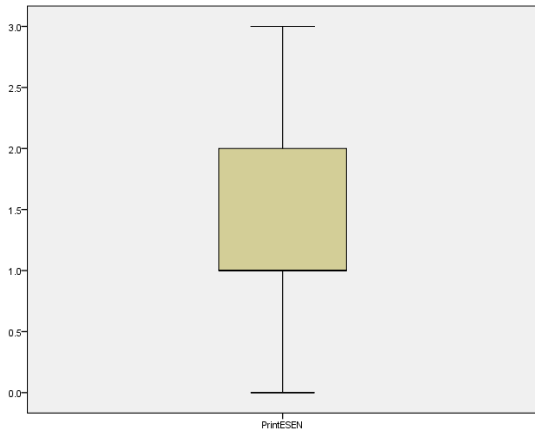
Statistics



Informative Document Elements

Statistics

	PhotoDEU	ImgDEU	CorrEDEU	CalcDEU	HandSkDEU	DiagDEU	TableDEU	TexDEU	SigDEU	FormCADDEU	OtherDEU
Mean	2.6462	2.6462	1.9538	2.1231	1.9692	2.2923	2.1385	1.9846	1.1385	1.6462	.1077
Mode	3.00	3.00	2.00	3.00	2.00	3.00	3.00	2.00	1.00	2.00	.00



Box Plots Ranking Comparison for Strategies Employed to View PDF

Access Time for PDF Limiting & Photograph Preference

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	16.996 ^a	6	.009
Likelihood Ratio	7.888	6	.246
N of Valid Cases	65		

a. 9 cells (75.0%) have expected count less than 5. The minimum expected count is .02.

Crosstab

			PhotographsDEU				Total
			high	low	medium	Off	
AccessTimeLimitUsefulness	2	Count	19	0	3	2	24
		% within AccessTimeLimitUsefulness	79.2%	0.0%	12.5%	8.3%	100.0%
		% within PhotographsDEU	37.3%	0.0%	33.3%	50.0%	36.9%
		% of Total	29.2%	0.0%	4.6%	3.1%	36.9%
	0	Count	0	0	0	1	1
		% within AccessTimeLimitUsefulness	0.0%	0.0%	0.0%	100.0%	100.0%
		% within PhotographsDEU	0.0%	0.0%	0.0%	25.0%	1.5%
		% of Total	0.0%	0.0%	0.0%	1.5%	1.5%
	1	Count	32	1	6	1	40
		% within AccessTimeLimitUsefulness	80.0%	2.5%	15.0%	2.5%	100.0%
		% within PhotographsDEU	62.7%	100.0%	66.7%	25.0%	61.5%
		% of Total	49.2%	1.5%	9.2%	1.5%	61.5%
Total	Count	51	1	9	4	65	
	% within AccessTimeLimitUsefulness	78.5%	1.5%	13.8%	6.2%	100.0%	
	% within PhotographsDEU	100.0%	100.0%	100.0%	100.0%	100.0%	
	% of Total	78.5%	1.5%	13.8%	6.2%	100.0%	

Cohort expertise & Photograph Preference

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	19.392 ^a	9	.022
Likelihood Ratio	13.209	9	.153
N of Valid Cases	65		

a. 13 cells (81.3%) have expected count less than 5. The minimum expected count is .06.

CohortExpertise * PhotographsDEU Crosstabulation

		PhotographsDEU				Total
		high	low	medium	Off	
CohortExpertise 1	Count	26	0	2	1	29
	% within CohortExpertise	89.7%	0.0%	6.9%	3.4%	100.0%
	% within PhotographsDEU	51.0%	0.0%	22.2%	25.0%	44.6%
	% of Total	40.0%	0.0%	3.1%	1.5%	44.6%
3	Count	6	0	2	0	8
	% within CohortExpertise	75.0%	0.0%	25.0%	0.0%	100.0%
	% within PhotographsDEU	11.8%	0.0%	22.2%	0.0%	12.3%
	% of Total	9.2%	0.0%	3.1%	0.0%	12.3%
4	Count	2	0	0	2	4
	% within CohortExpertise	50.0%	0.0%	0.0%	50.0%	100.0%
	% within PhotographsDEU	3.9%	0.0%	0.0%	50.0%	6.2%
	% of Total	3.1%	0.0%	0.0%	3.1%	6.2%
2	Count	17	1	5	1	24
	% within CohortExpertise	70.8%	4.2%	20.8%	4.2%	100.0%
	% within PhotographsDEU	33.3%	100.0%	55.6%	25.0%	36.9%
	% of Total	26.2%	1.5%	7.7%	1.5%	36.9%
Total	Count	51	1	9	4	65
	% within CohortExpertise	78.5%	1.5%	13.8%	6.2%	100.0%
	% within PhotographsDEU	100.0%	100.0%	100.0%	100.0%	100.0%
	% of Total	78.5%	1.5%	13.8%	6.2%	100.0%

Cohort expertise is strongly associated with search or browse preference (p value low for statistical significance)

Crosstab

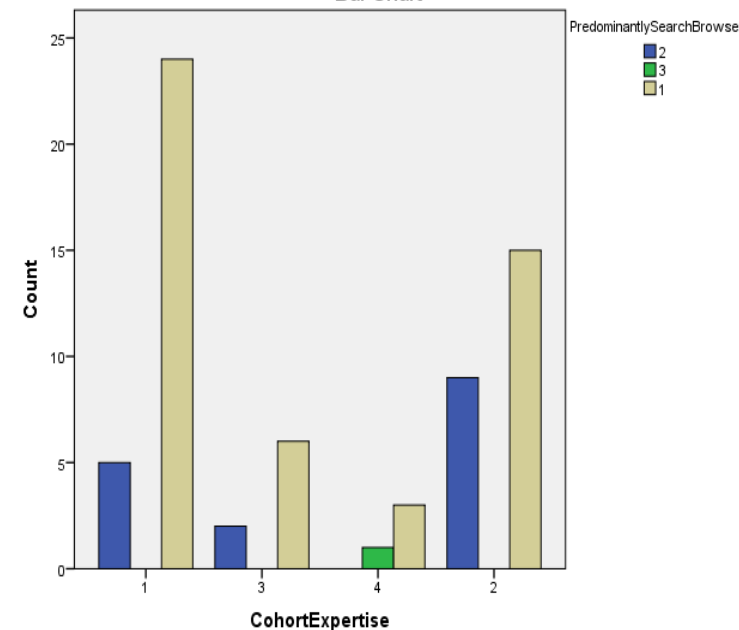
		PredominantlySearchBrowse			Total	
		2	3	1		
CohortExpertise	1	Count	5	0	24	29
		% within CohortExpertise	17.2%	0.0%	82.8%	100.0%
		% within PredominantlySearchBrowse	31.2%	0.0%	50.0%	44.6%
		% of Total	7.7%	0.0%	36.9%	44.6%
	3	Count	2	0	6	8
		% within CohortExpertise	25.0%	0.0%	75.0%	100.0%
		% within PredominantlySearchBrowse	12.5%	0.0%	12.5%	12.3%
		% of Total	3.1%	0.0%	9.2%	12.3%
	4	Count	0	1	3	4
		% within CohortExpertise	0.0%	25.0%	75.0%	100.0%
		% within PredominantlySearchBrowse	0.0%	100.0%	6.2%	6.2%
		% of Total	0.0%	1.5%	4.6%	6.2%
2	Count	9	0	15	24	
	% within CohortExpertise	37.5%	0.0%	62.5%	100.0%	
	% within PredominantlySearchBrowse	56.2%	0.0%	31.2%	36.9%	
	% of Total	13.8%	0.0%	23.1%	36.9%	
Total	Count	16	1	48	65	
	% within CohortExpertise	24.6%	1.5%	73.8%	100.0%	
	% within PredominantlySearchBrowse	100.0%	100.0%	100.0%	100.0%	
	% of Total	24.6%	1.5%	73.8%	100.0%	

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	19.227 ^a	6	.004
Likelihood Ratio	10.399	6	.109
N of Valid Cases	65		

a. 7 cells (58.3%) have expected count less than 5. The minimum expected count is .06.

Bar Chart



Cohort expertise is strongly associated with “seeking additional supporting repair cases” (p value low for statistical significance)

Crosstab

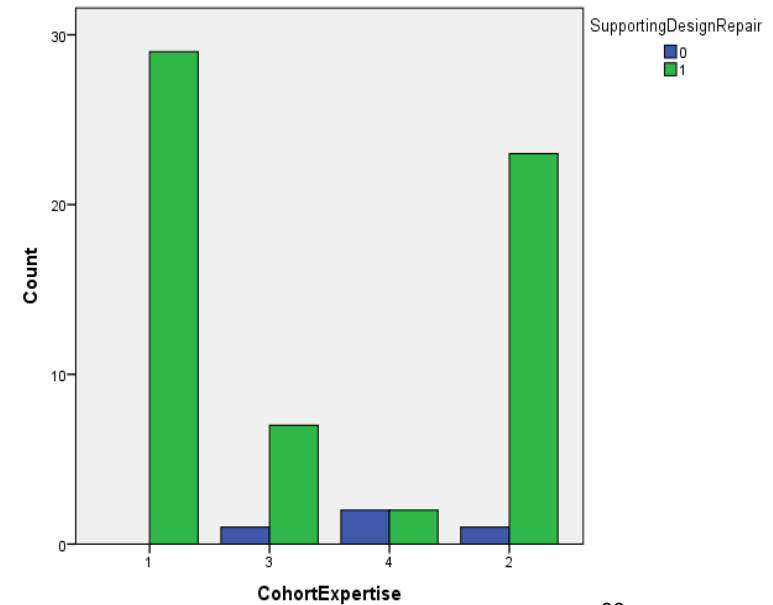
		SupportingDesignRepair		Total
		0	1	
CohortExpertise 1	Count	0	29	29
	% within CohortExpertise	0.0%	100.0%	100.0%
	% within SupportingDesignRepair	0.0%	47.5%	44.6%
	% of Total	0.0%	44.6%	44.6%
3	Count	1	7	8
	% within CohortExpertise	12.5%	87.5%	100.0%
	% within SupportingDesignRepair	25.0%	11.5%	12.3%
	% of Total	1.5%	10.8%	12.3%
4	Count	2	2	4
	% within CohortExpertise	50.0%	50.0%	100.0%
	% within SupportingDesignRepair	50.0%	3.3%	6.2%
	% of Total	3.1%	3.1%	6.2%
2	Count	1	23	24
	% within CohortExpertise	4.2%	95.8%	100.0%
	% within SupportingDesignRepair	25.0%	37.7%	36.9%
	% of Total	1.5%	35.4%	36.9%
Total	Count	4	61	65
	% within CohortExpertise	6.2%	93.8%	100.0%
	% within SupportingDesignRepair	100.0%	100.0%	100.0%
	% of Total	6.2%	93.8%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	15.939 ^a	3	.001
Likelihood Ratio	10.166	3	.017
N of Valid Cases	65		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is .25.

Bar Chart



Cohort expertise is strongly associated with “PDF Access Limiting Usefulness” (less confident (90%) statistical significance)

Crosstab

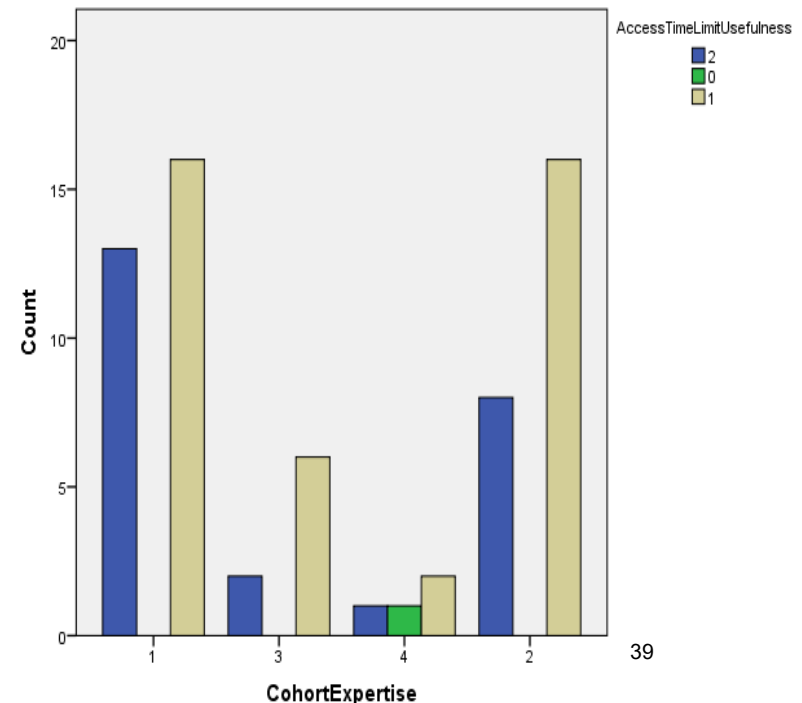
		AccessTimeLimitUsefulness			Total	
		2	0	1		
CohortExpertise	1	Count	13	0	16	29
		% within CohortExpertise	44.8%	0.0%	55.2%	100.0%
		% within AccessTimeLimitUsefulness	54.2%	0.0%	40.0%	44.6%
		% of Total	20.0%	0.0%	24.6%	44.6%
	3	Count	2	0	6	8
		% within CohortExpertise	25.0%	0.0%	75.0%	100.0%
		% within AccessTimeLimitUsefulness	8.3%	0.0%	15.0%	12.3%
		% of Total	3.1%	0.0%	9.2%	12.3%
	4	Count	1	1	2	4
		% within CohortExpertise	25.0%	25.0%	50.0%	100.0%
		% within AccessTimeLimitUsefulness	4.2%	100.0%	5.0%	6.2%
		% of Total	1.5%	1.5%	3.1%	6.2%
2	Count	8	0	16	24	
	% within CohortExpertise	33.3%	0.0%	66.7%	100.0%	
	% within AccessTimeLimitUsefulness	33.3%	0.0%	40.0%	36.9%	
	% of Total	12.3%	0.0%	24.6%	36.9%	
Total	Count	24	1	40	65	
	% within CohortExpertise	36.9%	1.5%	61.5%	100.0%	
	% within AccessTimeLimitUsefulness	100.0%	100.0%	100.0%	100.0%	
	% of Total	36.9%	1.5%	61.5%	100.0%	

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	16.902 ^a	6	.010
Likelihood Ratio	7.254	6	.298
N of Valid Cases	65		

a. 8 cells (66.7%) have expected count less than 5. The minimum expected count is .06.

Bar Chart



InServiceExperience * PredominantlySearchBrowse

Crosstab

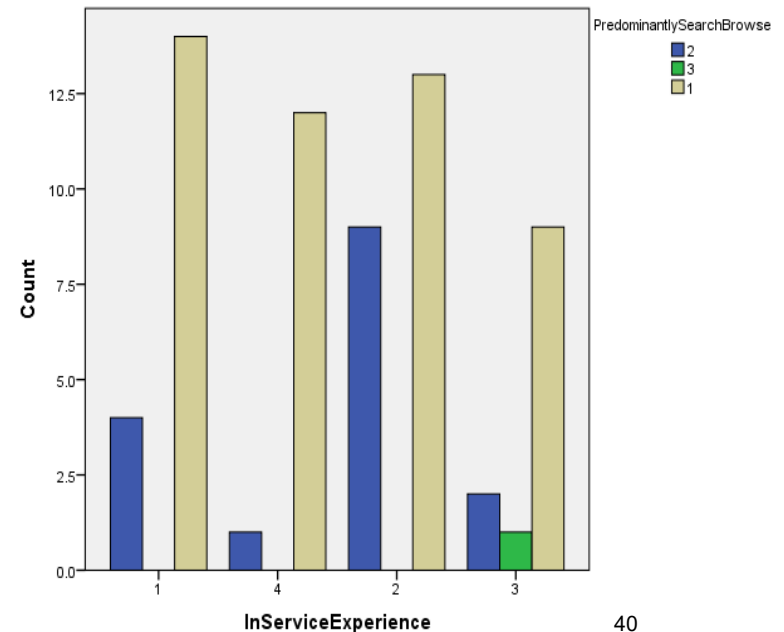
		PredominantlySearchBrowse			Total
		2	3	1	
InServiceExperience 1	Count	4	0	14	18
	% within InServiceExperience	22.2%	0.0%	77.8%	100.0%
	% within PredominantlySearchBrowse	25.0%	0.0%	29.2%	27.7%
	% of Total	6.2%	0.0%	21.5%	27.7%
4	Count	1	0	12	13
	% within InServiceExperience	7.7%	0.0%	92.3%	100.0%
	% within PredominantlySearchBrowse	6.2%	0.0%	25.0%	20.0%
	% of Total	1.5%	0.0%	18.5%	20.0%
2	Count	9	0	13	22
	% within InServiceExperience	40.9%	0.0%	59.1%	100.0%
	% within PredominantlySearchBrowse	56.2%	0.0%	27.1%	33.8%
	% of Total	13.8%	0.0%	20.0%	33.8%
3	Count	2	1	9	12
	% within InServiceExperience	16.7%	8.3%	75.0%	100.0%
	% within PredominantlySearchBrowse	12.5%	100.0%	18.8%	18.5%
	% of Total	3.1%	1.5%	13.8%	18.5%
Total	Count	16	1	48	65
	% within InServiceExperience	24.6%	1.5%	73.8%	100.0%
	% within PredominantlySearchBrowse	100.0%	100.0%	100.0%	100.0%
	% of Total	24.6%	1.5%	73.8%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	9.940 ^a	6	.127
Likelihood Ratio	9.110	6	.168
N of Valid Cases	65		

a. 7 cells (58.3%) have expected count less than 5. The minimum expected count is .18.

Bar Chart



PriorDesignEngineeringExperience * IndicatesAdditionalPurpose

Crosstab

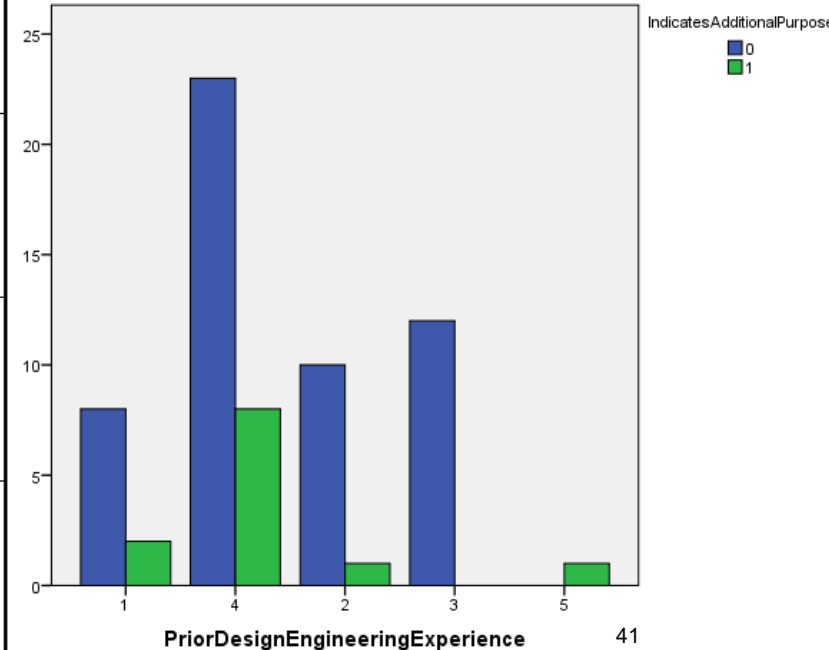
		IndicatesAdditionalPurpose		Total	
		0	1		
PriorDesignEngineeringExperience	1	Count	8	2	10
		% within PriorDesignEngineeringExperience	80.0%	20.0%	100.0%
		% within IndicatesAdditionalPurpose	15.1%	16.7%	15.4%
		% of Total	12.3%	3.1%	15.4%
		4	Count	23	8
	% within PriorDesignEngineeringExperience	74.2%	25.8%	100.0%	
	% within IndicatesAdditionalPurpose	43.4%	66.7%	47.7%	
	% of Total	35.4%	12.3%	47.7%	
	2	Count	10	1	11
		% within PriorDesignEngineeringExperience	90.9%	9.1%	100.0%
		% within IndicatesAdditionalPurpose	18.9%	8.3%	16.9%
		% of Total	15.4%	1.5%	16.9%
		3	Count	12	0
	% within PriorDesignEngineeringExperience	100.0%	0.0%	100.0%	
	% within IndicatesAdditionalPurpose	22.6%	0.0%	18.5%	
	% of Total	18.5%	0.0%	18.5%	
	5	Count	0	1	1
		% within PriorDesignEngineeringExperience	0.0%	100.0%	100.0%
		% within IndicatesAdditionalPurpose	0.0%	8.3%	1.5%
		% of Total	0.0%	1.5%	1.5%
Total		Count	53	12	65
% within PriorDesignEngineeringExperience	81.5%	18.5%	100.0%		
% within IndicatesAdditionalPurpose	100.0%	100.0%	100.0%		
% of Total	81.5%	18.5%	100.0%		

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.902 ^a	4	.064
Likelihood Ratio	10.068	4	.039
N of Valid Cases	65		

a. 5 cells (50.0%) have expected count less than 5. The minimum expected count is .18.

Bar Chart



Story Board of In-Service Supporting Case Decision Making

Emily Carey

June 2014



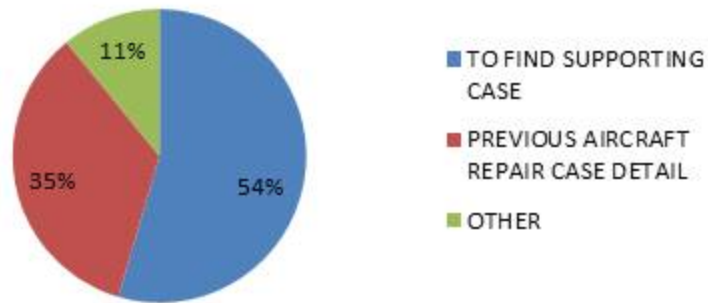
Emily Carey

Previous experience in teaching undergraduate Computer Science and Mathematics Support at Coventry University prior work includes Planning and Control, Resource and Forecasting for AXA Life. Current project in conjunction with Airbus contributes to PhD studies at University of Bath.

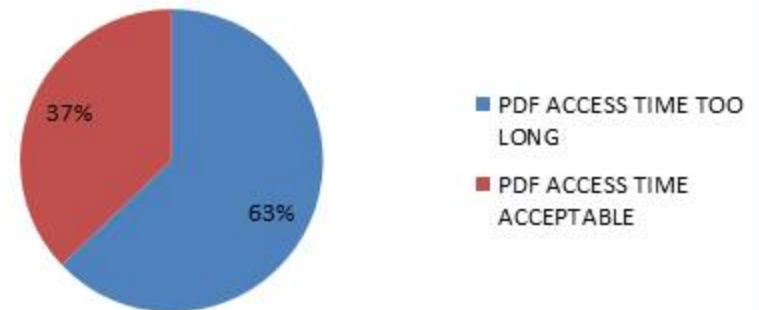
Research Focus – Building Upon Questionnaire Results

Two of the key purposes stated for searching through historic repair information were “for a supporting repair design case” and “previous aircraft repair case detail”.

Purpose for Reuse of Historic Repair



PDF Access Perception



*It was indicated the **time it takes to access historic repair case information** find that this is a **limiting factor** for its use, thus this workshop aims to **build a deeper understanding of the issue**.*⁴⁴

Today's Objectives

- Opportunity for you to actively participate in the design of information systems to support repair design
- Share your expertise amongst your sub-teams, in particular any time saving methods
- In Task 1 to work collectively and individually for Task 2

Workshop Outline

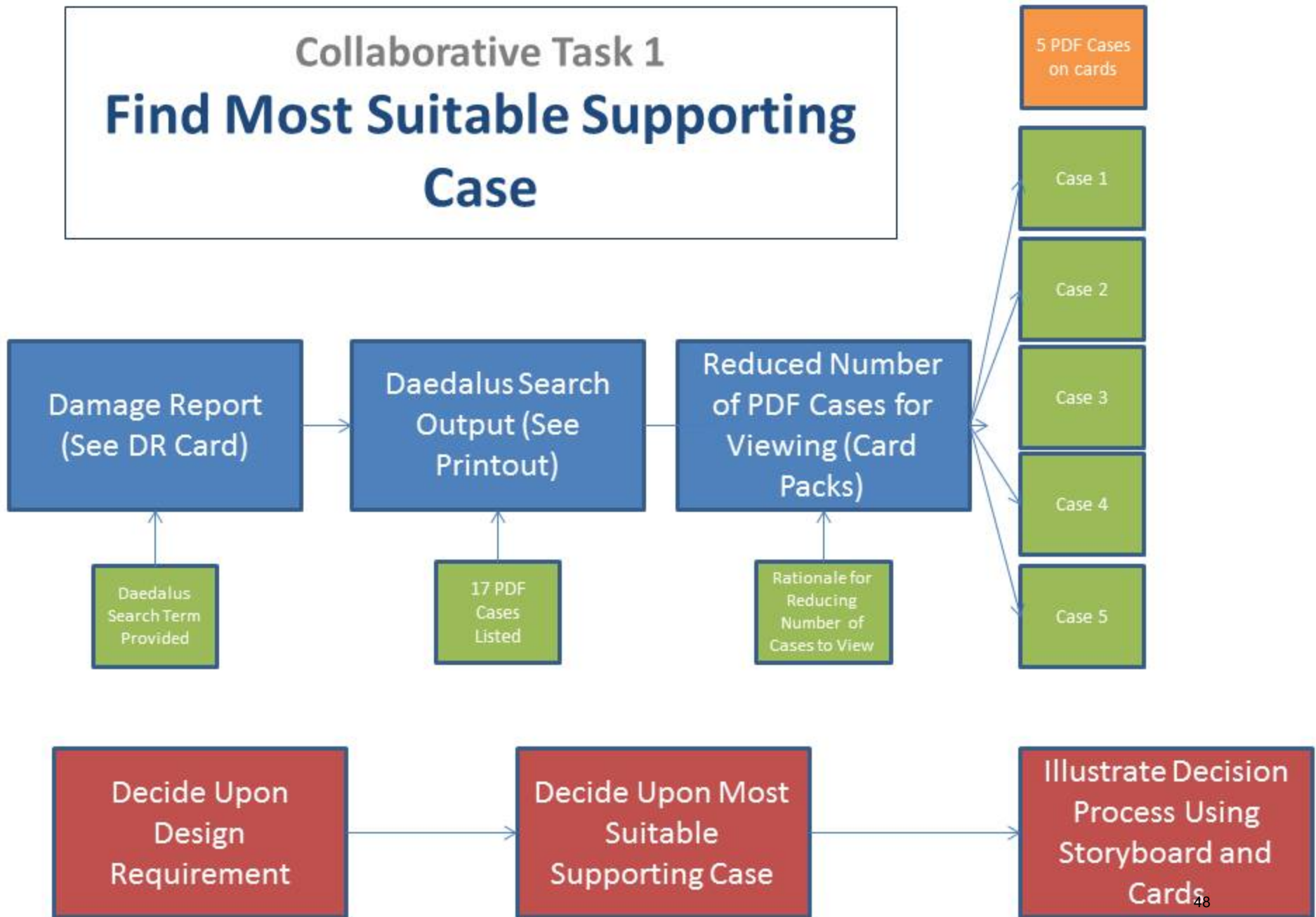
Session 9am	Session 11am	Duration	Task
9.00 am	11.00 am	10 minutes	Workshop & Research Introduction
9.10 am	11.10 am	10 minutes	Task 1 Briefing
9.20 am	11.20 am	40 minutes	Task 1 Completion
10.00 am	12.00 noon	10 minutes	Task 1 Reflection
10.10 am	12.10 pm	5 minutes	Break
10.15 am	12.15 pm	10 minutes	Task 2 Briefing
10.25 am	12.25 pm	20 minutes	Task 2 Completion
10.45 am	12.45 pm	10 minutes	Task 2 Reflection
10.55 am	12.55 pm	10 minutes	Summary and Questions

Just a Reminder

- This session is being recorded simply because we can't take notes fast enough!
- We expect a variety of approaches and there are **no right or wrong answers**
- Any Questions before we continue?

Collaborative Task 1

Find Most Suitable Supporting Case



Daedalus Search Term

Pylon attachment

*This has been provided by an experienced member of the In-Service team.

Daedalus Output 1

A320 FAMILY ISQ DATABASE.xlsm [Read-Only] - Microsoft Excel

File Home Insert Page Layout Formulas Data Review View Add-Ins Acrobat

Clipboard Font Alignment Number Styles

Damage, Trailing Edge Seal Plate, Right Hand Wing.

Find ISQ

AIRBUS

Bolt Loc. Drgs

A320 Family ISQ Database

1 DAEDALUS

ISQ FILE RAS FOLDER

2 pylon

Att Pylon Pick Up
Pylon Attachment
Pylon Corrosion
Pylon Reinforcing Plate
Pylon Systems
Pylon Systems Mounting Plate

SI Reference	In Date	Title	MSN	ATA	A/C type	Airline	Engineer	File Location	Stress Ref.	Fatigue Ref.
195	29138/2014	Wear Pylon System Mounting Plate, LH Wing	1332	57-21-11	A320-200	LAN	Hill,Dennis			
278	28994/2014	Corrosion, Btm Skin Pylon Reinforcing Plate, Lower Surface, LE OH, Ribs 6-7, RH Wing	1699	57-21-11	A319-100	AFR	Kaba,Tim	WICHITA	A319/R/57-22	
304	28761/2014	Wear Damage, Pylon D-Nose Skin, Both Wings	3545	57-41-11	A320-200	AFL	Fensome,Chris	FILTON	A320/R/57-41	
399	28487/2014	Corrosion, Pylon Reinforcing Plate, Rib 8, Stringer 5, Right Hand Wing	2382	57-21-11	A319-100	AMC	GALLIVAN,Mike	SITEC	A319/R/57-22	
438	28402/2014	Impact Damage, Pylon Cantilever, Left Hand Wing	1549	57-26-19	A319-100	DAL	PERRIN,Joseph			
444	28362/2014	Wear, Pylon Reinforcing Plate, Bottom Skin, Ribs 8 - 9, Forward of Front Spar, Right Hand Wing	1725	57-21-11	A320-200	VVC	Scambler,Andy	SITEC	A320/R/57-22	
452	28333/2014	Gouge, Pylon Systems Support Mounting Plate, Right Hand Wing	1207	57-21-11	A321-200	MON	Simmons,Andrew			
455	28330/2014	Wear, Bottom Skin Panel 3, Ribs 7-8 at Pylon Systems Mounting Plate, Right Hand Wing	1197	57-21-11	A319-100	BAW	Simmons,Andrew	FILTON	A319/R/57-22	
572	27930/2014	Corroded Fastener/Nut, Pylon Forward Attachment Fitting, Left Hand Wing	990	57-26-19	A320-200	PIC	UDALL,Mark	FILTON	A320/R/57-26	
607	27859/2014	Corrosion, Btm Skin Pylon Reinforcing Plate, Inboard Edge, LH Wing	583	57-21-11	A321-100	AZA	Salem-Kizzlar,Shari	WICHITA	A321/R/57-22	
641	27719/2014	Elongated Holes, Pylon Systems Mounting Plate, RH Wing	1825	57-21-11	A320-200	TAM	Holland,Nicole	WICHITA	A320/R/57-22	
655	27667/2014	Fretting Damage, Pylon Systems Mounting Plate, LH Wing	1415	57-21-11	A319-100	AFR	UDALL,Mark			
665	27651/2014	Scratch Damage, Iner Face of Pylon Forward Pickup Fitting Outboard Lug at Rib 7, Right Hand Wing	1763	57-26-19	A321-200	MON	UDALL,Mark	FILTON	A321/R/57-26	
969	26798/2013	Damages, Bottom Skin Panel 3, Pylon Systems Cutout, LH Wing	1804	57-21-11	A320-200	TAM	Kobza,Mark	WICHITA	A320/R/57-22	
994	26726/2013	Missing Fastener, Bottom Skin Aft of Rear Spar at Pylon Reinforcing, RH Wing	2091	57-21-11	A319-100	AFL	Hill,Dennis	FILTON	A319/R/57-22	
1050	26575/2013	Corrosion, Pylon Reinforcing Plate, RH Wing - SEE 12872	1747	57-21-11	A320-200	AJM	Hill,Dennis	NA	A320/R/57-22	
1141	26388/2013	Gouge, Pylon Reinforcing Plate, Bottom Skin, Ribs 8-9, Left Hand Wing	2800	57-21-11	A320-200	VRD	Pulido,Carlos	SITEC	A320/R/57-22	
1178	26301/2013	Corrosion, Pylon Reinforcing Plate, Rib 8, RH Wing	2665	57-21-11	A320-200	AMC	Hill,Dennis	FILTON	A320/R/57-22	
1275	26025/2013	Chafing, Pylon Reinforcing Plate, RH Wing	1760	57-21-11	A320-200	BAW	Puszko,Beata	FILTON	A320/R/57-22	
1298	25927/2013	Corrosion, Pylon Reinforcing Plate, Lower Inboard Surface, LH Wing	1798	57-21-11	A321-200	SAS	Kaba,Tim	WICHITA	A321/R/57-22	
1310	25896/2013	Oversize hole, Bottom Skin Panel 3, Pylon system mounting plate, Left Hand Wing	1672	57-21-11	A320-200	TAM	Hart,Martin	SITEC	A320/R/57-22	
1313	25891/2013	Fuel Leak, Forward Pylon Pick-up Fitting, Left Hand Wing	1351	57-26-19	A320-200	LAN	Rietz-Schwind,Army	FILTON	A320/R/57-26	
1395	25864/2013	Wear & Damaged Holes, Bottom Skin Panel 3, Pylon Systems Mounting Plate, Ribs 7-8, Left Hand Wing	277	57-21-11	A320-200	ACA	UDALL,Mark	FILTON	A320/R/57-22	
1423	25591/2013	Tooling Mark, Engine Pylon Spigot Fitting, RH Wing	468	57-26-19	A321-100	DLH	Hill,Dennis	FILTON	A321/R/57-26	
1448	25533/2013	Corrosion, Pylon Reinforcing Plate, RH Wing	2194	57-21-11	A319-100	BMA	Wilson,Steven			
1505	25393/2013	Gouge/Chafing Damage, Leading Edge D Nose Skins Inboard of Pylon, Both Wings	3227	57-41-11	A320-200	IGO	UDALL,Mark	FILTON	A320/R/57-41	
1539	25110/2013	Wear, Bottom Skin Panel 3, Pylon System Hole, Ribs 7-8, Left Hand Wing	1096	57-21-11	A319-100	TAM	Pulido,Carlos	SITEC	A319/R/57-22	
1599	25167/2013	Wear, Bottom Skin Panel 3, Ribs 7-8 at Pylon Systems Mounting Plate, Left Hand Wing	1593	57-21-11	A320-200	TAM	UDALL,Mark	FILTON	A320/R/57-22	
1600	25166/2013	Wear, Bottom Skin Panel 3, Ribs 7-8 at Pylon Systems Mounting Plate, Left Hand Wing	1760	57-21-11	A320-200	BAW	Simmons,Andrew	FILTON	A320/R/57-22	
1822	24824/2013	Chafing, Bottom Skin Panel 3, Ribs 7-8 at Pylon Systems Mounting Plate, Left Hand Wing	1852	57-21-11	A320-200	CQH	Simmons,Andrew	FILTON	A320/R/57-22	
1894	24444/2013	Wear, Pylon Reinforcing Plate, Bottom Skin, RH Wing	3060	57-21-11	A320-200	CSA	Dade,Derek	WICHITA	A320/R/57-22	
1895	24442/2013	Wear, Pylon Reinforcing Plate, Bottom Skin, LH Wing	3060	57-21-11	A320-200	CSA	Dade,Derek	WICHITA	A320/R/57-22	
1911	24397/2013	Wear & Damaged Hole, Bottom Skin Panel 3, Pylon Systems Mounting Plate, Ribs 7-8, Left Hand Wing	1512	57-21-11	A320-200	LAN	Guy,Alan	SITEC	A320/R/57-22	
1951	24325/2013	Disbonded Conduit Harness Bracket, Pylon No. 2	3159	57-26-19	A320-200	IGO	WHITFORD,Daniel			
1953	24304/2013	ELONGATED HOLE, PYLON SYSTEMS MOUNTING PLATE, LEFT HAND WING	1733	57-21-11	A319-100	AFR	Fensome,Chris	FILTON	A319/R/57-22	50
1994	23994/2013	Gouge, Pylon Reinforcing Plate, Lower Outboard Surface, RH Wing	3161	57-21-11	A319-100	VRD	Salem-Kizzlar,Shari	WICHITA	A319/R/57-22	
2107	23710/2013	Corrosion Damage, Bottom Skin By Pylon Reinforcing Plate Between ribs 6 and 7, LH Wing - SEE 06163	466	57-21-11	A320-200	GFA	UDALL,Mark	NA	A320/R/57-22	

AIRDOC 2004 > Aircraft Histories Configuration Filters Sheet1

Daedalus Output 2

A320 FAMILY ISQ DATABASE.xlsm [Read-Only] - Microsoft Excel

File Home Insert Page Layout Formulas Data Review View Add-Ins Acrobat

Clipboard Font Alignment Number Styles

Damage, Trailing Edge Seal Plate, Right Hand Wing

1 **DAEDALUS** pylon attachment Find ISQ

2 ISQ FILE RAS FOLDER Bookmarks: Number of Pages: Last Modification: AIRBUS Bolt Loc. Drgs

SI Reference	In Date	Title	MSN	ATA	A/C Type	Airline	Engineer	File Location	Str	
572	27930/2014	22-Feb-14	Corroded Fastener/Nut, Pylon Forward Attachment Fitting, Left Hand Wing	990	57-26-19	A320-200	PIC	UDALL, Mark	FILTON	A320
2453	22716/2013	21-Feb-13	Corroded Nuts, Pylon FWD Attachment Fitting, Rib 7 to Rib 9, LH Wing	707	57-26-19	A320-200	AJ	Adams, Samuel	FILTON	A320
2730	22159/2013	04-Jan-13	Anchor Nut Damage, Pylon Fixed Leading Edge Panel 521BT Attachment, LH Wing - SEE 16339	2097	57-26-19	A320-200	QTR	Mitchell, Dave	NA	A320
3100	21460/2012	23-Oct-12	Fretting, Aft Pylon Attachment Lug Fitting, RH Wing	1320	57-26-19	A320-200	TOM	Maxwell, Mark	WICHITA	A320
4443	18813/2012	04-Feb-12	Damage, Fwd Pylon Attachment Fitting Bush, Right Hand Wing	1251	57-26-19	A320-200	TAM	Simmons, Andrew	SA 290	A320
4524	18678/2012	24-Jan-12	Nut Corrosion, Pylon Forward Attachment Fitting, Right Hand Wing	216	57-26-19	A320-200	DLH	Rayson, Andy	SITEC	A320
4749	18263/2011	08-Dec-11	Gouge, Rear Pylon Attachment Fitting Lug, Left Hand Wing	748	57-26-19	A319-100	UAL	Jennings, Graham	SITEC	A319
5043	17726/2011	24-Oct-11	Arcing Damage, Inboard Forward Pylon Attachment Fitting, Right Hand Wing	111	57-26-19	A320-200	DLH	Guy, Alan	SA 284	A320
5767	16339/2011	23-May-11	Anchor Nut Damage, Pylon Fixed Leading Edge Panel 521BT Attachment, LH Wing	2097	57-41-11	A320-200	QTR	Mitchell, Dave	FILTON	A320
6905	14319/2010	14-Oct-10	LH WING-TO-PYLON FWD ATTACHMENT - WEAR	341	57-26-19	A320-200	ACA	Churches, Gary	SA 230	A320
7042	14053/2010	13-Sep-10	Corrosion, Bottom Skin Panel 1, Upper Surface, FWD Spar Pylon Attachment, LH Wing - SEE 11912	331	57-21-11	A320-200	G2X	Churches, Gary	NA	A320
7089	13979/2010	02-Sep-10	Corrosion, Bottom Skin Panel 1, FWD Spar Pylon Attachment, LH Wing - SEE 11912	331	57-21-11	A320-200	G2X	STAMMERS, Kevin	NA	A320
7438	13322/2010	31-May-10	Corrosion, Pylon Forward Attachment, Outboard Fitting Bush, Left Hand Wing	1096	57-26-19	A319-100	TAM	BEGUE, Mathilde	SA 217	A320
7562	13072/2010	30-Apr-10	BEARING ROTATION, WING TO PYLON REAR ATTACHMENT BEARING, LH	3723	57-26-19	A320-200	MUN	MALCOLM, Colin	SA 211	A320
7579	13039/2010	27-Apr-10	LH WING PYLON FWD ATTACHMENT FITTING CRACK	894	57-26-19	A320-200	CIB	Mitchell, Dave	SA 216	A320
7809	12619/2010	10-Mar-10	Corrosion, Bottom Skin Panel No.1, Forward Of Front Spar, Rib 7 & 8, Adjacent to Pylon Attachment Brackets, Both Wings	555	57-21-11	A321-100	TNA	Mitchell, Dave	SA 200	A320
8339	11744/2009	25-Nov-09	LH BOTTOM SKIN PANEL AT PYLON ATTACHMENT	343	57-21-11	A320-200	XLF	Simmons, Andrew	SA 275	A320
8801	10978/2009	26-Aug-09	DAMAGE TO PYLON ATTACHMENT FTG, RH WING	248	57-26-19	A320-200	ACA	Churches, Gary	SA 169	A320
9302	10067/2009	30-Apr-09	Nicks, Rear Pylon Attachment, Right Hand Wing	231	57-26-19	A320-200	ACA	BEGUE, Mathilde	SA 152	A320
9336	10013/2009	24-Apr-09	Rotation, Pylon Rear Attachment Bearing, LH Wing	3213	57-26-19	A320-200	ADH	Morgan, Jonathan	SA 149	A320
9389	09910/2009	09-Apr-09	Hard Landing (3 12G) Pylon Attachment Inspections - SEE 09846	2942	57-00-00	A319-100	NKS	Sidwell, Chris	NA	A320
10062	08600/2008	28-Oct-08	Scratch, Bottom skin lower surface at Pylon Fairing Attachment area, LH Wing	477	57-21-11	A321-100	AZA	Churches, Gary	A320/128	A320
10625	07378/2008	19-May-08	PYLON TO WING ATTACHMENT FITTING, CORROSION ON BEARING	1618	57-26-19	A319-100	MXA	Lewis, Steven	A320/110	A320
10785	07043/2008	26-Mar-08	Corrosion, RH wing bottom skin at pylon attachment - SEE 03464	220	57-21-11	A320-200	AFR	Morgan, Jonathan	NA	A320
10860	06884/2008	03-Mar-08	Wear marks RH Pylon spigot attachment fitting	78	57-26-19	A320-200	DLH	Izard, George	A320/83	A320
11289	05885/2007	17-Oct-07	Pylon #1 to Wing fwd RH Attachment fitting - gouge - See 05742	802	57-26-19	A321-200	ANA	Miller, Terry	NA	A320
11290	05884/2007	17-Oct-07	RH Spigot Fitting Gouge, Pylon attachment	802	57-26-19	A321-200	D2F	Sidwell, Chris	Not Filed	A320
11329	05809/2007	03-Oct-07	RH Spigot Fitting Gouge, Pylon attachment	802	57-26-19	A321-100	D2F	Sidwell, Chris	A320/56	A320
11372	05742/2007	19-Sep-07	Pylon #1 to Wing fwd RH attachment fitting - gouge	802	57-26-19	A321-100	ANA	Miller, Terry	A320/49	A320
11481	05500/2007	08-Aug-07	Wing to pylon forward attachment fitting lug, LHS, nick	666	57-26-19	A321-200	AJM	Lewis, Steven	A320/44	A320

Collaborative Task 1 - Instructions

1. Please work with your colleagues to find a joint solution to this task
2. Read through **damage report card** provided and view **Daedalus search results** to identify repair design requirement
3. The shortlisted cases are provided as segmented information elements on each card. Please use them to find the information elements you may require to identify a suitable supporting design case
4. Order the cards and information elements on the roll of paper provided in the sequence that you have viewed them, to create a collective storyboard of your thinking. Once you've agreed, tape the elements to the paper roll
5. Add the additional elements card to each information element to add detail to the thinking behind your decisions
6. Feel free to highlight and annotate your story to illustrate your thoughts. In particular, where did you all agree or disagree strongly?

Individual Task 2

Understand Case to Apply Solution



Individual Task 2 - Instructions

1. Each of you should complete this task individually
2. You are provided with a printed copy of one of the PDF repair cases from the previous task.
3. Please imagine you are using this case to apply the design principle to your current design task.
4. View the case in the order you would normally to find the information you would require. Indicate on the document using numbers the sequence you view the information. For example, if you view the “title” description on the “Daily Repair Sheet” first please highlight this and mark it as item 1
5. Add as much detail as possible and for items of particular significance please mark the item and describe its significance. For example, if you view text detailing the location of a repair then please add detail of what this helps you to understand
6. The task is complete when you feel you have viewed enough items to apply the design solution to your current repair task



Thank you for your participation, please let me know if you have any questions or comments?

Feel free to contact me emcc20@bath.ac.uk

Group 1 Images

10

COVER
PG 1 -
25616

CE PG 1 I 1

Daily Repair Book

Account Types: 4000, 5000, 6000
ATA 01-01-01
ATA 01-01-02
ATA 01-01-03
ATA 01-01-04
ATA 01-01-05
ATA 01-01-06
ATA 01-01-07
ATA 01-01-08
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ATA 01-01-100

Account	Account Type	Account Name	Account Address	Account City	Account State	Account Zip	Account Phone	Account Fax	Account Email	Account Website
1	4000	Account 1	Address 1	City 1	State 1	Zip 1	Phone 1	Fax 1	Email 1	Website 1
2	4000	Account 2	Address 2	City 2	State 2	Zip 2	Phone 2	Fax 2	Email 2	Website 2
3	4000	Account 3	Address 3	City 3	State 3	Zip 3	Phone 3	Fax 3	Email 3	Website 3
4	4000	Account 4	Address 4	City 4	State 4	Zip 4	Phone 4	Fax 4	Email 4	Website 4
5	4000	Account 5	Address 5	City 5	State 5	Zip 5	Phone 5	Fax 5	Email 5	Website 5
6	4000	Account 6	Address 6	City 6	State 6	Zip 6	Phone 6	Fax 6	Email 6	Website 6
7	4000	Account 7	Address 7	City 7	State 7	Zip 7	Phone 7	Fax 7	Email 7	Website 7
8	4000	Account 8	Address 8	City 8	State 8	Zip 8	Phone 8	Fax 8	Email 8	Website 8
9	4000	Account 9	Address 9	City 9	State 9	Zip 9	Phone 9	Fax 9	Email 9	Website 9
10	4000	Account 10	Address 10	City 10	State 10	Zip 10	Phone 10	Fax 10	Email 10	Website 10

DAMAGE
REFLECT
PG 4 -
25616

1000
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CD PG 4 I 1

Group 1

COVER
PG 1
25616

Information Item:	
Meaning of Information Item:	
Supporting Relevance or Irrelevance:	find sheet info not correct, not being updated
Additional Information:	

(X)

PHOTOS
PG 6
25616

PH fitting A7-ACI



Information Item:

Meaning of Information Item:

Supporting Relevance or Irrelevance:
Test covered by photo.

Additional Information:

CONSER
PG 1
10978

CA PG1 I.1
Daily Report Request

Item No.	Item Name	Item Description	Item Status
1
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DAMAGE
REPORT
PG 3
10978

SIMULAE A/C
TYPE WITHIN
DATABASE EG
A328, A321 ETC

AIRBUS

CA PG 3 I.1

3

2 X

Damage
Reference
P64
25743

CF P64 I1

CF P64 I1

Item No.	Part No.	Description	QTY	Unit	Remarks
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100					

25743

3

Reference
P64
10476



Reference
P67
10476



AIRBUS

To A
Page 2
25/11/23

Information Item:
TIS No.:

Meaning of Information Item:
Identify the details which are to be used for the TIS.

Supporting Relevance or Importance:
Identify relevant drawings from which the TIS is derived.

Additional Information:
Any other items which may be relevant.

CA 105211
REPAIR DESIGN INITIAL SHEET

Sheet No. 1 of 1

Scale: 1:1

Drawn: []
Checked: []
Date: []

S/S
P/S
B/S
P/S
10/1/26

Check for changes
report leaves only
pages to look at,

TO / AI
Checking if TO / AI is
included in the pack
Going through to TIS
to check the relevance.



Checked
Page 2
25/11/23

8572
8591
8592
10/1/26

CA 10639 I-1

Sheet No. 1 of 1

Scale: 1:1

Drawn: []
Checked: []
Date: []



Tech: TD A
 PG 8
 20743

Information Item: TD No*
Meaning of Information Item: drawing for details which can be used for my job.
Supporting Relevance or Irrelevance: Different materials, material properties.
Additional Information: They used some details may be used.

SIS PG 5
 PASA PG 56
 10478

short case so read a

CA PG 56, I.1
 REPAIR DESIGN APPROVAL SHEET

REF ID: 10478	REV: 1
DATE: 27/03/01	BY: [Signature]
APPROVED BY: [Signature]	DATE: 27/03/01

lets affect on change
 report - leaves, only
 changes to look at,

VAL SHEET

NO. 120	REV: 1
DATE: 27/03/01	BY: [Signature]
APPROVED BY: [Signature]	DATE: 27/03/01

For composites
 In case of damage to composites, only recent cases are relevant as methods for repairing composites changed.

aircraft type
 checking if the pack is relevant for stress - aircraft type would have to match exactly in most cases

AIRBUS®

CB 063-14

CB 064-14

Information Item:

Meaning of Information Item:

Supporting Relevance or Irrelevance:

Additional Information:

Possible to point to log over the hole with this one to see if TA was ever issued. Could also go back to Toulouse.

T.

4 NOT enough into

IP ENGINEERING REPORT

NO	DESCRIPTION	DATE	STATUS	REVISION	BY
1
2
3
4
5

CHECK RUPA CASE SEE THE PROCEDURES

CA

- 1. The hole is to be repaired.
- 2. The repair is to be done in accordance with the applicable repair manual.
- 3. The repair is to be done in accordance with the applicable repair manual.
- 4. The repair is to be done in accordance with the applicable repair manual.
- 5. The repair is to be done in accordance with the applicable repair manual.

LEFT COOKING
FOR CASE WHICH
SEEM BETTER.

Handwritten notes in blue ink, partially obscured by other papers.

Additional Information:
Supporting Relevance or Irrelevance:
Meaning of Information Item:
Information Item:

Engineering Report form with fields for Name, Title, Date, and various checkboxes. Includes a table with columns for 'APPROVED' and 'APPROVED'.

Handwritten text: 'Program Info' in blue ink.



Form with fields: Information Item: 15092, Meaning of Information Item: Resistor, Supporting Relevance or Irrelevance, Additional Information.

Form with fields: Information Item, Meaning of Information Item, Supporting Relevance or Irrelevance, Additional Information. Handwritten notes in blue ink are present in the Additional Information field.

Vertical pink sticky note with handwritten text: 'Diagram P35-15092'.

Group 2 Images

Group 2

Information Item:
Amesbury type
Meaning of Information Item:
*could also be called
"organism of case?"*
Supporting Relevance or Irrelevance:
Additional Information:

Information Item:
Al Type
Meaning of Information Item:
*could info on justification
to work cases?*
Supporting Relevance or Irrelevance:
Additional Information:

*Color
Page
18692*

CC PG&I
Daily Report

Information Item:	<i>title</i>
Meaning of Information Item:	<i>Not on vision</i>
Supporting Relevance or Irrelevance:	<i>Not relevant</i>
Additional Information:	

PreInfo :

Handwritten notes on a narrow strip of paper, possibly a bookmark or a small note, with some illegible text.

CA-PG1 I

Daily Repair Request

No. 10078

Submittal Editable Location #1 Est. #1
 ATA 57-26-10 MDA 1004 Address Air Canada / Tower
 Aircraft Type: A320X31X Damage Group(s): PC 20078 Est. 50743
 Title: Repair Damage, Bottom, Pylon Mount Assembly
 Priority: Not Set

Submitted: 07-26-10
 Requested Part: Wing Pylon Filter
 SOAS Reference: 79020410000
 Comp. Serial No. Part No. Aircraft/Block/Alt. Alt.
 Version: 26-08-2009 TargetDate: 26-08-2009
 CIP: Fred Desjardins, 444 251 577 806 8027
 CEC: Mike Gallivan, 444 251 577 879 8288
 CSW: David Goodman, 444 251 577 879 2088
 CAA: Liam

Order	Qty	Part No.	Alt.	Alt. Description	Status
1	1	79020410000	26-08-2009	signed	
2	1	79020410000	26-08-2009	Gary Chouhine	signed
3	1	79020410000	27-08-2009	Gary Chouhine	signed
4	1	79020410000	27-08-2009	signed	
5	1	79020410000	27-08-2009	Gary Chouhine	signed
6	1	79020410000	27-08-2009	signed	
7	1	79020410000	27-08-2009	signed	
8	1	79020410000	27-08-2009	signed	
9	1	79020410000	27-08-2009	signed	
10	1	79020410000	27-08-2009	signed	
11	1	79020410000	27-08-2009	signed	
12	1	79020410000	27-08-2009	signed	
13	1	79020410000	27-08-2009	signed	
14	1	79020410000	27-08-2009	signed	

Repair Damage Approval Sheet

10/04/2009



10078
AIRBUS®

CA-PG3-I1

Customer Services Directorate
 1. Attachment #1: Signature of the Reporting Officer
 2. Attachment #2: Signature of the Reporting Officer
 3. Attachment #3: Signature of the Reporting Officer
 4. Attachment #4: Signature of the Reporting Officer
 5. Attachment #5: Signature of the Reporting Officer
 6. Attachment #6: Signature of the Reporting Officer
 7. Attachment #7: Signature of the Reporting Officer
 8. Attachment #8: Signature of the Reporting Officer
 9. Attachment #9: Signature of the Reporting Officer
 10. Attachment #10: Signature of the Reporting Officer
 11. Attachment #11: Signature of the Reporting Officer
 12. Attachment #12: Signature of the Reporting Officer
 13. Attachment #13: Signature of the Reporting Officer
 14. Attachment #14: Signature of the Reporting Officer
 15. Attachment #15: Signature of the Reporting Officer
 16. Attachment #16: Signature of the Reporting Officer
 17. Attachment #17: Signature of the Reporting Officer
 18. Attachment #18: Signature of the Reporting Officer
 19. Attachment #19: Signature of the Reporting Officer
 20. Attachment #20: Signature of the Reporting Officer

Information Item:

Title: Fwd Pylon

Meaning of Information Item:

Supporting Relevance or Irrelevance:

Affected Pylon is AFT.

Additional Information:

Information Item:

Title: T.H.

Meaning of Information Item:

Supporting Relevance or Irrelevance:

Additional Information:

Information Item:

Title of job would

Meaning of Information Item:

change with additional
information regarding

Supporting Relevance or Irrelevance:

8 new search

Additional Information:

New
info

- * Common info mentioned in early production (long long)
- * Find previous case solved by a TA (Quedley)
- * Previous TA used as reference for signature on new case.
- * Previous statements used as ref on new TA.

COVER
PG 1 -
256616

CE
Daily

Account Types: 0000-000-0000 454 0000-00
Title: [illegible]
Business Organization: [illegible]
Address: [illegible]
City: [illegible]
State: [illegible]
Country: [illegible]
Telephone: [illegible]
Fax: [illegible]
E-Mail: [illegible]
Web: [illegible]

Product Approval Status	Approval Date	Approval Type
1 - [illegible]	[illegible]	[illegible]
2 - [illegible]	[illegible]	[illegible]
3 - [illegible]	[illegible]	[illegible]
4 - [illegible]	[illegible]	[illegible]
5 - [illegible]	[illegible]	[illegible]
6 - [illegible]	[illegible]	[illegible]
7 - [illegible]	[illegible]	[illegible]
8 - [illegible]	[illegible]	[illegible]
9 - [illegible]	[illegible]	[illegible]
10 - [illegible]	[illegible]	[illegible]

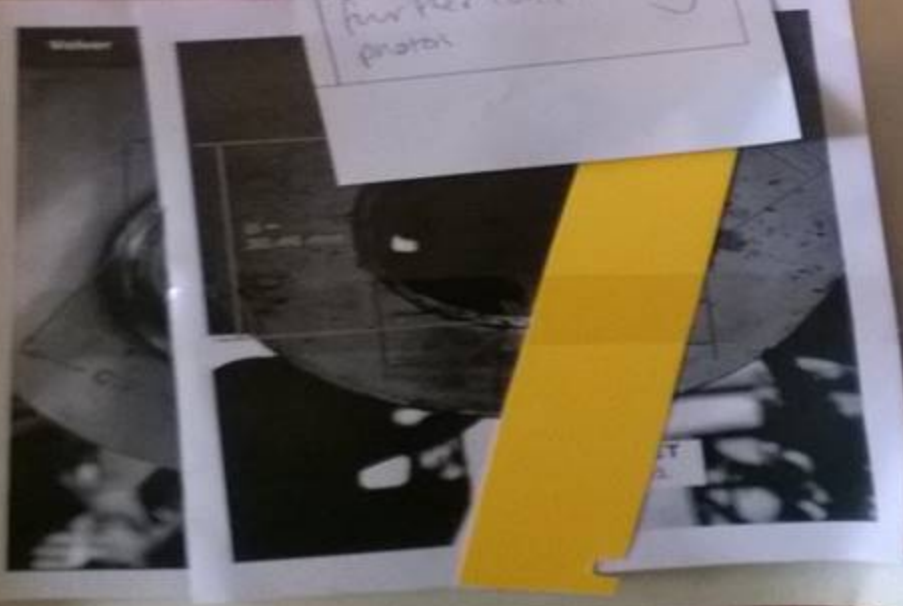
Information Item
202002
FOIA
2-25-16

Form with various fields and checkboxes, partially obscured by a yellow strip.

CP Ref 11
Daily Report Review
Form with various fields and checkboxes, partially obscured by a yellow strip.

Information Item:
Title: *Special Suspect*
Meaning of Information Item:
*may be relevant but
has not been quickly
assessed for relevance or irrelevance*
Supporting Relevance or Irrelevance:
*is not relevant
further confirmed by
photos*

Information Item:
Seen enough
Meaning of Information Item:
*Gone to TPO
Not relevant*
Supporting Relevance or Irrelevance:
Additional Information:



Descriptive Analysis of Storyboard Group 1

1. Read Collectively through Repair Request Report, one engineer taking the lead and utilising document.
2. Each engineer in turn views the Repair Request Report and skim reads through text.
3. Engineers individually move to printed cases and separately pick up a case to look through.
4. Start Sub 1: Take case 25616 and open at Coversheet.
5. Skim read to seek "Title" field of repair on Coversheet.
6. Elicit key text/terminology in title.
7. Compare repair title to repair request understanding.
8. Go to Damage Report using Bookmark provided.
9. Skim read text throughout correspondence until reach damage reporting details.
10. Skim read damage reporting text to seek key description detail.
11. Elicit key text terms/terminology to compare to current repair request.
12. Thinking Detail: Text Term Sought "Ref:SRM 57-26-16".
13. Thinking Detail: Text Term Sought "internal diameter of bushing P/N NSA5101276".
14. Go to Photos using Bookmark provided.
15. Scroll through each page with Damage Report images until all viewed.
16. Thinking Detail: Text is followed by images.
17. Compare images to current "thinking".
18. Thinking Detail: Seeing image supports thinking that case is irrelevant.
19. Make Decision Case is irrelevant to current task.
20. End Sub 1: Case Understanding complete.
21. Supporting case not yet found so seek next shortlisted case.
22. Start Sub 2: Take case 25743 and open at Coversheet.
23. Skim read to seek "Title" field of repair on Coversheet.
24. Elicit key text/terminology in title.
25. Compare repair title to repair request understanding.
26. Go to Damage Report using Bookmark provided.
27. Skim read text throughout correspondence until reach damage reporting details.
28. Skim read damage reporting text to seek key description of damage.
29. Elicit key text/terminology to compare to current repair request.
30. Thinking Detail: Text Term Sought "bearing P/N NSA 8133-10x" (Part No).
31. Thinking Detail: Text Term Sought: "bearing was removed".
32. Thinking Detail: Text Term Sought: "bushing slightly exceeds".
33. Thinking Detail: Text Term Sought: "F57253078" (Drawing No).
34. Thinking Detail: Text Term Sought: "Approaching the limits".
35. Thinking Detail: Text Term Sought: "Slightly exceeds the tolerance".
36. Thinking Detail: Text Term Sought: "Requested Actions".
37. Go to Photos using Bookmark provided.
38. Scroll through each image in sequence.
39. Compare images to current "thinking".
40. Go to TDA using Bookmark provided.
41. Skim read text on TDA subdocument.

42. Elicit key text/terminology to indicate useful link to resource to support completing my current repair request.
43. Thinking Detail: "looking for details which can be used for my current task".
44. Thinking Detail: Text Term Sought: "Ref:TD_J1_S3_25743_2013".
45. Thinking Detail: "different aircraft part is affected".
46. Thinking Detail: "irrelevance of case as supporting to current repair design".
47. Thinking Detail: "Tabs and some details can be used for current task".
48. Make Decision case is irrelevant to current task but some details may be able to be reused.
49. End Sub 2: Case understanding is complete.
50. Supporting case not yet found so seek next shortlisted case.
51. Start Sub 3: Take case 18678 and open at Coversheet.
52. Skim read to seek "Title" field of repair on Coversheet.
53. Elicit key text/terminology in title.
54. Compare repair title to repair request understanding.
55. Thinking Detail: "Nut corrosion description is not bearing installation issue".
56. Thinking Detail: "issue does not match and thus irrelevance of case is supported".
57. Make Decision case is irrelevant.
58. End Sub 3: Case understanding is complete.
59. Supporting case is not yet found so seek next shortlisted case.
60. Start Sub 4: Take case 13072 and open at Coversheet.
61. Skim read to seek "Title" field of repair on Coversheet.
62. Elicit key text/terminology in title.
63. Compare repair title to repair request understanding.
64. Skim pages to reach Damage Report.
65. Thinking Detail: "Small case does not require using Bookmarks, easier to skim".
66. Skim read three pages of text of correspondence to seek damage reporting.
67. Skim read damage reporting text to seek description of damage.
68. Elicit key text/terminology to compare to current repair task.
69. Thinking Detail: Text Term Sought: "sealant found cracked around bearing".
70. Skim to Diagram page.
71. View diagrams.
72. Elicit key text/terminology from diagram label.
73. Thinking Detail: Text Term Sought: "AMM figure 57-26-12-991-001".
74. Thinking Detail: "Case could match so seek further details about UK response".
75. Scroll to response correspondence.
76. Elicit key text/terminology to understand response given.
77. Thinking Detail: Text Term Sought: "No response given".
78. Thinking Detail: "No TA issued in pack – speak to engineer involved in case to see if TD was ever issued".
79. Thinking Detail: "Speak to Toulouse call centre to see what may have been issued to the airline for the case".
80. Thinking Detail: "Reading whole pack indicates relevance of case, could utilise any answer previously given if the detail can be found".
81. Make Decision case is relevant but requires further information to be able to reuse.
82. End Sub 4: Case understanding is complete.

83. Supporting response not yet found so seek next shortlisted case.
84. Start Sub 5: Take case 10978 and open at Coversheet.
85. Skim read to seek "title" in title field of Coversheet.
86. Elicit key text/terminology in title.
87. Compare repair title to current repair request understanding.
88. Go to Damage Report using Bookmarks provided.
89. Skim read two pages of correspondence to seek damage reporting detail.
90. Skim read damage reporting text to seek damage description.
91. Elicit key text/terminology to compare to current repair request understanding.
92. Thinking Detail: Text Term Sought: "Aircraft family detail – A320-211".
93. Thinking Detail: Text Term Sought: "Complete damage report description covering numerous lines of text".
94. Thinking Detail: Text Term Sought: "Drawing No.'s D572526 7023600, D572526 71001, D572526 72001".
95. Thinking Detail: Text Term Sought: "AIB Drawing D57252670".
96. Thinking Detail: "Similar A/C Type, Within Database e.g. A318, A321 etc".
97. Browse Bookmarks to see what subdocuments are contained.
98. Go to Pictures 1 using Bookmark provided.
99. Skim pictures to support current thinking.
100. Go to Pictures 2 using Bookmark provided.
101. Skim pictures to support current thinking.
102. Go to R57258938A (Drawing Ref) using Bookmark provided.
103. Browse two pages of drawings.
104. Thinking Detail: "Browse Bookmarks for TD/RI".
105. Thinking Detail: "Checking if TD/RI is included in the pack".
106. Thinking Detail: "Going straight to the TD/RI to check the relevance".
107. Thinking Detail: "Checking the TD/RI gives immediate check for relevance".
108. Thinking Detail: "Lots of text on damage report leaves only images to look at the quickly understand".
109. Go to RASA using Bookmark provided.
110. Skim/Browse text of RAS to seek TD/RI References.
111. Go to SIS using Bookmark provided.
112. Skim/Browse text of SIS to seek relevant key acronyms or text fields to link to additional information such as SRM/AMM or drawing references.
113. Thinking Detail: "Additional references link to additional information sources".
114. Skim/Browse to end of document.
115. Thinking Detail: "Seek additional supporting information sources by browsing documents as frequently found if present just past RAS".
116. Thinking Detail: "In case of damage to composites, only recent cases are relevant as methods for repairing composites changed".
117. Thinking Detail: "Checking the pack is relevant for stress – the aircraft type would have to match exactly in most cases".
118. Make Decision that case is irrelevant.
119. End Sub 5: Case understanding is complete.

- 120.Thinking Detail: All cases viewed and not perfect decision for relevance made so need to review the damage report details”.
- 121.Access Repair Reporting documents via ICARUS.
- 122.Skim text for AMM/Drawing Reference to link to additional information.
- 123.Elicit key text/terminology: Text Term Sought: “ AMM 57-26-12 PB401”.
- 124.Thinking Detail: “Check AMM CHAP to see the procedure”.
- 125.Thinking Details: “Utilise the most recent case as original signature may still be in the department. This will make signing off the job easier”.
- 126.Thinking Detail: “Kept looking for case which seems better”.
- 127.Final Decision Made to keep looking for relevant supporting case.

Detailed Storyboard Descriptive Group 2

1. Read through repair reporting request.
2. Engineers move to cases.
3. Engineers discuss the detail on repair request.
4. Two engineers identify that the scenario is effected utilising a repair case they have been involved in preparing or have seen in last 24hours.
5. Intervention is to remind them to utilise the shortlisted cases and to illustrate the storyboard assuming these would have been the cases they shortlisted. If it appears that none of the cases are relevant then this outcome is perfectly acceptable.
6. Thinking Detail: "Aircraft Type and Loads etc affect the judgement of design case".
7. Thinking Detail: "A/C Type – Seeking the same A/C type for justification purpose is much easier".
8. Access Repair Reporting documents via ICARUS.
9. Skim/Browse Text on repair reporting.
10. Elicit key text/terminology for understanding.
11. Thinking Detail: Text Term Sought: "No damage or signs of rotation have been identified".
12. Start Sub 1: Take case 18678 and open at Coversheet.
13. Skim read to seek "title" in title field of Coversheet.
14. Elicit key text/terminology in title.
15. Compare repair title to current repair request understanding.
16. Thinking Detail: "Title is nut corrosion supporting thinking this case is thus not relevant".
17. Make Decision case is not relevant.
18. End Sub 1: Close case as understanding is complete.
19. Supporting case not yet found so seek next shortlisted case.
20. Start Sub 2: Take case 13072 and open at Coversheet.
21. Skim read to seek "title" in title field of Coversheet.
22. Elicit key text/terminology in title.
23. Compare repair title to current repair request understanding.
24. Thinking Detail: "title not relevant to damage reported".
25. Skim/Browse pages to seek images.
26. Compare images to current understanding.
27. Make decision case is not relevant.
28. End Sub 2: Close case as understanding is complete.
29. Supporting case is not yet found so seek next shortlisted case.
30. Start Sub 3: Take case 10978 and open at Coversheet.
31. Skim read to seek "title" in title field of Coversheet.
32. Elicit key text/terminology in title.
33. Compare repair title to current repair request understanding.
34. Skim to next page to seek Damage Report.
35. Skim read several pages of correspondence text to seek damage report description.
36. Skim to next page to seek Damage Report.
37. Skim read several pages of Damage Report text to seek damage description.
38. Elicit key text/terminology to compare to current understanding.
39. Thinking Detail: Text Term Sought: "D75252672-001" (Drawing No).

40. Thinking Detail: Text Term Sought: "damages are located at the ID edges".
41. Thinking Detail: Text Term Sought: "Aveos intend to replace the bushings. However, the replacements were.....".
42. Skim pages of Damage Report text to reach images of damage reported.
43. Thinking Detail: "Title, FWD, Pylon supports relevance as affected pylon is AFT".
44. Thinking Detail: "Title may be relevant".
45. Thinking Detail: "Production Information, called upon damage reports usually open them to check what structure is affected, to support relevance of case".
46. View each of four images.
47. Go to previous Damage Report Text.
48. Skim read text.
49. Thinking Detail: Text Terms/Fields Sought: "Drawing No's, Part No's, Measurement details for Pylon Bracket, Original Bushing and Replacement Bushing".
50. Thinking Detail: "Pictures within original damage report are information item".
51. Thinking Detail: "Even if a job is irrelevant I may look through the pictures out interest".
52. Make Decision case is not relevant to current repair task.
53. Make Decision to keep hold onto the repair reporting details for this case for future reference due to drawing and part number content.
54. End Sub 3: Close case as understanding is complete.
55. Supporting case is not yet found so seek next shortlisted case.
56. Start Sub 4: Take case 25616 and open at Coversheet.
57. Skim read to seek "title" in title field of Coversheet.
58. Elicit key text/terminology in title.
59. Compare repair title to current repair request understanding.
60. Go to Damage Report using Bookmark provided.
61. Skim read text.
62. Go to Photos using Bookmark provided.
63. View two photographs of original damage reporting.
64. Thinking Detail: "Title suggests may be relevant but damage report quickly tells irrelevant further confirmed by photographs".
65. Make Decision case is not relevant to current repair design task.
66. End Sub 4: Close case as understanding is complete.
67. Supporting case is not yet found so seek next shortlisted case.
68. Start Sub 5: Take case 25743 and open at Coversheet.
69. Skim read to seek "title" in title field of Coversheet.
70. Elicit key text/terminology in title.
71. Compare repair title to current repair request understanding.
72. Thinking Detail: "Seen enough pics so gone straight to TAS, case not relevant".
73. Go to TAS using Bookmark provided.
74. Skim read text on TAS.
75. Thinking Detail: Text Term Sought: "Repair Description: Both bearings were removed and the bushes inspected for damage, the LH bush was found to be within drawing tolerance and the RH bush was found to be slightly out of tolerance to production drawing F572-53078. New bearings were installed in accordance with TD_J1_S3_25743_2013 Issue A without deviation as confirmed in damage report ES-DE/260920135ZC-02".

76. Make Decision case is not relevant.
77. End Sub 5: Close case as case understanding is complete.
78. Supporting case is not yet found so seek next shortlisted case.
79. Start Sub 6: New Information for Repair Reporting for current request.
80. Thinking Detail: "Title of job would (potentially) change additional information, requiring a new search (for supporting case)".
81. Thinking Detail: "A new search potentially leads back to one of the cases".
82. Open updated repair request document from ICARUS.
83. Read in detail.
84. Make Decision for new Daedalus search based upon additional information.
85. Conduct Daedalus search (retrieves similar case to that already shortlisted).
86. End Sub 6: Updated understanding of repair request complete.
87. Seek supporting case from those shortlisted in Daedalus.
88. Start Sub 7: Reopen case 13072 at Coversheet.
89. Scroll through correspondence.
90. Skim read page text.
91. Go to Images of Damage Report by scrolling.
92. Thinking Detail: Text Term Sought from image: "AMM-Figure 57-26-12-991-001/sheet 4011/1".
93. Thinking Detail: "Would have gone back when rotation was found, IPC picture and comment bearing TA from correspondence, PIC from IPC gives ATA Chapter".
94. Thinking Detail: "*Common case mentioned in early production (long range), *Find previous case solved by TA (Daedalus), *Previous TA used as reference for signature on new case, *Previous statements used as reference on new TA".
95. Make Decision TA issued is relevant to current repair task.

Document Information Summaries

Taken from Informative Elements
Utilised on Storyboard

Group 1

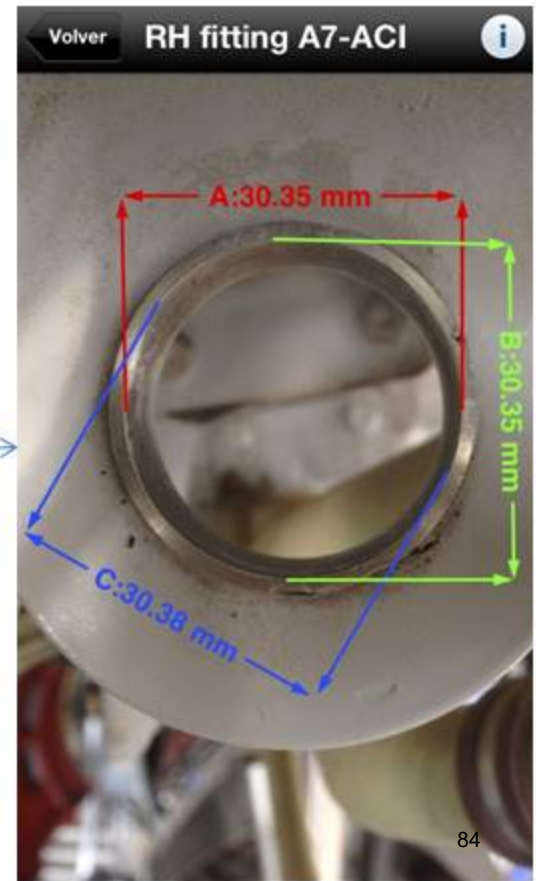
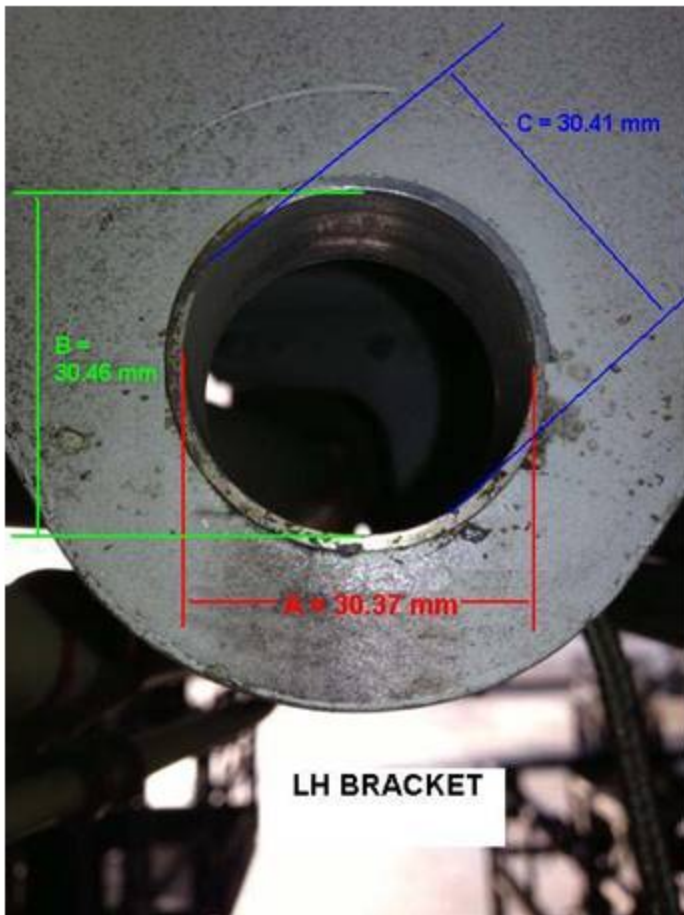
Case 1 (25616)

4. Start Sub 1: Take case 25616 and open at Coversheet.
5. Skim read to seek "Title" field of repair on Coversheet.
6. Elicit key text/terminology in title.
7. Compare repair title to repair request understanding.
8. Go to Damage Report using Bookmark provided.
9. Skim read text throughout correspondence until reach damage reporting details.
10. Skim read damage reporting text to seek key description detail.
11. Elicit key text terms/terminology to compare to current repair request.
12. Thinking Detail: Text Term Sought "Ref:SRM 57-26-16".
13. Thinking Detail: Text Term Sought "internal diameter of bushing P/N NSA5101276".
14. Go to Photos using Bookmark provided.
15. Scroll through each page with Damage Report images until all viewed.
16. Thinking Detail: Text is followed by images.
17. Compare images to current "thinking".
18. Thinking Detail: Seeing image supports thinking that case is irrelevant.
19. Make Decision Case is irrelevant to current task.
20. End Sub 1: Case Understanding complete.

Title	Damage
Bearing Migration, Pylon Fairing Rear Attachment, Both Wings.	

Subject aircraft is presently undergoing C-check here in Doha. During inspection, bearing P/N NSA8133-10X was found migrated on both LH and RH pylon fairing bracket (Ref: SRM 57-26-16).

The bearing was removed to check the internal diameter of bushing P/N NSA5101276. The internal diameter of the bushing slightly exceeds the tolerance per Airbus drawing F57253078, as detailed in the attached illustrations.



Case 2 (25743)

22. Start Sub 2: Take case 25743 and open at Coversheet.
23. Skim read to seek "Title" field of repair on Coversheet.
24. Elicit key text/terminology in title.
25. Compare repair title to repair request understanding.
26. Go to Damage Report using Bookmark provided.
27. Skim read text throughout correspondence until reach damage reporting details.
28. Skim read damage reporting text to seek key description of damage.
29. Elicit key text/terminology to compare to current repair request.
30. Thinking Detail: Text Term Sought "bearing P/N NSA 8133-10x" (Part No).
31. Thinking Detail: Text Term Sought: "bearing was removed".
32. Thinking Detail: Text Term Sought: "bushing slightly exceeds".
33. Thinking Detail: Text Term Sought: "F57253078" (Drawing No).
34. Thinking Detail: Text Term Sought: "Approaching the limits".
35. Thinking Detail: Text Term Sought: "Slightly exceeds the tolerance".
36. Thinking Detail: Text Term Sought: "Requested Actions".
37. Go to Photos using Bookmark provided.
38. Scroll through each image in sequence.
39. Compare images to current "thinking".
40. Go to TDA using Bookmark provided.
41. Skim read text on TDA subdocument.
42. Elicit key text/terminology to indicate useful link to resource to support completing my current repair request.
43. Thinking Detail: "looking for details which can be used for my current task".
44. Thinking Detail: Text Term Sought: "Ref:TD_J1_S3_25743_2013".
45. Thinking Detail: "different aircraft part is affected".
46. Thinking Detail: "irrelevance of case as supporting to current repair design".
47. Thinking Detail: "Tabs and some details can be used for current task".
48. Make Decision case is irrelevant to current task but some details may be able to be reused.
49. End Sub 2: Case understanding is complete.

Title **Damage**

Bearing Migration, Pylon Fairing Rear Attachment, Both Wings.

Subject aircraft is presently undergoing C-check here in Doha. During inspection, bearing P/N NSA8133-10X was found migrated on both LH and RH pylon fairing bracket (Ref: SRM 57-26-16).

The bearing was removed to check the internal diameter of bushing P/N NSA5101276. The internal diameter of the bushing slightly exceeds the tolerance per Airbus drawing F57253078, as detailed in the attached illustrations.

LH Wing-Side: Approached the limits ::::::::::::::: RH Wing: slightly exceeds the tolerance

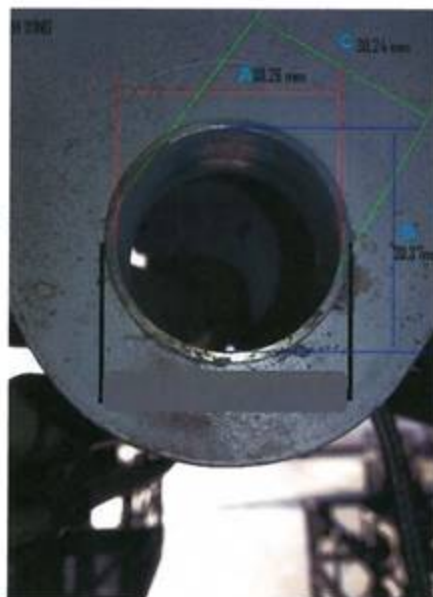
Presently, QTR does not have the capability to replace the bushing P/N NSA5101276 per Airbus drawing F57253078.

QTR Proposal: (As previously approved per RDAS Ref:70582881/003/2013 for MSN0746)

Requested Actions:

1. Please advise if QTR proposal is acceptable as permanent solution.
3. We kindly request for your initial comments by COB Hours tomorrow, 27 September 2013 Toulouse time.
4. RDAS is requested by close of Toulouse business hours on Monday, 30 September 2013.

Aircraft is scheduled for maintenance release on 01st October, 2013.



Airbus		Technical Disposition		Ref.: TD_01_2014_012
AC: A330-300-012	MSN: 0768	Task Ref.: 19883357	Issue: A	
Compteur: A. Raza-Schmidt	J.R.	Date: 27 Sep 2013	Page: 1 of 1	
Drawn: T. MAHWOOD		Approved: A. Simons		
Bearing Migration, Pylon Fairing Rear Attachment Bracket, Both Wings.				
Introduction:				
During inspection the pylon fairing rear attachment bearing was found to have migrated from the bush on both wings. Both bearings were removed and the bushes inspected for damage. The LH bush was found to be within drawing tolerance and the RH bush was found to be slightly out of tolerance to production drawing F572-53078.				
Repair References:				
Operator's damage report: EIS-DE/26082013S2C-01				
Production Drawing: F572-53078				
Repair Procedure:				
For both wings,				
1. Inspect the brackets to ensure no further damage / corrosion.	NTM 51-10-02			
2. Fit protect bare metal as necessary.	SRM 51-25-11			
3. Install new bearings in accordance with F572-53078 using Loctite 290 (3M, 025847), and cure in accordance with the manufacturer's instruction.				
4. Fit-stone paint finish as necessary.	SRM 51-75-12			
5. Report back endorsement details to Airbus for repair approval.				

Case 3 (18678)

51. Start Sub 3: Take case 18678 and open at Coversheet.

52. Skim read to seek "Title" field of repair on Coversheet.

53. Elicit key text/terminology in title.

54. Compare repair title to repair request understanding.

55. Thinking Detail: "Nut corrosion description is not bearing installation issue".

56. Thinking Detail: "issue does not match and thus irrelevance of case is supported".

57. Make Decision case is irrelevant.

58. End Sub 3: Case understanding is complete.

Title

Damage Corrosion

Nut Corrosion, Pylon Forward Attachment Fitting, Right Hand Wing.

Case 4 (13072)

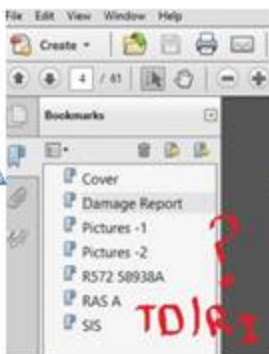
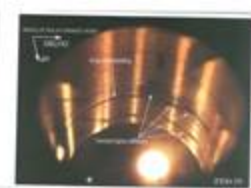
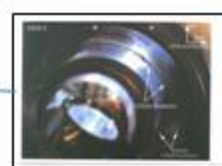
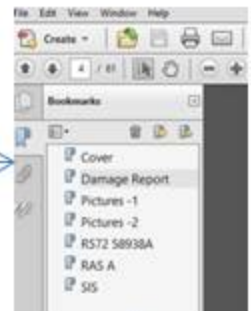
60. Start Sub 4: Take case 13072 and open at Coversheet.
61. Skim read to seek "Title" field of repair on Coversheet.
62. Elicit key text/terminology in title.
63. Compare repair title to repair request understanding.
64. Skim pages to reach Damage Report.
65. Thinking Detail: "Small case does not require using Bookmarks, easier to skim".
66. Skim read three pages of text of correspondence to seek damage reporting.
67. Skim read damage reporting text to seek description of damage.
68. Elicit key text/terminology to compare to current repair task.
69. Thinking Detail: Text Term Sought: "sealant found cracked around bearing".
70. Skim to Diagram page.
71. View diagrams.
72. Elicit key text/terminology from diagram label.
73. Thinking Detail: Text Term Sought: "AMM figure 57-26-12-991-001".
74. Thinking Detail: "Case could match so seek further details about UK response".
75. Scroll to response correspondence.
76. Elicit key text/terminology to understand response given.
77. Thinking Detail: Text Term Sought: "No response given".
78. Thinking Detail: "No TA issued in pack – speak to engineer involved in case to see if TD was ever issued".
79. Thinking Detail: "Speak to Toulouse call centre to see what may have been issued to the airline for the case".
80. Thinking Detail: "Reading whole pack indicates relevance of case, could utilise any answer previously given if the detail can be found".
81. Make Decision case is relevant but requires further information to be able to reuse.
82. End Sub 4: Case understanding is complete.

Case 5 (10978)

84. Start Sub 5: Take case 10978 and open at Coversheet.
85. Skim read to seek "title" in title field of Coversheet.
86. Elicit key text/terminology in title.
87. Compare repair title to current repair request understanding.
88. Go to Damage Report using Bookmarks provided.
89. Skim read two pages of correspondence to seek damage reporting detail.
90. Skim read damage reporting text to seek damage description.
91. Elicit key text/terminology to compare to current repair request understanding.
92. Thinking Detail: Text Term Sought: "Aircraft family detail – A320-211".
93. Thinking Detail: Text Term Sought: "Complete damage report description covering numerous lines of text".
94. Thinking Detail: Text Term Sought: "Drawing No.'s D572526 7023600, D572526 71001, D572526 72001".
95. Thinking Detail: Text Term Sought: "AIB Drawing D57252670".
96. Thinking Detail: "Similar A/C Type, Within Database e.g. A318, A321 etc".
97. Browse Bookmarks to see what subdocuments are contained.
98. Go to Pictures 1 using Bookmark provided.
99. Skim pictures to support current thinking.
100. Go to Pictures 2 using Bookmark provided.
101. Skim pictures to support current thinking.
102. Go to R57258938A (Drawing Ref) using Bookmark provided.
103. Browse two pages of drawings.
104. Thinking Detail: "Browse Bookmarks for TD/RI".
105. Thinking Detail: "Checking if TD/RI is included in the pack".
106. Thinking Detail: "Going straight to the TD/RI to check the relevance".
107. Thinking Detail: "Checking the TD/RI gives immediate check for relevance".
108. Thinking Detail: "Lots of text on damage report leaves only images to look at the quickly understand".
109. Go to RASA using Bookmark provided.
110. Skim/Browse text of RAS to seek TD/RI References.
111. Go to SIS using Bookmark provided.
112. Skim/Browse text of SIS to seek relevant key acronyms or text fields to link to additional information such as SRM/AMM or drawing references.
113. Thinking Detail: "Additional references link to additional information sources".
114. Skim/Browse to end of document.
115. Thinking Detail: "Seek additional supporting information sources by browsing documents as frequently found if present just past RAS".
116. Thinking Detail: "In case of damage to composites, only recent cases are relevant as methods for repairing composites changed".
117. Thinking Detail: "Checking the pack is relevant for stress – the aircraft type would have to match exactly in most cases".
118. Make Decision that case is irrelevant.
119. End Sub 5: Case understanding is complete.

Title
 Gouge Damage, Bushes, FWD Inboard Pylon Attachment
 Fitting, RH Wing

Damage Gouge(s)



Repair Request

Group 2

Case 1 (18678)

12. Start Sub 1: Take case 18678 and open at Coversheet.
13. Skim read to seek "title" in title field of Coversheet.
14. Elicit key text/terminology in title.
15. Compare repair title to current repair request understanding.
16. Thinking Detail: "Title is nut corrosion supporting thinking this case is thus not relevant".
17. Make Decision case is not relevant.
18. End Sub 1: Close case as understanding is complete.

Title

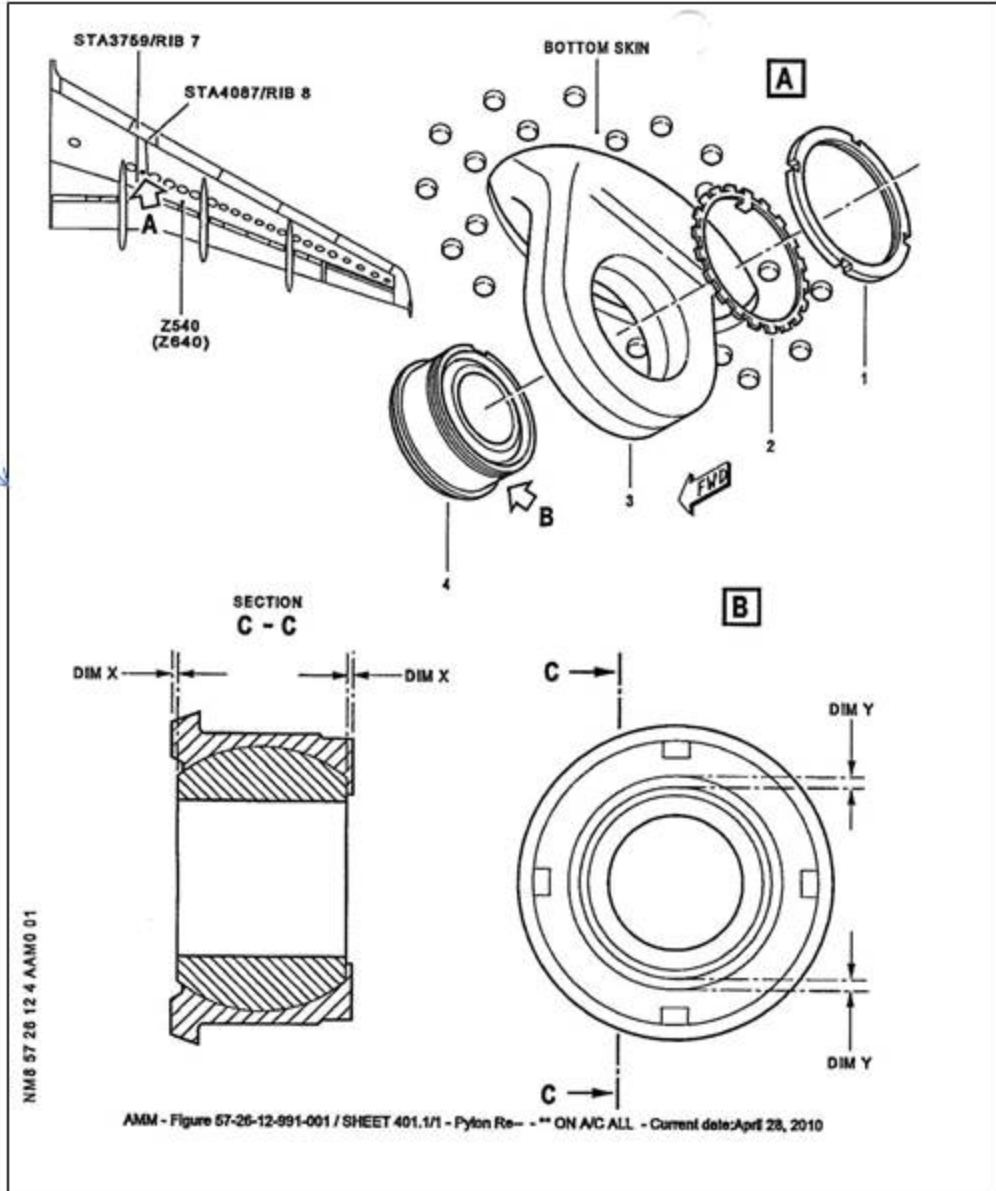
Damage Corrosion

Nut Corrosion, Pylon Forward Attachment Fitting, Right Hand Wing.

Case 2 (13072)

20. Start Sub 2: Take case 13072 and open at Coversheet.
21. Skim read to seek "title" in title field of Coversheet.
22. Elicit key text/terminology in title.
23. Compare repair title to current repair request understanding.
24. Thinking Detail: "title not relevant to damage reported".
25. Skim/Browse pages to seek images.
26. Compare images to current understanding.
27. Make decision case is not relevant.
28. End Sub 2: Close case as understanding is complete.

Title Damage Sealant problems
 BEARING ROTATION, LH WING TO PYLON REAR
 ATTACHMENT BEARING



Case 3 (10978)

30. Start Sub 3: Take case 10978 and open at Coversheet.
31. Skim read to seek "title" in title field of Coversheet.
32. Elicit key text/terminology in title.
33. Compare repair title to current repair request understanding.
34. Skim to next page to seek Damage Report.
35. Skim read several pages of correspondence text to seek damage report description.
36. Skim to next page to seek Damage Report.
37. Skim read several pages of Damage Report text to seek damage description.
38. Elicit key text/terminology to compare to current understanding.
39. Thinking Detail: Text Term Sought: "D75252672-001" (Drawing No).
40. Thinking Detail: Text Term Sought: "damages are located at the ID edges".
41. Thinking Detail: Text Term Sought: "Aveos intend to replace the bushings. However, the replacements were.....".
42. Skim pages of Damage Report text to reach images of damage reported.
43. Thinking Detail: "Title, FWD, Pylon supports relevance as affected pylon is AFT".
44. Thinking Detail: "Title may be relevant".
45. Thinking Detail: "Production Information, called upon damage reports usually open them to check what structure is affected, to support relevance of case".
46. View each of four images.
47. Go to previous Damage Report Text.
48. Skim read text.
49. Thinking Detail: Text Terms/Fields Sought: "Drawing No's, Part No's, Measurement details for Pylon Bracket, Original Bushing and Replacement Bushing".
50. Thinking Detail: "Pictures within original damage report are information item".
51. Thinking Detail: "Even if a job is irrelevant I may look through the pictures out interest".
52. Make Decision case is not relevant to current repair task.
53. Make Decision to keep hold onto the repair reporting details for this case for future reference due to drawing and part number content.
54. End Sub 3: Close case as understanding is complete.

Case 4 (25616)

56. Start Sub 4: Take case 25616 and open at Coversheet.

57. Skim read to seek "title" in title field of Coversheet.

58. Elicit key text/terminology in title.

59. Compare repair title to current repair request understanding.

60. Go to Damage Report using Bookmark provided.

61. Skim read text.

62. Go to Photos using Bookmark provided.

63. View two photographs of original damage reporting.

64. Thinking Detail: "Title suggests may be relevant but damage report quickly tells irrelevant further confirmed by photographs".

65. Make Decision case is not relevant to current repair design task.

66. End Sub 4: Close case as understanding is complete.

Title

Bearing Migration, Pylon Faring Rear Attachment, Both Wings.

Damage

From: marcos@qatarairways.com.qa
 To: atfc@airbus.com
 Date: 17-09-2013, 14:33
 Cc: marco@qatarairways.com.qa
 Cc: Ole@airbus.com
 Cc: reginald@qatarairways.com.qa
 Cc: subhojit@qatarairways.com.qa
 Cc: pb@airbus.com
 Cc: leon@airbus.com

Subject: QTR AIRWAY: TM/AN/ACTU/1 and RH Pylon Fairing [-]
 -WORK STOPPAGE-

Our Reference: ES-DE-1700103VA-01

Aircraft F#: 3020-06

Aircraft IC: 6807

Dear Airbus,

Subject aircraft is presently undergoing C-check here in Doha. During inspection, bearing P/N NSAA133-103 was found migrated on both LH and RH pylon fairing brackets (Ref: XSM 15-26-36).

The bearing was removed to check the internal diameter of bearing P/N NSAA133-103. The internal diameter of the bearing slightly exceeds the tolerance per Airbus drawing 177210376, as detailed in the attached illustration.

Presently, QTR does not have the capability to replace the bearing P/N NSAA133-103 per Airbus drawing 177210376.

As per NSAA133 standard, bearing P/N NSAA133-103 should have an outer diameter of 30.52 mm.

QTR Proposal:

- Perform detailed visual inspection on the bearings to confirm NO further damage.
- Install new bearing P/N NSAA133-103 per P/N 1-05-27 using E-6000 adhesive on both LH and RH brackets. We note that E-6000's adhesive is used for gaps up to 0.14 mm. The maximum gap at location where maximum fit was measured should be 0.147 mm, and less than 0.14 mm on all other locations.

Best regards,

(/WORK STOPPAGE/)

Our Reference: ES-DE-1700103VA-01

Aircraft F#: 3020-06

Aircraft IC: 6807

Dear Airbus,

Subject aircraft is presently undergoing C-check here in Doha. During inspection, bearing P/N NSAA133-103 was found migrated on both LH and RH pylon fairing brackets (Ref: XSM 15-26-36).

The bearing was removed to check the internal diameter of bearing P/N NSAA133-103. The internal diameter of the bearing slightly exceeds the tolerance per Airbus drawing 177210376, as detailed in the attached illustration.

Presently, QTR does not have the capability to replace the bearing P/N NSAA133-103 per Airbus drawing 177210376.

As per NSAA133 standard, bearing P/N NSAA133-103 should have an outer diameter of 30.52 mm.

QTR Proposal:

- Perform detailed visual inspection on the bearings to confirm NO further damage.
- Install new bearing P/N NSAA133-103 per P/N 1-05-27 using E-6000 adhesive on both LH and RH brackets. We note that E-6000's adhesive is used for gaps up to 0.14 mm. The maximum gap at location where maximum fit was measured should be 0.147 mm, and less than 0.14 mm on all other locations.

Requested Action:

- Please advise if QTR proposal is acceptable as per current solution.
- Otherwise, please advise if acceptable until next aircraft C-check (28 months).
- We kindly request for your initial comments at 0900 hours, on 18 September 2013 (Tuesday) time, due to work stoppage situation.
- QTR is requested by close of business hours on Friday, 20 September 2013.

Aircraft is scheduled for maintenance release on 23 September 2013.

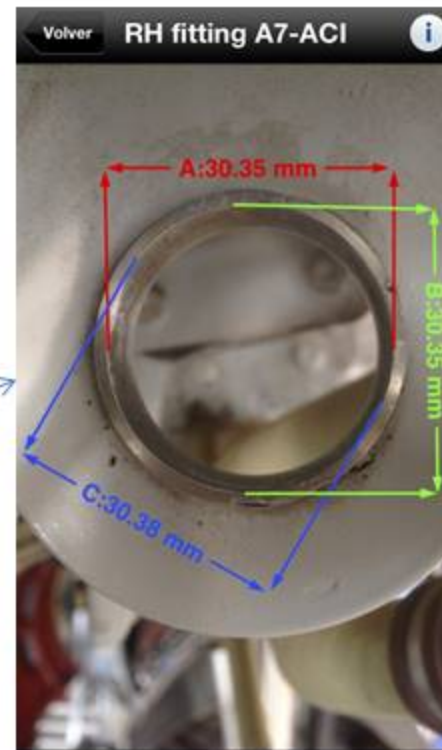
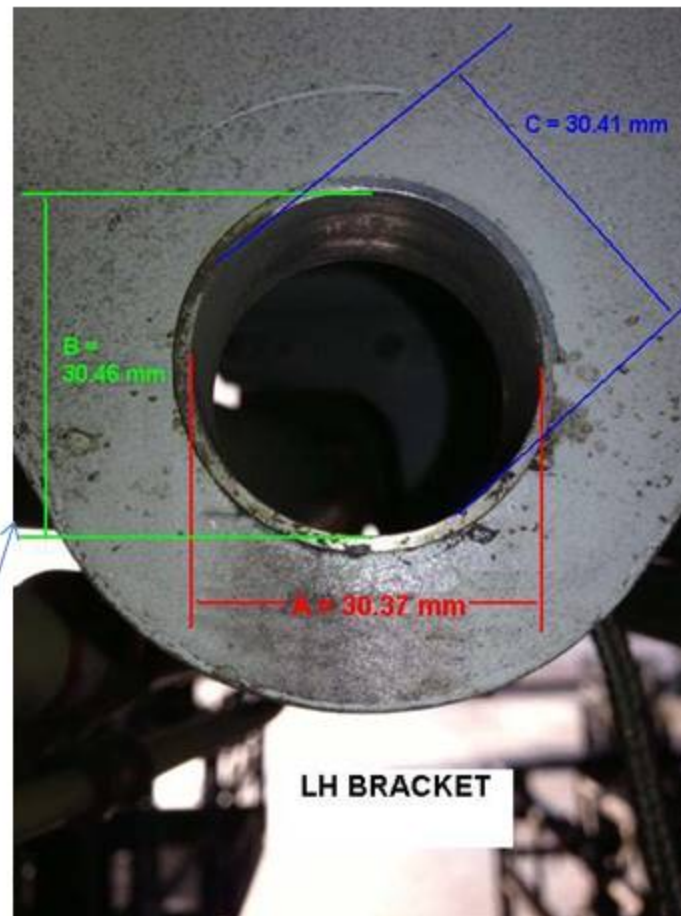
Best regards,

Osly Pasha-Semara

Development Engineer - Aircraft Structures

Mobile No: +974 93 130271

Fax No: +974 48800000



Case 5 (25743)

68. Start Sub 5: Take case 25743 and open at Coversheet.

69. Skim read to seek "title" in title field of Coversheet.

70. Elicit key text/terminology in title.

71. Compare repair title to current repair request understanding.

72. Thinking Detail: "Seen enough pics so gone straight to TAS, case not relevant".

73. Go to TAS using Bookmark provided.

74. Skim read text on TAS.

75. Thinking Detail: Text Term Sought: "Repair Description: Both bearings were removed and the bushes inspected for damage, the LH bush was found to be within drawing tolerance and the RH bush was found to be slightly out of tolerance to production drawing F572-53078. New bearings were installed in accordance with TD_J1_S3_25743_2013 Issue A without deviation as confirmed in damage report ES-DE/2609201352C-02".

76. Make Decision case is not relevant.

77. End Sub 5: Close case as case understanding is complete.



Repair Design Technical Approval Sheet

19. RDAS Ref.: TAS_J1_S3_25743_2013#A	1. RDAS Ref.: 70583357/003/2013#A	20. Page 1 of 3
4. A/C Type: A330-202-052	5. MSN: 0760	6. ATA: 57-26-16
8. P/N:	7. FH: 35592	
9. S/N:		FC: 6701

10. Title: Bearing Migration, Pylon Fairing Rear Attachment, Both Wings.

11. Damage Description:

During inspection, the pylon fairing rear attachment bearing was found to have migrated from the bush on both wings, as described in damage report ES-DE/26092013SZC-01.

12. Repair Description:

Both bearings were removed and the bushes inspected for damage, the LH bush was found to be within drawing tolerance and the RH bush was found to be slightly out of tolerance to production drawing F572-53078. New bearings were installed in accordance with TD_J1_S3_25743_2013 Issue A without deviation as confirmed in damage report ES-DE/26092013SZC-02.

Repair Ref.: See Damage / Repair Description.

21. Previous approved repair applicable ?

If YES fill reference below, if NO go to 22

YES NO

21.1. Previous approved repair reference :

21.2. Transfer list reference / justification :

22. Additional work to show compliance ?

If NO fill 22.1 and 22.2. if YES go to 23

YES NO

22.1. Document reference (incl. specific paragraph) :

22.2. Justification : SJD: SAS_J1_S3_25743_2013#A
FJD: SAS_J1_S3_25743_2013#A

23. Additional work to show compliance to applicable certification requirements

NOT APPLICABLE

16. Part 21A. 435 Classification

MAJOR MINOR

Reason: Temporary repair with a life limitation not for fatigue reasons

17. Repair categorization

A Permanent repair with no additional requirements
B Permanent repair with inspection required
C Temporary or life limited repair

24. Repair Technical Engineer

A Structure Repair Design approval can be released with a temporary time limitation providing that this temporary period is justified in front of §25.571.

Name : R. Hallett
Date : 29-Sep-2013

25. Compliance Verification Engineer (when there is additional work to show compliance)

Name :
Date :

Title	Damage
Bearing Migration, Pylon Fairing Rear Attachment, Both Wings.	

Repair Request

Comparison Case by Case IE Usage

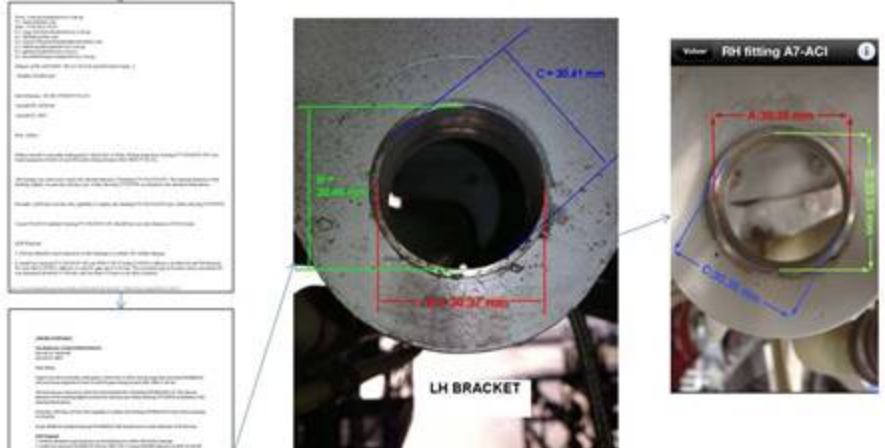
Emily Carey 2014

25616

1

Title
Bearing Migration, Pylon Fairing Rear Attachment, Both Wings

Damage



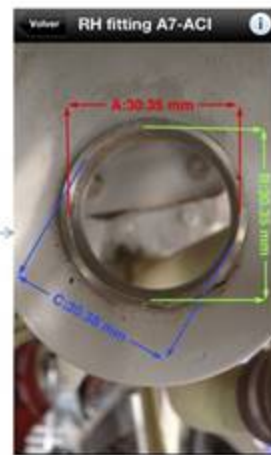
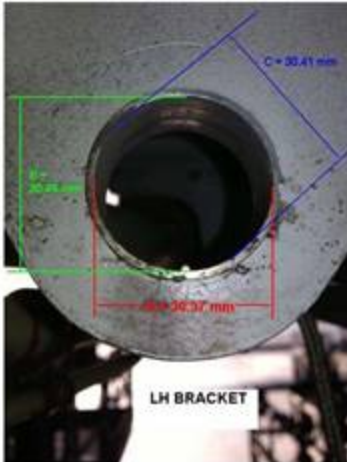
The technical drawing shows a circular hole with dimensions: C = 30.41 mm (outer diameter), A = 30.37 mm (inner diameter), and B = 30.41 mm (width). The photographs show the actual components with these dimensions overlaid. The LH BRACKET photo shows a bearing that has migrated from its intended position. The RH fitting A7-AC1 photo shows a similar component with a bearing that has also migrated.

2

Title
Bearing Migration, Pylon Fairing Rear Attachment, Both Wings

Subject aircraft is presently undergoing C-check here in Doha. During inspection, bearing P/N NSA8133-10X was found migrated on both LH and RH pylon fairing bracket (Ref: SRM 57-26-16).

The bearing was removed to check the internal diameter of bushing P/N NSA5101276. The internal diameter of the bushing slightly exceeds the tolerance per Airbus drawing F57253078, as detailed in the attached illustrations.



18678

1

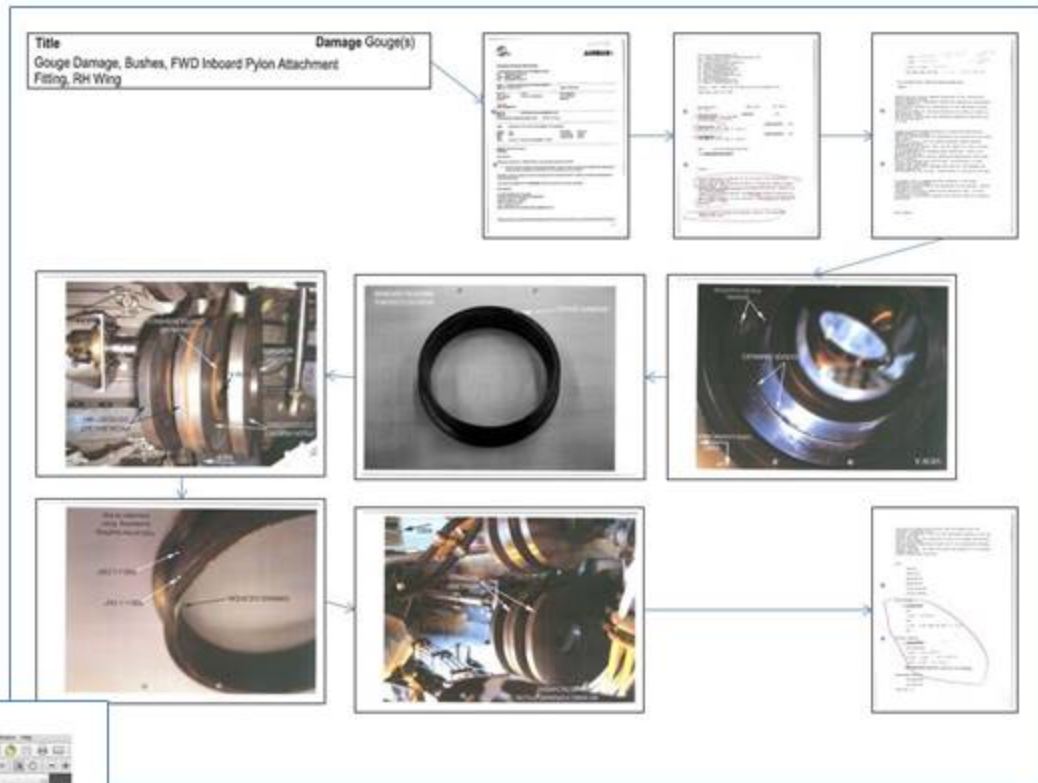
Title	Damage Corrosion
Nut Corrosion, Pylon Forward Attachment Fitting, Right Hand Wing.	

2

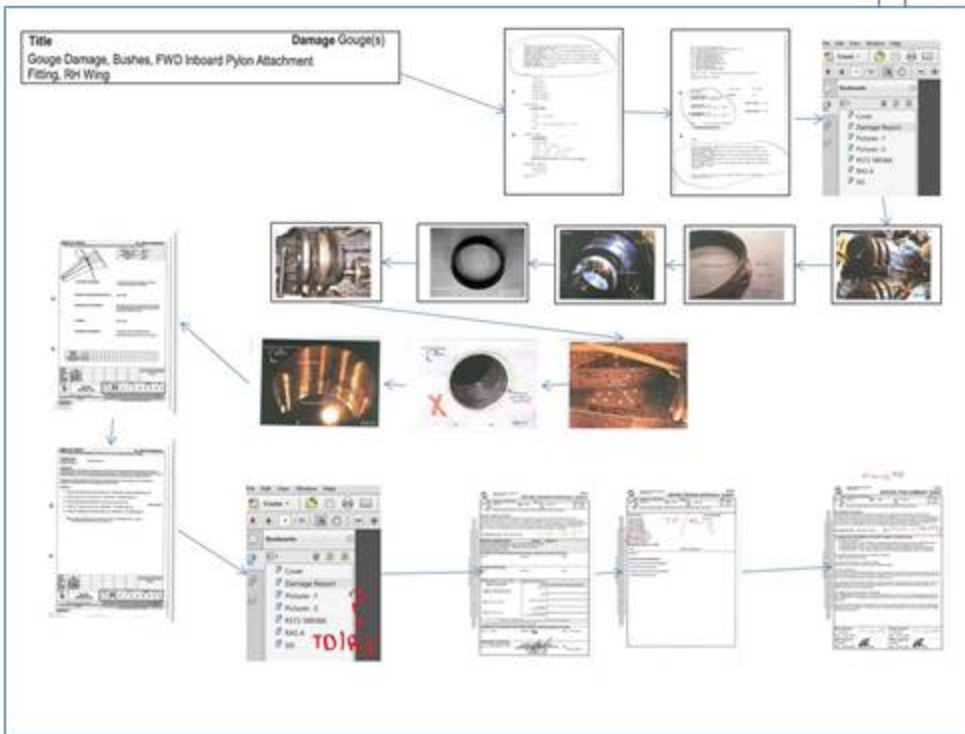
Title	Damage Corrosion
Nut Corrosion, Pylon Forward Attachment Fitting, Right Hand Wing.	

10978

1



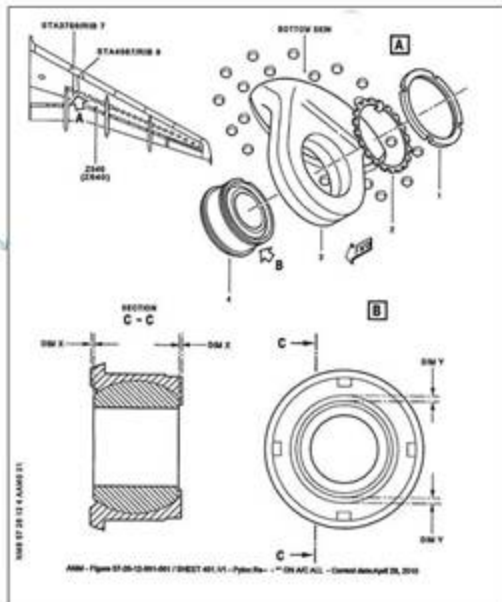
2



13072

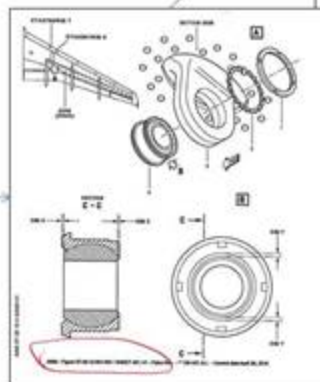
1

Title BEARING ROTATION, LH WING TO PYLON REAR ATTACHMENT BEARING
Damage Sensitive problems



2

Title BEARING ROTATION, LH WING TO PYLON REAR ATTACHMENT BEARING
Damage Sensitive problems



Workshop Audio Key Statements

Emily Carey Aug 2014

Group 1

Key Statements

- “What parts are damaged particularly if there’s a part number in there, its easier to get the drawings up”
- “Half of its useless”
- “how relevant the two reports are, you look for another report that is exactly the same”
- “If not an exact one filter it down from there”
- “look for similar symptoms”
- “the key point is they have already looked for concessions”
- “initially title for matching”
- “Go straight to initial damage report, then the photos to see if it looks similar”
- “So title and then initial damage report”
- “The first thing I did was look at the title and then I would have flicked down and looked at and then the next thing is have a quick look through the text for part no’s”
- “see if it had anything interesting”
- “the last thing I did would be to check the picture and that clearly shows that its of no relevance at all”
- “If the picture has come first then I would have stopped there”
- “Yeah I normally would go straight to the picture”
- “Sometimes I just go straight to the picture, sometimes you can see from the picture its nothing to do with it, then you could go back to the text if you have some doubt or are not sure”

- “but the picture definitely kills it off as helpful”
- “And then I would have gone on to the picture and seen that’s no good”
- “trying to match them”
- “sometimes the damage reports have broken English etc”
- “the picture will always say that’s what we’ve got”
- “we cant get confused with a picture”
- Quickly scroll down look at picture then go back to text”
- “if its one page then can read quickly”
- “use them together”
- “sometimes the text doesn’t always come out well as that, its just the way IT systems work, so its always easier to go to the picture”
- “Its easier to keep scrolling down”
- “quite often text refers to figure in the picture”
- “sometimes you get a picture like that and you think well ok where is that!?”
- “often go back [to airline] for better pictures”
- But sometimes with drawing no’s that they provide you and SRM references, then you can go to those documents and that together with the photo can help you know where you are.....on the structure”

- “A picture starting in and then working out”
- “the ideal should be located on a drawing”
- “in previous cases can overlay, that they have matching up and can use the calcs for that then”
- “with drawing you have the location of erm all the other structure around it, fasteners and stuff that you need to be aware of or that your going to use”
- “bolt location numbers can narrow down [location] as they are all numbered”
- “yes, look to whittle it down on a first pass”
- “if struggling [for a supporting case] then go back”
- “whittle down on initial pass [from daedalus]”
- “every now and then I will open one that isn’t relevant because it might have info that I can use, it might have SRM references”
- “I will open a random one or roughly same place [damage location] and will use to fill in the gaps, can steal half of that repair”
- “A lot of it’s the location, the damage can be different but the allowable limits might be the same”
- “need to have ideally two screens to refer back to [new incoming] damage report for additional details”
- “if that one had a TA on it”
- “switched between two but text was first so read it first, could go either way [viewing image or text first]”
- “always go to the photos”
- “subconsciously because running out [of potential supporting cases] will look at in more detail”
- “Will write down TD no and if I find nothing else will copy it and start from there”

- “A lot of the cases are quite big, 600 pages or more so use bookmarks”
- “SRM References and chapters can help as much as previous cases in working out where you are [on the structure]”
- “AMM used in conjunction with others”
- “Matches AMM figure references and in the damage report figure [indicating relevance]”
- “almost ideal if sent through TA, as a lot of information [lots of technical information on TA with deviations from documentation but its not a repair”
- “Look at AMM and look at procedure”
- “Use previous case to find AMM references to locate info required”
- “No calcs [highlights probably not going to be much use to you”
- “only 7 pages means its not going to be much use to you as not enough room for RAS and TAS etc” [if not there definitely less relevant as a historic case”
- “damage report comes through, Toulouse will send through a supporting case, so they try to use it”
- “being honest I’s have got bored reading all the correspondence and then maybe gone to the pictures”
- “50/50 where its text over pictures, but when more communications would go straight to the pictures”
- “tell a lot more from the picture”
- “semi judge from the picture whether its worth looking through the text”
- “then to repair instruction and then go back in a pack this big”
- “straight to pictures then I look to see if the pictures looked relevant to what we are dealing with and if that wasn’t any good to the TAS possibly or RI first”

- “Flick down to pictures then go to see if RI on one of the tabs [bookmarks] and work my way back”
- “Big pack can go either way, it can either be a lot of information sort of communications and with nothing really of interest or big pack can have a lot of information and just mention the relevant bits between the pictures”
- “be pictures then text”
- “Reading through it to get an understanding of the history of what their question is?”
- “damage report is sent by the operator so more valuable”
- “still check aircraft type [even after daedalus] as even down to the little differences in weight variant”
- “Yes, [still check aircraft type] because it goes down to weight variants”
- “a lot of other little differences”
- “Daedalus can be single aisle but can be a single aisle A318 and A320, A319, A321. Still categories with single aisle, 321’s different to 18’s, if your just looking at skins then very similar. Especially for stress they need to be exactly the same”
- “if these 5 cases popped up, one minute on that one, 3 minutes on that one, as you get more desperate as the options run out!”
- “So might go back at the end, if you are desperate or speak to the engineer or Toulouse”
- “personally I would have kept looking, none of these cases perfect”
- Composite only look at recent cases as methods have changed, the most recent in date order, if one was 5 years old and one last week then more recent one [is used]”
- “if original person is still here then easier to sign off”

- “yes if I found a previous case that had somebodies name on it, that was working in our office you know I would say do you mind having a look at this one because you’ve done this one, and they can’t say I don’t like that or I’m not happy with that because they’ve already signed it and if they’ve signed a worse case off there’s nothing they can really say and if they’ve got signature for this part its helpful to know”
- “5 is most useful [contents wise] but it not really useful as its not the same part”
- “On average to get to this point can usually tell by initial description and pictures”
- “Up to 15 minutes to find a good one [in daedalus]”
- “I would say ½ hour”
- “Any further than ½ hour then better to start from scratch [discussion regarding timescales per each case and seeking information balance]”

Group 2

Key Statements

- “The one this I find with Daedalus is searching in this box here is [not great] the best way to do it, dropping on like the additional menus here and doing like [and if you use one you can’t use the box] [as soon as you search one and want to search another it resets it all] which is a big pain because sometimes you’ll know for example because this is pylon attachment you know what SRM chapter that’s going to be so you can narrow it down by ATA and then you could sort of, you could narrow it down by A320 previous cases or word specifics or crack but you can’t do both. You can only do one, a lot of people have mentioned this issue.”
- “There are some simplifications in Daedalus went there with regards for some of the ATA numbers, inboard outboard leading edge for instance we apparently taken, its been generalised a bit which , as you know, and there’s quite a lot missing, you see there’s quite a lot of white boxes down the sides, well bit guilty of that but then it takes so long....haven’t uploaded them. [thus not searchable] Yeah there is a bit of a backlog of them at the moment, a couple of thousand.”
- “so those three are single aisle so that would be your first look won’t it, so first thing I would do is single aisle literally because you got to click on in Daedalus long range, wide body or single aisle so you go to the one that’s the same aircraft.”
- “When we look for previous cases we always try to aim for the same aircraft is because it makes it easier to justify in your approval documentation, because they carry the same loads, because in 330 we have different weights for example on a different wing structure.”
- “I never look at the coversheet, I don’t know about you, because it doesn’t provide any information that you can’t find through the,..... Is it chapter menu you get on a pdf [BOOKMARKS].”
- “I just go straight to the damage report and see what they say”.
- “The coversheet could maybe pick up that [if it has been well titled] because its effectively an abstract.”

- “A quick brief summary of what we’re looking at, and often and that’s why you need to go to through the details as often that can be wrong or misinformed.”
- “Where do these titles come from because that title would probably get rejected....[its an old one though].”
- “The title is the information you have to look at you know, in ICARUS, short of going to the job itself.”
- “[you don’t use the title to rule out a case]”
- “if the title wasn’t correct and it didn’t detail the right part, I wouldn’t look at the case. I wouldn’t have time to be reading if the title was wrong.”
- “Going back onto Daedalus, one thing I just remembered, that we do have an issue with is with obviously you can do a title or word search, but sometimes what your looking for won’t be specified in the title. For example gear rib replacement, you wouldn’t have that in the title of the pack, gear rib crack, gear rib log, so you would have to search through everything that has gear rib in it because you can’t type in gear rib and crack.”
- “that’s something we’ve had a problem with in my team as we do a lot of gear rib replacements. [we search or our name as we know we’ve done a lot of them]”
- “If we see a TAS we know its likely to be a replacement. [possible link to complexity by information type presence]”
- “There should be a final decision call like, it would help.”
- “It would have to be like an additional thing the final solution was this.....”
- “its nut corrosion so its not the same you wouldn’t be able to use that.”
- “I would look at these two because.....because rotation it’s a bit of desperation really.”
- “You’re looking for to see if someone put one in the wrong way.....so an installation issue.”
- “but bearing rotation that could be an installation issue.”

- “The second you see there’s no bearing rotation you would disregard it.”
- “you can read through all the history as some of them are incredibly well documented and some of them have a lot of experienced assumptions, there is a bit of subjectivity. So I would go to the tabs at the end to see what was done.”
- “[if something is irrelevant would you open] only if you had nothing and had no other relevant titles come up, you pick the closest.”
- “[easy repairs you could find hundreds, but because they’re quite easy I don’t bother I just get it done], but if it was someone just starting I would say this is what we do...[referring to search for previous case].”
- “from my experience it depends on the repair, if its just a simple repair instruction and its all been signed off on a previous case then it is relevant and it is recent, you might change a few details but the general structure of the instruction I’ve used a couple of times now.”
- “And we do kind a float in between people that are approving and how they’re feeling so you try and get recent examples so if you get an old one maybe three years ago they might ask you a few questions. Some general procedures do change but some people change their minds about things. [so you would refer back to alternative case options].”
- “From a new start point of view on all the jobs I’ve done so far I’ve been looking at previous cases, it’s the main thing I’m told to do, given a job have a look at a previous case.”
- Not knowing from a new start point of view I was just like opening everything and reading everything. [after six months now I wouldn’t open everything]”
- “Toulouse get the previous case from the contact operators, they often come up with loads of previous cases and they don’t have Daedalus. [Toulouse RMT using]”
- “With RMT I’ve done searches in there and found stuff that’s not in ICARUS....but its not easy to search because you can’t compile the pack.”

- “they often ask to use the same TD because if it’s the same operator, we can say if it’s a very minor deviation and if it’s the same parts, to dot he same repair in principles.”
- “We cant really send another TD to our other operators because its considered to be passing on information.”
- “We all know the titles might be a bit dodgy but damage report also may be a bit dodgy but the pictures are quite conclusive, if the pictures are the right part.”
- “Also depending on the size of the pack, because that ones a bit bigger, you might not do this but if the pack is about eighteen pages then you’d find the damage report, look at the pictures, but because its in chronological order, fingers crossed, you could probably then continue down then follow in order the next thing that that will probably come up is our first response and that could have a solution in or have other questions that we bought up. But if it’s a bigger pack you’re going to be a bit more selective in what you look at.”
- [decent number of pages]
- “The pictures are part of the damage report. It’s a description with pictures, or drawings with circles, highlighted information maybe that narrows you in, you can’t go wrong If it’s a picture of a part or fitting or if it’s a drawing with highlighted area that is the bit then you are talking about then you know, you know you’re looking at the right thing.”
- “You’d have a quick skim of the damage report text and then go to the damage report pictures and see if it’s the item you’re looking for.”

- “For me its, if you see the pictures in the pdf its click that straight away, have a run through just to see if it’s a similar item.”
- [two separate things like pictures, damage report, its not really two different things but the same]
- “A picture doesn’t lie to you, it tells you exactly what the issue is, sometime we’ve had incoming damage reports but they’ve provided the wrong location.”
- “If they provide pictures it makes it a lot easier to do our job.”
- “We like damage reports with pictures.”
- “Its clarification really. [referring to pictures]”
- “you probably wouldn’t flick to the picture because this ones going to have a repair instruction on it. [.....though I would still look at the picture]”
- “Usually in this it gives you reference numbers of your drawing so usually on a job like that, if I’ve not seen it before or I don’t have much experience of it, if it calls up any drawings and things I will get them up straight away. First of all I’ll check I’m looking at the right one cos the manufacturers don’t look at the correct...{spectivity} of the drawing. Usually things on here that are referenced you’ve got your Airbus production drawing. That be one of the things you’d highlight.”
- “I’d read it but I wouldn’t read the numbers...I’d probably just skim to the pictures even though I knew it wasn’t correct.”
- “How far you get with the pictures depends upon how good they are.”
- “Or how much you might laugh at them”.
- “My favourite ones are doodles”
- “So you’d bounce between the two just to make sure you’re not wrong”

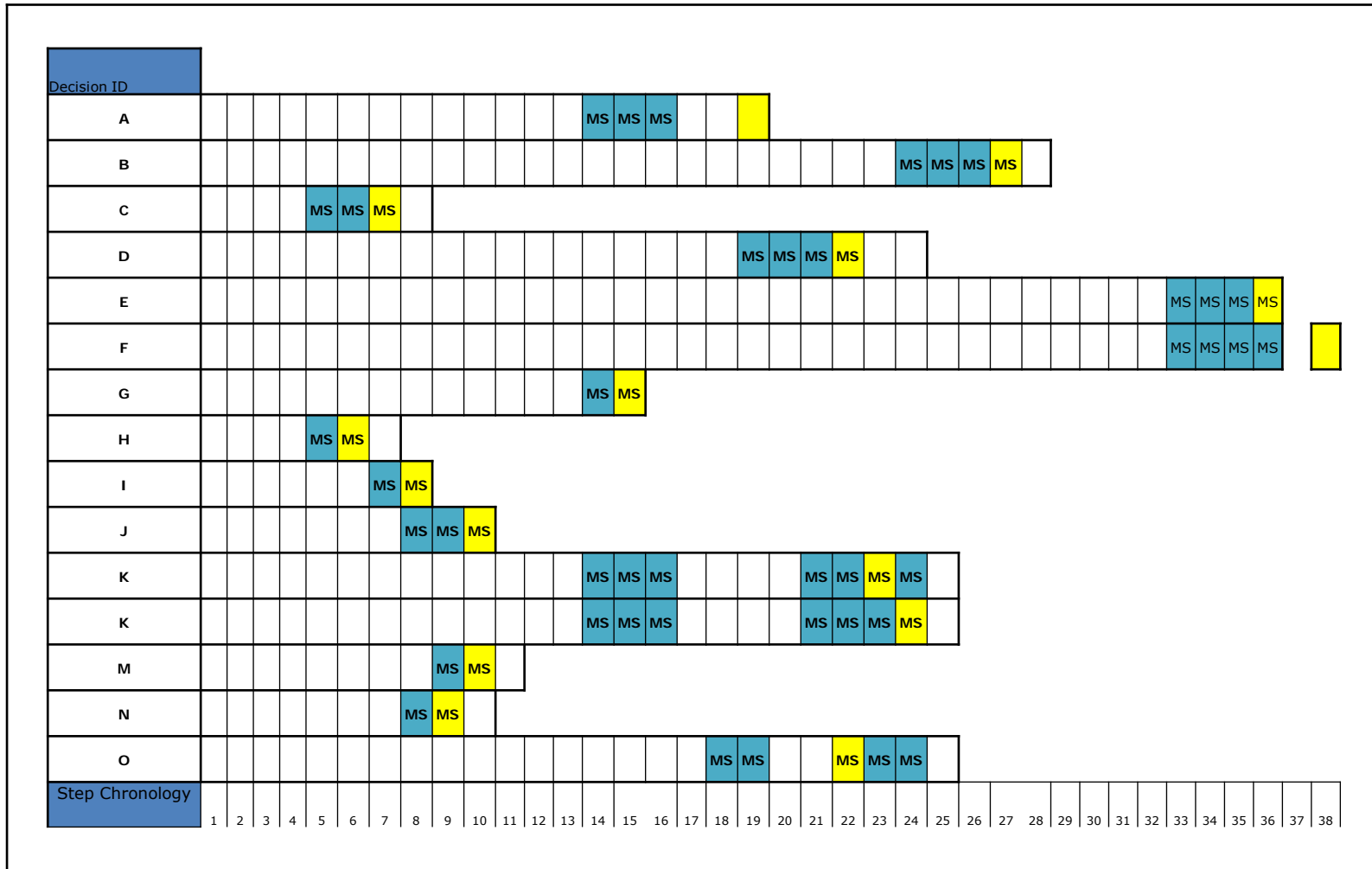
- “because you’re teaching yourself as well because its just like ‘erm, you see a lot of similar things, its just so infinitely complex, you start to talk in a bit of garble after a while, to when maybe you started doing this,not because anyone’s crazy but your immersed in this jungle of bits and pieces.”
- “Yeah I look at the pictures because I don’t even know what the parts look like. I have to look at a drawing so I think I’ll have a look at that.”
- “Sometimes I’ve looked at jobs on Daedalus, because the titles come up and I’m having a browse and I think that looks interesting.”
- “You don’t get too much contact with the actual aircraft, and people not having actual contact with the parts and having pictures is the way of knowing what they are talking about.”
- “When I walked in here and some one said gear rib I couldn’t tell you what that was, where that was, what it looked like, so through pictures is, that is how you learn.”
- “After looking at SRM’s, AMM’s you often think what the hell does it look like, until you get the actual pictures.”
- “A problem with the pictures and things often you have no concept of scale, when they say a bush, is it that big or that big, if you see some ones thumb next to it in a picture it still helps.”
- “I’d have gone straight to the picture...that doesn’t look like I’d have expected, a triangle or something.”
- “NAMING CONVENTION FOR CASES.... Title should be damage description then the component name.” [There is no description of the solution for searching purposes]

- “What I would have said is, you’ve gone through these three and you’ve stopped here, that has been the most relevant one you have found for single aisle. At this point I’d say other aircraft are designed the same basically the same, everything is an A300 wing..... So go to long range.”
- “Oh look there’s a picture of it that’s really useful and oh look there’s an answer a TA was raised, so at that point I’d be particularly interested in this job and basically I’m going by the answer and the picture.”
- “Pic + TA, Pic + RI = Pic + Answer”
- “The photographs in this case shows that its just the change in the diameter of the internal three point measurement and again it just augments what they said in the report. They are right after one another so its just....”
- “The boundaries between drawings, maybe, writing, what you look at is blurred.”
- “If you have two screens you might put the pictures in one screen and scroll through on another and flick between the two so for me its not really a separate process.”
- “It’s a short case and I literally went like that and had a quick look at the picture and straight away I saw there was an issue.”
- “Some pictures are more useful than others.”
- “The previous ones just show where the damage is, this actually shows what the damage is.”
- “TAS tells a succinct story, the damage report and the solution.”
- “It takes longer to prove the case you have is relevant than to rule them out.”
- “If I’d been looking at Daedalus and I’ve looked at twenty pictures of lugs in the area and I would now be smarter in my searching.”
- “Static sometimes write more in there so is more useful information.”

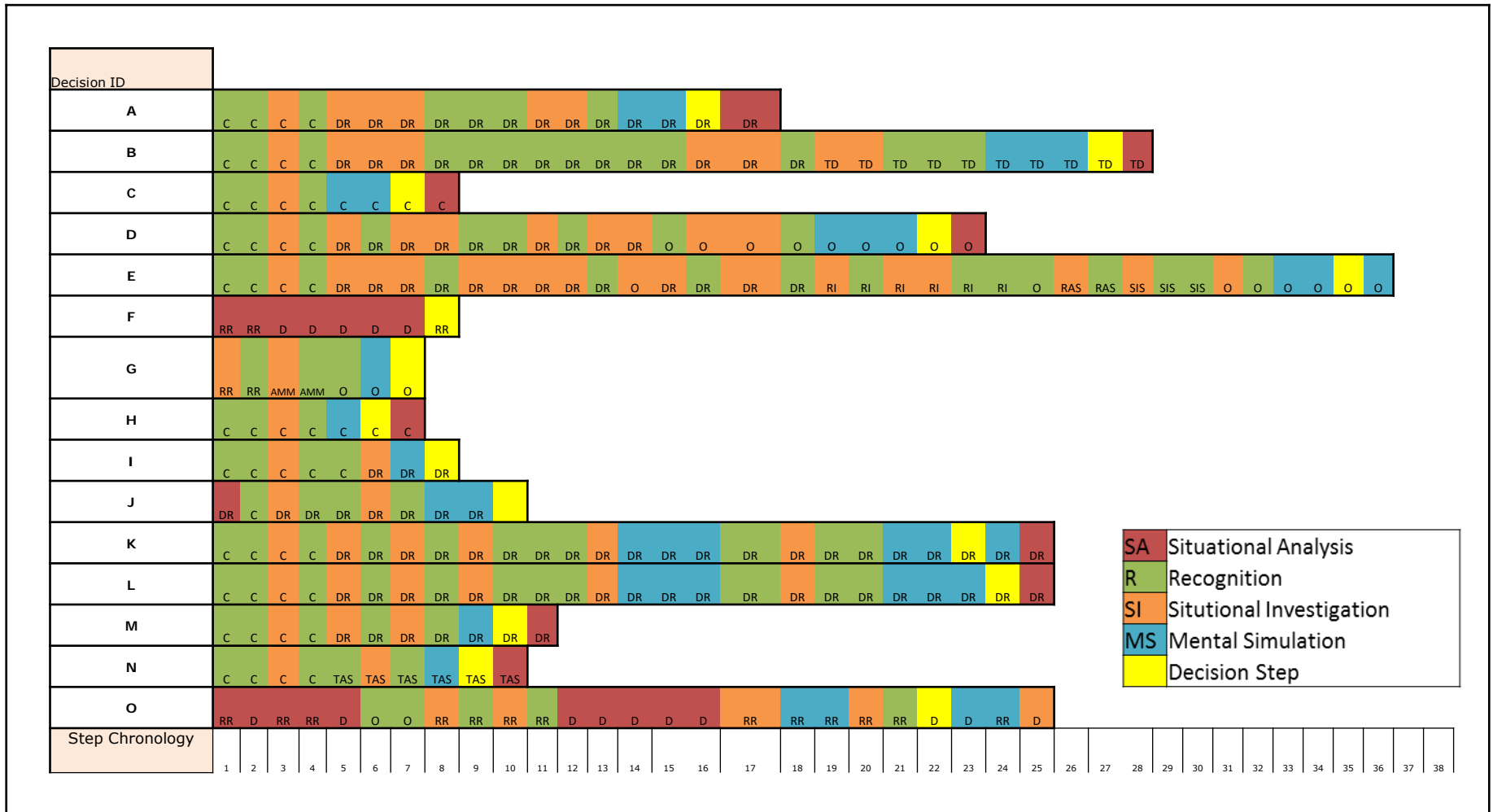
Storyboard Analysis Illustrations

Emily Carey 2014

Chronology & Decision Stage (3)

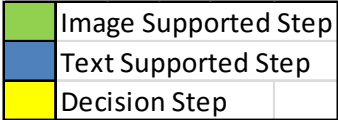
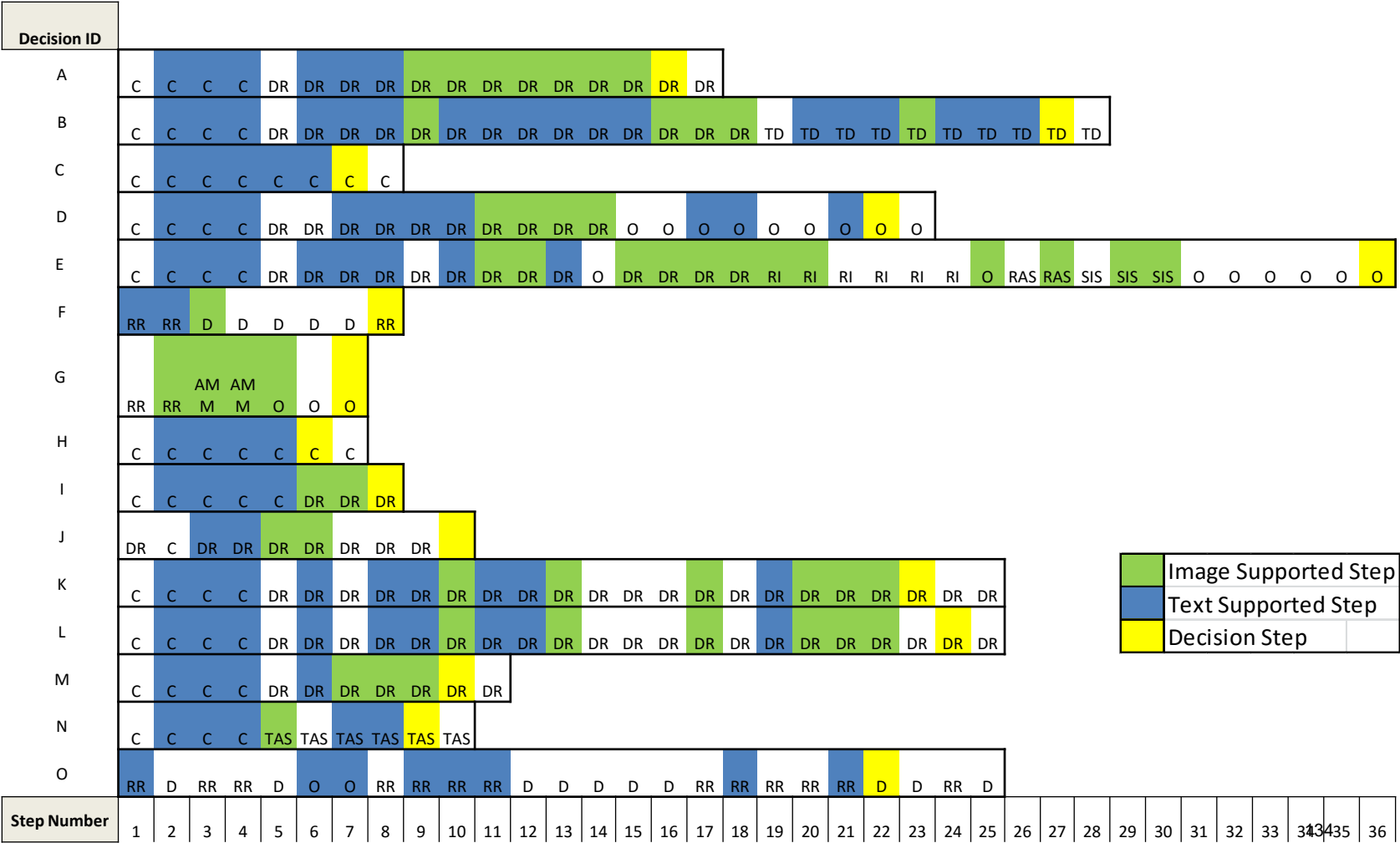


Information Source & Decision Making

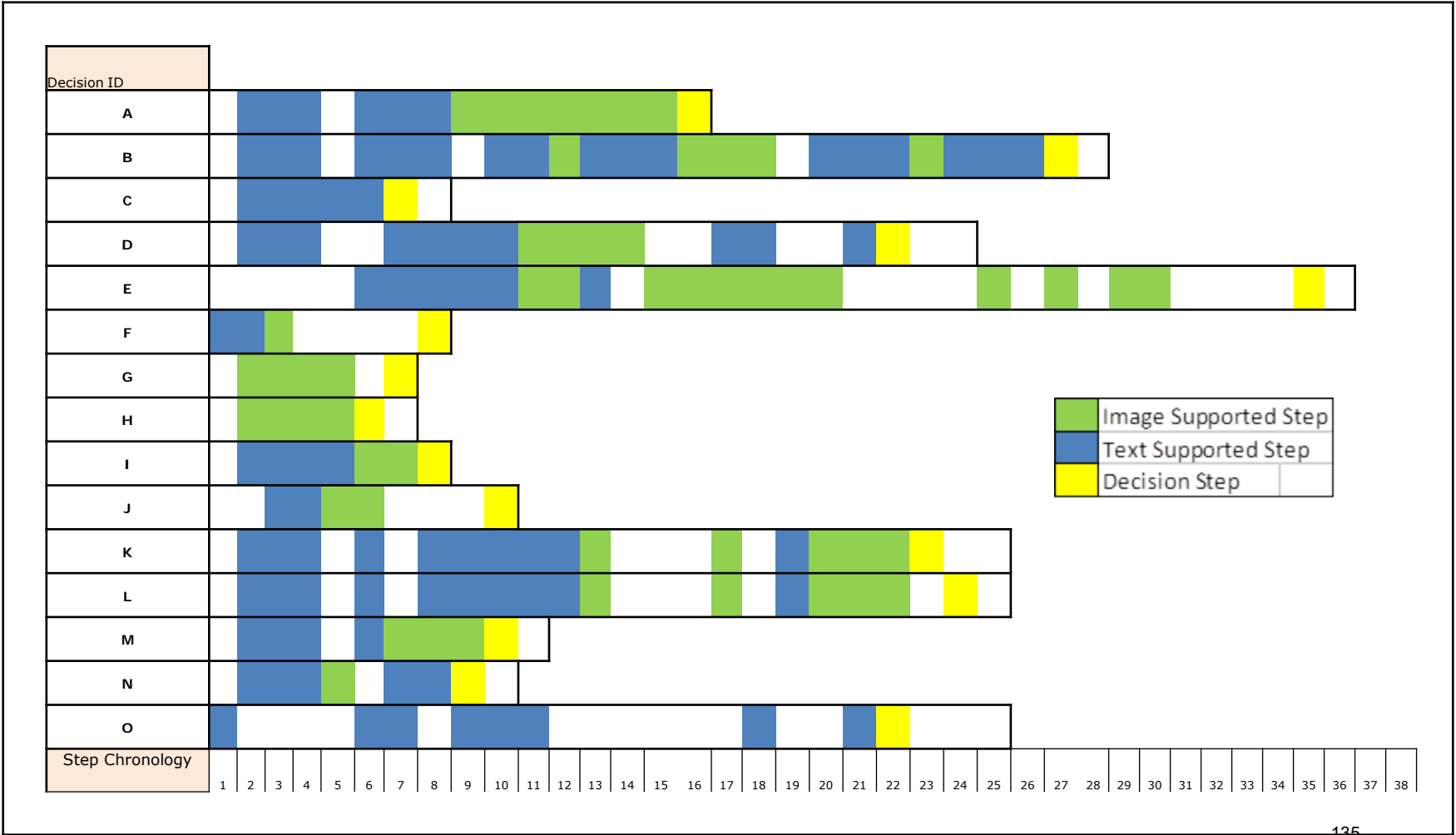


SA	Situational Analysis
R	Recognition
SI	Situational Investigation
MS	Mental Simulation
	Decision Step

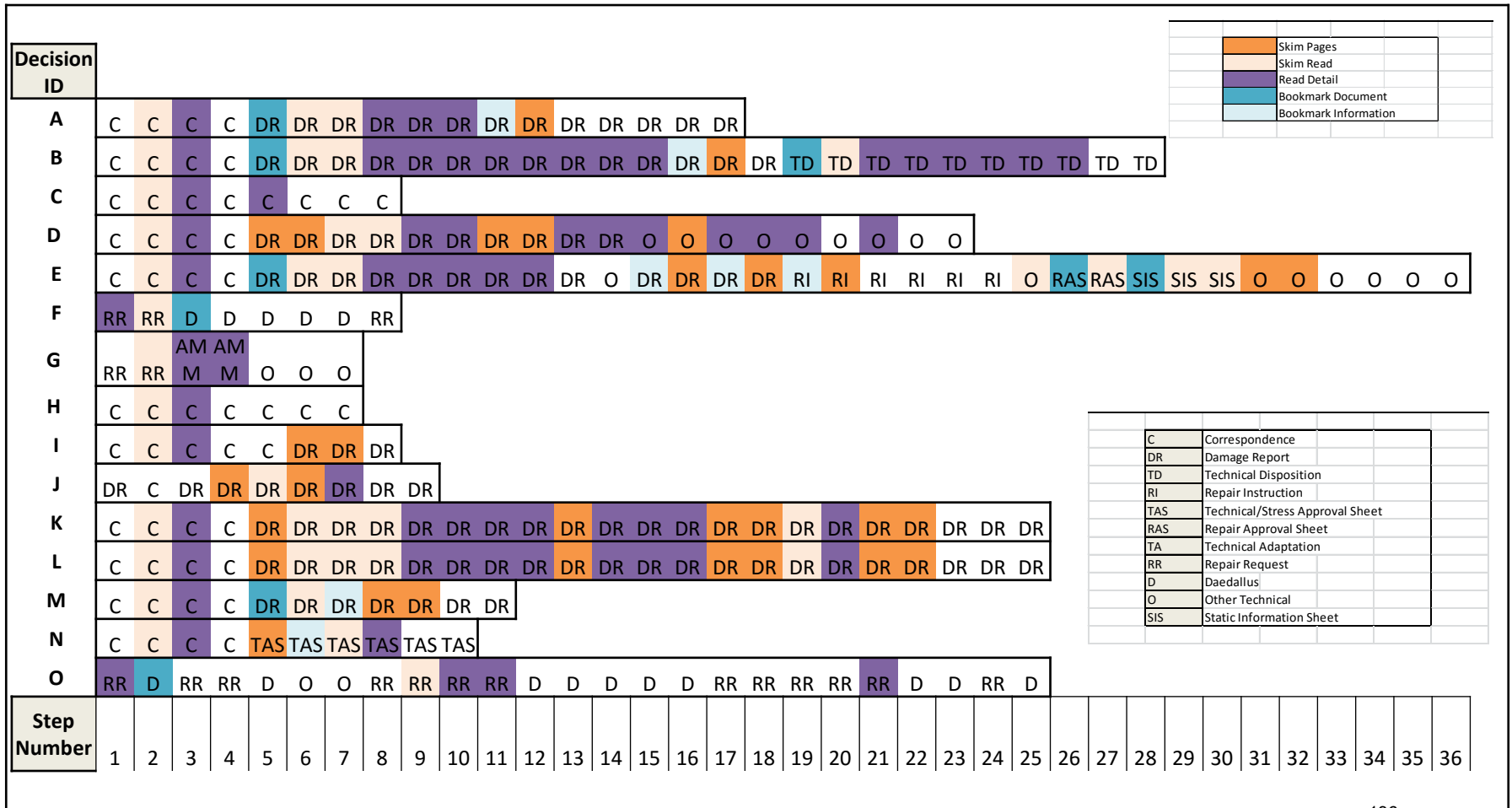
Subdocument and Information Type Sought



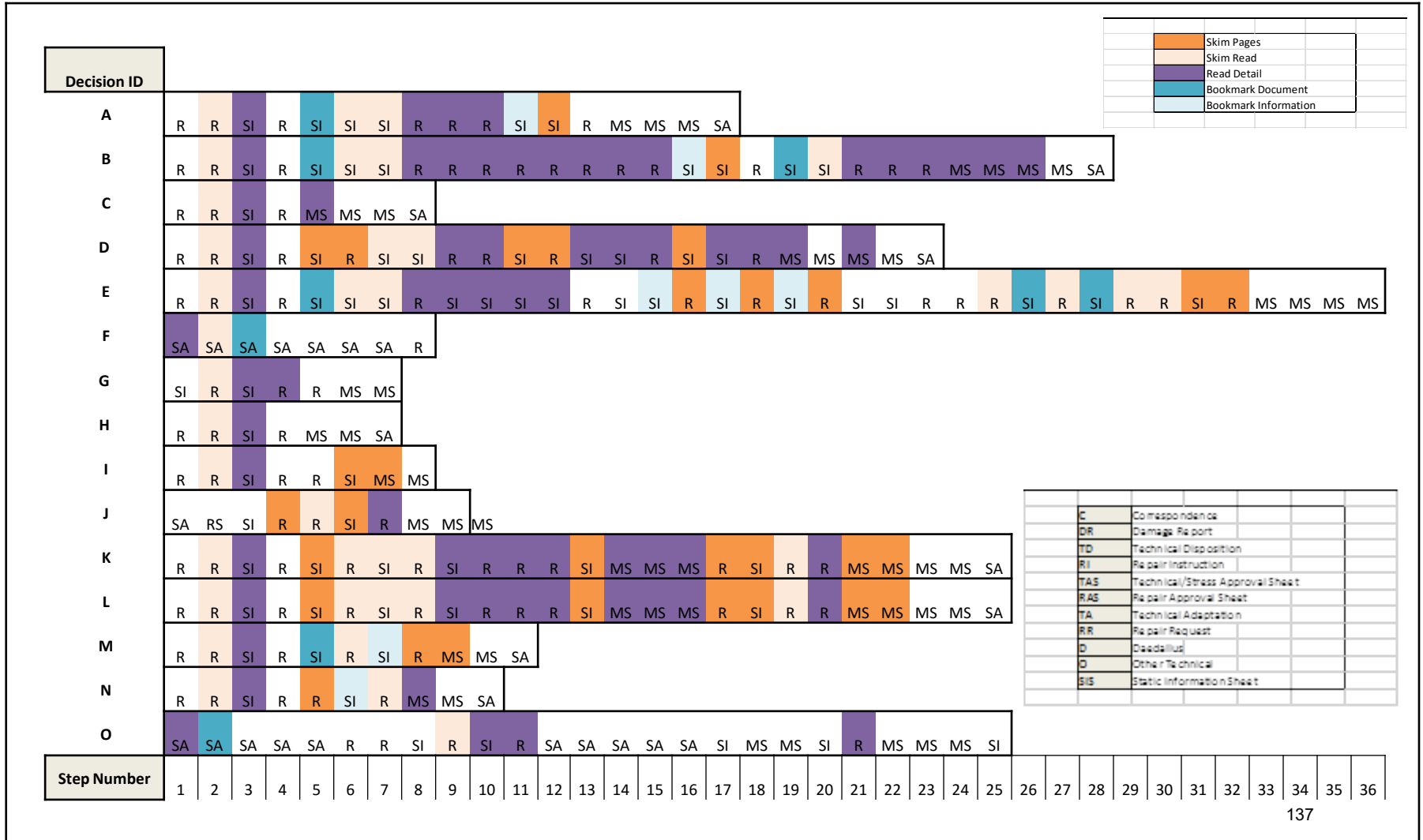
Decision Proximity to Information Type Sought



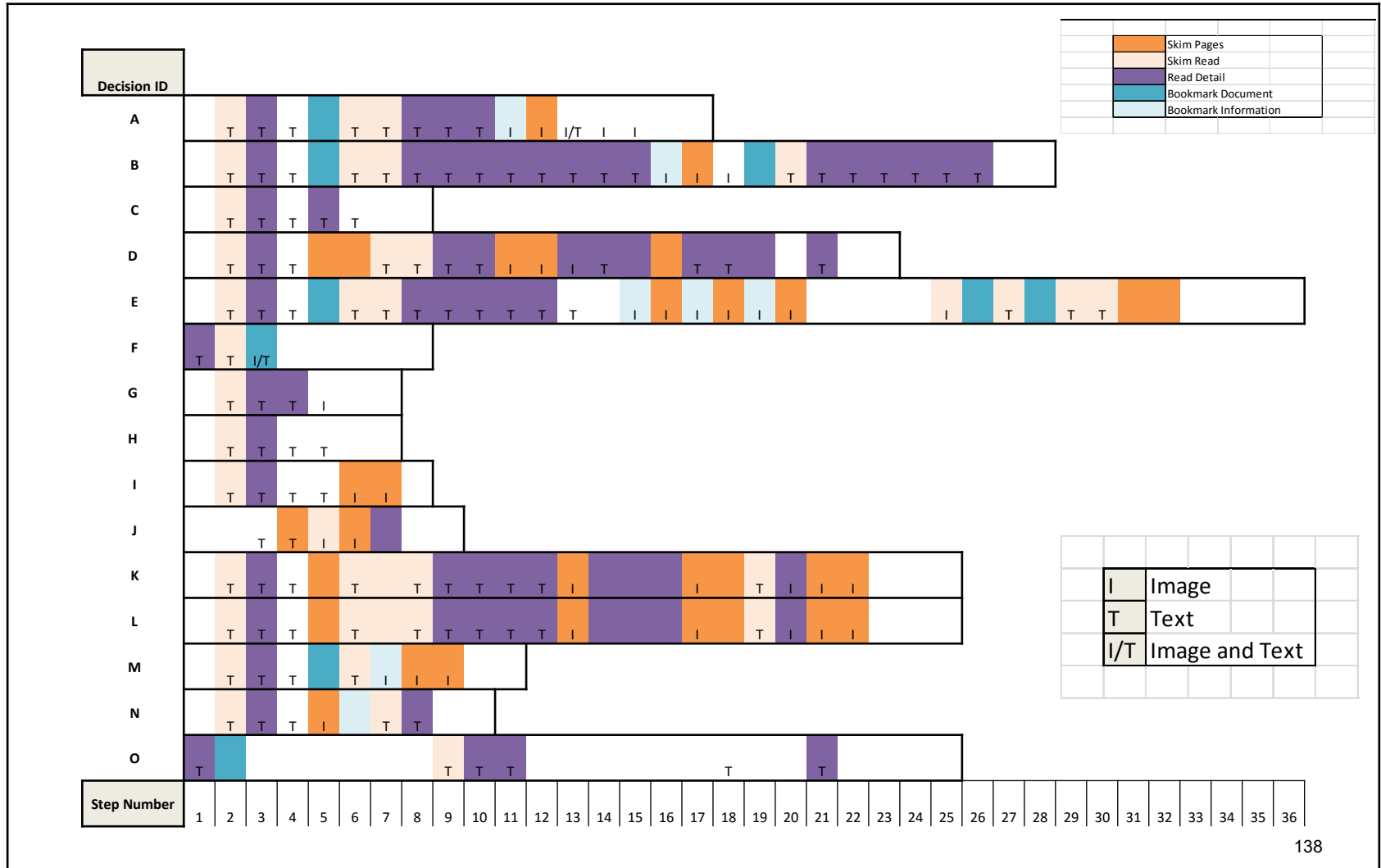
Viewing Strategy & Sub Doc Type



Viewing Strategy & Decision



Viewing Strategy & Informative Element



Case Summaries

	18678	25743	13072	25616	10978
Case Position Story 1	3 C	2 B	4 D	1 A	5
Case Position Story 2	1 H	5 M	2 I & 6 N	4 K & L	3 J
Number of Pages	19	17	6	28	61
Number of Image Elements	14	8	5	15	34
No of Text Elements	16	15	5	21	48
File Size (KB)	1142	2706	359	3138	8958
Number of Sub-Documents	12	9	4	15	15
Date of Case Beginning	24.01.201 2	27.09.201 3	30.04.201 0	17.09.201 3	26.08.200 9
Date of Case End	01.02.201 2	29.09.201 3	30.04.201 0	20.09.201 3	06.10.200 9
	18678	25743	13072	25616	10978
"Subdoc" Pages					
Cover Sheet	1	1	1	1	2
Correspondence	8	4	2	7	27
Damage Report	10	4	3	6	19
Repair Instruction	0	0	0	0	3
Technical Disposition	0	1	0	3	0
Repair Approval Sheet	0	4	0	3	2
Technical Adaptation	0	0	0	0	0
Technical Approval Sheet/SAS	0	2	0	3	0
Static Information Sheet	0	0	0	0	1
Other Technical	0	1	0	5	7

"Subdoc" Occurrences	18678	25743	13072	25616	10978
Cover Sheet	1	1	1	1	1
Correspondence	8	3	2	6	5
Damage Report	3	1	1	2	4
Repair Instruction	0	0	0	0	1
Technical Disposition	0	1	0	2	0
Repair Approval Sheet	0	1	0	1	1
Technical Adaptation	0	0	0	0	0
Technical Approval Sheet/SAS	0	1	0	2	0
Static Information Sheet	0	0	0	0	1
Other Technical	0	1	0	1	2
Image Occurrences	18678	25743	13072	25616	10978
Cover Sheet	0	0	1	0	0
Correspondence	3	2	0	3	11
Damage Report	11	2	4	2	8
Repair Instruction	0	0	0	0	3
Technical Disposition	0	1	0	2	0
Repair Approval Sheet	0	1	0	1	1
Technical Adaptation	0	0	0	0	0
Technical Approval Sheet/SAS	0	0	0	2	0
Static Information Sheet	0	1	0	0	1
Other Technical	0	1	0	5	10
	14	8	5	15	34

Document Case Summaries

Appendix 6 - Technological Review and Feasibility Studies

In Chapter 4 the character of current Knowledge Management Provision and the Information Resources available to Design Engineers. It is evident from the preliminary observations in industry and the research studies described in Chapter 2 that complex heterogeneous document information resources in Engineering Design are particularly important in the Design Process, for the capture and reuse of design knowledge, see Figure 4.19 and Section 4.7. However, many concerns are raised about the effectiveness of utilising documents as a knowledge capture tool and as a platform for effective reuse of knowledge. In this Chapter a more detailed exploration of the tools, techniques and technologies for reusing document information formats are described that contribute to enabling utilisation of their informative contents.

Preliminary Studies

There are a number of preliminary studies described in this Chapter to assess the feasibility of the methods for achieving the objectives for this project. The table below (Figure 5.1) provides a summary of each study and their expected contribution.

Study Description	Principles Evaluated
Study 1: Literature Review for Automated Media Extraction Methods	Literature review for image and pattern recognition related to implementing media extraction from image documents including analysis of the techniques & methods available for media parsing.
Study 2: Media & Feature Extraction Technology State of the Art Review	Analysis of the tools available for the purpose of automating document content extraction.
Study 3: Adobe Document Software Testing	Sample testing of the features in the Adobe Professional software suite for the purposes of automatically extracting media content from image pdf documents
Summary: Review of Potential Developments	Summary of key findings from media extraction studies and suggestion of the possible support developments for design engineering documents.
Study 4: Adobe Bookmarking	Manual implementation and testing of a PDF file bookmarking system to overcome image matching limitations for media feature extraction including considerations for automation.
Study 5: Related Research Studies	Exploration of document content extraction, summarisation and understanding and evaluation of visualisation techniques for document contents.

Table 5.1: Preliminary Studies Overview

First the studies 1, 2 and 3 consider the potential for automating the extraction and reuse of information media then study 4 relates the key findings to design engineering support

requirements and the potential for developments. Then in studies 5 and 6 specific hypothesis that are important in the provision of support for the reuse of document information media are further explored.

Each of the studies is described individually in the sections below with a summary of the overall contribution to the research design. In subsection 5.5 there is an interim summary of key findings and in 5.8 there is a summary of all of the findings related to the industrial knowledge reuse challenges identified in Chapter 4.

Included in this are preliminary experiments upon sample documents and a summary of other related document explorations. In study 6 the outcomes of closely related research projects with the same collaborators, by Hunter (2010), Humphries (2013) and McMullen (2011) are reviewed in relation to the purpose of this thesis. The combined focus of these studies is to explore the potential for using automated techniques in support for engineering design document information utilisation. In particular the focus is upon the possibilities for developing current provision and any limitations that may be shaping the current industrial processes. The feasibility studies described here demonstrate the technological and literature considerations that have directed the aims and objectives for this research.

Practical and Industrial Influences

In section 4.3 the in-service design engineering department and their information needs have been characterised, in particular figure 4.3 and 4.4 illustrate the key information requirement points for design engineers. The design engineering information resources and requirements have been elicited in more depth in section 4.5 (the in-service information audits) and document information resources have been described and their contents audited in section 4.6.

This has built evidence of the overwhelming need for design engineers to utilise the rich media content of documented information, thus the need for the extraction of information features from engineering documents is clear. The prevalence of visual media found in engineering documents (see figure 4.16 and the outcomes in section 4.7) suggests that the information elements are of a visual media type are of particular importance. Hence it has been necessary to focus the review of media extraction literature and tools upon the automatic extraction of image related media. From chapter 4 it is evident that rich design knowledge stories are in the main captured in document format, hence the complex heterogeneous nature of the historic design engineering repair document collections. This format of documents within engineering design has focussed this review in particular upon those tools and technologies relevant for image media extraction.

In chapter 2 both the human and design engineering need to process and understand information has been highlighted. This is in conjunction with the historic document files that have been studied as the basis for extracting media and described in section 4.3.5. It is thus necessary to understand how best to support design engineers in information supported processes. The large nature of engineering design data collections naturally lend themselves to visualisation techniques and thus one of the studies focus upon the performance of document summarisation of tools and another upon the appropriateness of visualisation tools and techniques for engineering design data collections.

In summary there are four guiding considerations that have driven the need for these preliminary investigations. These are listed below;

- The need to integrate historic data and to reuse information from "image" document formats.
- The need to reuse information rich "heterogeneous media" formats in particular image media.

- The need to (re)access certain features within the information media, hence the need to be able to recognise and extract information media types.
- The need for design engineers to understand the content of documents to enable them to effectively “reuse” this knowledge for their current task.

The key findings from each of the studies explore some of the support requirements for one or more of the above considerations and thus contribute to the aims and objectives of this thesis.

Study 1: Literature Review for Automated Media Extraction

This section describes a review of literature related to automated analysis and extraction of content and features from image media. The work reported here is part of a literature review for the automation of document media parsing and media extraction systems. This was originally conducted as a state of the art review for industrial purposes and can be found in the bibliography section (Carey 2012). The key literature and findings of this report are described in this subsection to enable synthesis of the requirements for implementing an automated industrial document content and feature extraction system. This is then utilised to further the guide latter preliminary studies described in this chapter.

The method for this review is to extract from media extraction related literature the purpose of the text and the media extraction principle being demonstrated. This was then categorised to enable further analysis of the collective literature. The review includes literature for image recognition techniques and media extraction methods as both are relevant to the implementation of an automated document parsing system.

In this part of the review the analysis is purely to establish where research techniques are more mature and currently available for utilisation industrially. The second study utilises these findings to synthesise a complete development requirement list for implementing an automated document media extraction system that could potentially be useful for processing and recognising image document media.

The table 5.2 below is a summary of the reviewed texts for reference throughout this section. This summary includes details regarding the purpose of the literature, categorisation of how the literature reviewed fits into the requirements for automating media extraction, a summary of the key principles and a citation. The texts that relate to current patents are considered important and are included to suggest where techniques are more likely to be developed enough to be embedded in software applications.

Citation	Literature Category	Purpose	Principle Demonstrated
(Ali & Abla 2012)	Technique	Image Matching	Enhanced image match algorithm
(Assodallahi & Bordag 2012)	Patent	Media Extraction	Text extraction to facilitate additional search function
(Appian Technology 2012)	System	Media Extraction	Recognition of number plates from images.
(Bae et al. 2011)	Technique	Media Extraction	Extraction for classification of documents

(Ballard 1981)	Technique	Image Matching	Enhanced image match algorithm
(Bassil & Alwani 2012)	Technique	Post-Processing	Error reduction in extraction output
(Basu et al. 2012)	Technique	Media Extraction using Artificial Intelligence	Improved text extraction using artificial intelligence
(Bayram et al. 2012)	Patent	Image Matching	Fingerprint matching for image and video
(Boose & Shema 2003)	Patent	Image Matching and pre-processing	Conversion of raster drawings to vector images
(Bunke & Wang 1997)	Technique	Image Matching	Optical Character Recognition
(Burl et al. 1999)	System	Feature Extraction	System architecture for image data mining
(Cao & McDonald 2012)	Technique	Feature Extraction and Image Matching	Improved feature extraction for more accurate image match
(Cullen et al. 1999)	Patent	Media Extraction and Image Matching	Description of system for extracting document features
(Evangelou et al. 2001)	Technique	Media Extraction using Artificial Intelligence	Mining image data with neural network algorithm
(Deb & Zhang 2004)	Technique	Media Extraction and Image Matching	Image extraction with additional frequency metrics
(Definiens)	System	Image Matching	Analysis of image data tool
(Ding et al. 2012)	Technique	Feature Extraction	Review of feature extraction techniques
(Duda & Hart 1972)	Technique	Feature Extraction and Image Matching	Algorithm for matching image feature elements
(Dutta et al. 2012)	Technique	Pre-Processing and Image Matching	Improved optical character recognition by pre-process of image data

(Eakins & Graham 1999)	Technique	Media Extraction	Feature extraction using image content as search parameter
(El sayad et al. 2012)	Technique	Media Extraction	Improved content based image retrieval
(Fedorov & SHIGAROV 2011)	Technique	Image Matching	Approach for image recognition
(Feng et al. 2012)	Technique	Feature Extraction and Image Matching	Extraction of images from mobile robot imagery
(Flynn et al. 2012)	Technique	Image Matching	Matching images based upon approximate match against a reference data set
(Google Goggles)	System	Image Matching	Image based search function
Google Drive	System	Image Matching	Improved image and text based search function
(Grimmer & Stewart 2013)	Technique	Media Extraction	Review of text extraction performance
(Hajjdiab et al. 2012)	Technique	Image Matching	Algorithm for image matching
(Artium et al. 2011)	Technique	Media Extraction	Automated document content summaries
(Hirasawa et al. 2014)	Patent	Image Matching	Patient positioning device using image recognition for decision making
(A. Holambe et al. 2012)	Technique	Feature Extraction	Review of feature extraction for optical character recognition
(Holland et al. 2002)	Technique	Feature Extraction	CAD drawing feature extraction for decision making
(Huang & Tseng 2004)	Technique	Media Extraction	Algorithm for document retrieval system
(Hundt 2011)	Technique	Image Matching	Computational requirement of image matching

(Hwang 2014)	Patent	Image Matching	Image matching method and tools
(Jain et al. 2009)	System	Image Matching	Tattoo matching for person identification
(Jayaprabha & Somasundaram 2012)	Technique	Media Extraction	Algorithm for content based image retrieval
(Jones 1992)	Technique	Media Extraction	Automated document content analysis
(Gilmour et al. 1996)	Technique	Artificial Intelligence	Document content analysis
(Kacem et al. 2011)	Technique	Media Extraction	Automated reading of student sheets for marking
(Cohn & Kanade 2007)	Technique	Image Matching	Facial recognition for emotion classification
(Kettig & Landgrebe 1976)	Technique	Media Extraction	Image object definition and classification for reading image data
(Krowne & Halbert 2004)	Technique	Media Extraction	Review of library content browsing using extraction methods
(Koivusaari 1997)	Technique	Media Extraction	Document content characterisation method for multimedia retrieval
(Ganapathi & Lourde 2006)	Technique	Feature Extraction and Image Matching	Optical Character Recognition and raster image analysis
(Last et al. 2001)	Technique	Media Extraction and Feature Extraction	Algorithm for feature recognition
(Liang et al. 2012)	Technique	Image Matching	Algorithm for image matching
(Liao et al. 2012)	Technique	Image Matching	Efficient image matching
(Lins & Silva 2011)	Technique	Feature Extraction	Algorithm for discrimination between digital and scanned photographs

(Liu et al. 2012)	System	Image Matching	Speedier algorithm for image matching
(Liu et al. 2007)	System	Media Extraction	System for engineering document content extraction
(Lowe 1999)	Technique	Image Matching	Algorithm for image and feature matching
(Lumbantobing et al. 2001)	Technique	Media Extraction and Image Matching	Application of optical character, mark and word recognition
(Malin et al. 2010)	Technique	Media and Feature Extraction	Text extraction for annotating documents to support semantic text mining
(Manap & Soraghan 2012)	Technique	Image Matching	Image matching algorithm
(C McMahon et al. 2004)	System	Media Extraction	Document retrieval system using extracted media
(Misra et al. 2012)	Technique	Media Extraction using Artificial Intelligence	Text extraction from images using neural network algorithm
(Mitchell 1999)	Technique	Artificial Intelligence	Machine learning application
(Nixon & Aguado 2008)	Technique	Media Extraction	Image processing techniques and application
(Peng et al. 2012)	Technique	Media Extraction and Pre-Processing	Improved text extraction for handwriting using pre-processing method
(Xu et al. 2012)	Technique	Image Matching	Algorithm for matching images
(Rotter 2011)	Technique	Media Extraction	Method for multimedia retrieval
(Rubio et al. 2012)	Technique	Image Matching	Algorithm for image matching
(Ruta & Gabrys 2007)	Technique	Feature Extraction	Data reduction for improved feature extraction

(Saleem et al. 2012)	Technique	Image Matching	Performance evaluation of image matching algorithms SIFT and SURF
(Shi et al. 2012)	Technique	Image Matching	Algorithm for image matching
(Singh et al. 2011)	Patent	Media Extraction	Automated media extraction system description
(Steimann 1998)	Technique	Media Extraction	Media parsing for medical concepts
(Stringer-Hye 2005)	Technique	Media Extraction	Document summarisation systems review
(Suk et al. 2014)	Patent	Image Matching	Devices and methods for image matching
(Chaowei et al. 2012)	Technique	Image Matching	Algorithm for image matching
(Xun Tang 2012)	Technique	Image Matching	Book retrieval based upon image matching
(Vandana et al. 2012)	Technique	Image Matching	Algorithm for image match
(Venters & Cooper 2000)	Technique	Media Extraction	Review of content based image retrieval
(Vieux et al. 2012)	Technique	Media Extraction	Object detection for matching
(Vizilter & Zheltov 2012)	Technique	Image Matching	Shape correlation analysis for matching
(Wagner et al. 2008)	System	Image Matching	Algorithm for speeded up edge detection for images
(Witten & Frank 2000)	Technique	Feature Extraction and Artificial Intelligence	Machine learning techniques
(Wu et al. 2012)	Technique	Feature Extraction and Image Matching	Algorithm for image matching
(Wu & Murai 1997)	System	Image Matching	System for image matching using scanner

(Xie et al. 2008)	Technique	Image Matching	Shape image matching
(Yang et al. 2012)	Technique	Image Matching	Graffiti image matching
(Zhang & Zhang 2001)	Technique	Feature Extraction	Knowledge collection to support feature extraction
(Zhang & Gruen 2006)	Technique	Media Extraction	Image matching for reuse
(Zheng et al. 2012)	Technique	Image Matching	Optical Character Recognition for Chinese Handwriting
(Zhu 2001)	Technique	Feature Extraction	Feature extraction for data classification

Table 5.2: Document Media Extraction Literature Summary

Table 5.2 categorises the literature into three different areas (column 2). These are the pending patent information, current techniques employed in research and entire system descriptions (demonstrating part or all of the media extraction process). Each of these categories is discussed individually in the following sections.

The contribution (or purpose) of each publication to the overall requirements for developing a media extraction system is denoted in column 3. A summary of the frequencies of occurrence of literature relating to these topics is illustrated in table 5.3 below. This highlights both the current focus of research and potentially newer areas of research where techniques are not yet embedded into customisable software for industrial utilisation. This summary is discussed in the following sections to highlight the currently active research topics and potentially the shortfalls of current provision.

	Media Extraction	Feature Extraction	Image Matching	Pre-Processing	Post-Processing	Artificial Intelligence
Systems	3	1	7	-	-	-
Patent	3	-	6	1	-	-
Technique	26	12	31	2	1	6
Total	32	13	44	3	1	6

Table 5.3: Summary of Literature Topics

Media Extraction Patents

There are a number of pending patents within the literature for media extraction; these have been included within the cohort of literature as they are relevant to media extraction technology developments. These patents could relate to physical hardware requirements or less tangible methods and techniques for software implementation, more frequently they appear to describe both. These patents describe the use of previously theoretical techniques and how they may be implemented to carry out some required media extraction function. Interestingly, of the 87 pieces of literature

reviewed, only a small proportion relate to pending patents (8). This in some part could be explained by confidentiality of current industrial developments or immaturity of theoretical techniques for implementing image matching in practice to develop efficient systems and methods for patent application.

The use of some of these patents is demonstrated in the recording of literature classified as describing a system or the review of extraction tools in this report. The patent described in Singh et al. (2011) for an entire media extraction system can be seen embodied in the techniques applied in the Google Drive system. Some examples of embodied patent elements may be found within the tools developed, however, currently there are few examples.

The patents reviewed demonstrate principles related to a broad range of the many of functions required for a media extraction process. A majority (7) of the examples given in table 5.2 illustrate a number of methods combined with devices that are required to implement image matching tools. Another of the patents describes a technique that could be used for pre-processing images, to convert a raster format image into vector format Boose & Shema (2003), thus overcoming some of the traditional difficulties in current image matching techniques. This is a useful technique to aid matching simplistic shapes within images for comparison to predefined image collections. Other patents provide examples of using a media extraction system for the further classification of media content to support decision making required by systems for further information or image processing Assodallahi & Bordag (2012), uses content recognition to improve information search and Hirasawa et al. (2014), enables a patent to be more accurately repositioned utilising image recognition techniques).

The number of patents identified related to media extraction and thus reviewed in this chapter are significantly small and it is evident that these patents represent the capability of techniques to be implemented in software or tools available for current industrial application. Thus it is also significant that only two of these patent applications demonstrate complete systems to implement automation of media extraction (Singh et al. 2011; Cullen et al. 1999) and do not include the methods required for further processing and utilisation of any results. The remainder of the patents represent *partial* implementation of techniques and methods, thus these methods remain inaccessible to current industrial methods without considerable research and development.

Media Extraction Techniques

The themes identified in the literature reviewed (see table 5.2) provides some evidence that current research focuses upon the refinement of developed techniques and methods. This indicates a shift from the design of new techniques for image recognition challenges to reviewing and refinement of mature and usable methods. However few examples are found in the literature providing comprehensive review of the “usability” or performance of feature extraction methods. This is with the exception of Ding et al. (2012) and the review of feature extraction for optical character recognition in Holambe et al. (2012).

One example of a direct performance comparison for image recognition methods is found in the literature, where Saleem et al. (2012), compares the performance of two feature extraction algorithms, SIFT and SURF. This apparent lack of performance related literature suggests that these techniques are not yet mature enough to directly compare their implementations (in software) and thus means that this review of extraction techniques remains highly theoretical. Hence it has not been possible to suggest the performance or quality of such methods as a majority of the literature describes the design of such methods rather than the implementation of such techniques. Any conclusions must therefore be drawn by combining the literature findings with any examples of techniques implemented currently in software applications. It is thus necessary to test the hypothesis that the software available currently for media extraction performs well and is suitable for utilisation within

industrial applications. (Hence this is dealt more thoroughly in the review of available media extraction technologies in sub-section 5.4).

The literature reviewed for techniques was by far the most abundant with 68 publications reviewed. However, the technique application was broad in range across the entire spectrum of media extraction requirements. A majority of the techniques were related to the developing media extraction (26) which promises a maturity of the theoretical techniques. However, *new applications of image matching* (23) and feature extraction (15) techniques formed approximately 56% of the literature techniques. These are all *new research areas for image recognition or media extraction* illustrating less mature techniques and a diverse audience for application. The diverse nature of image research suggests that applications may need to be highly domain specific and that general techniques are not suitable, hence limiting the usefulness of one developed application to another domain. This reflects the heterogeneous nature of the media and technologies currently available or being utilised.

This immaturity is compounded by the lack of technical performance and comparison data available (see earlier for technical performance related comparison Ding et al., 2012 & Holambe et al., 2011). Although this reflects the difficulty in drawing technique comparison for one media application to another it limits the capability of embedding techniques within reliable applications. There appears also to be a focus upon improving current techniques with artificial intelligence techniques or adding further pre and post image processing techniques to improve the results, in particular for image matching and feature extraction (9 in total). Examples are the efforts to develop artificial intelligence methods improving analysis of images in the work by Evangelou et al. (2001) or classification of media in the work by Basu et al. (2012). More recent literature examples are the pre-processing of image data for more accurate optical character recognition from handwriting (Dutta et al. 2012) and post-processing of retrieval results for error correction purposes (Bassil & Alwani 2012). These trends suggest that more research is required to address the weaknesses of current media extraction techniques.

Media Extraction Systems

The systems classification has been given to literature characterising entire systems meeting most of the requirements for implementing automated media extraction. This differs to the technique descriptions for individual functions or sub-components of an entire media extraction system. Within the sample reviewed a system could relate to theoretical description of an entire system solution though not yet be implemented. The performance of any of these systems is not evaluated in the literature and thus outside the scope of this review (the performance of implemented systems is considered in 5.4 where currently available media extraction technologies are compared).

Table 5.2 shows 11 instances of complete systems. A majority (8) of these demonstrate implemented systems. However the remaining (3) studies describe academic research that are not fully implemented solutions but include complete requirements lists for implementing such a system. McMahon et al. (2004) developed a system for the retrieval of engineering documents and another for the retrieval of information and media from engineering documentation (Liu et al. 2007). These two examples relate to academic systems for document content analysis and retrieval, with a particular focus upon engineering documents.

Media extraction system literature differs from technique descriptions as they describe complete implementations a required system, rather than individual methods. It is evident that each different system although complete consists of different components as the requirements vary subtly. For example a system to extract vector images requires different feature extraction approaches to facial recognition from photographs or additional hardware complexities to implement. Thus to understand the maturity of

media extraction tools or methods applicable for design engineering documents and media it is first necessary to consider the exact requirements needed for implementing such a system. Hence in subsection 5.3 the literature in the table has been utilised to synthesise a full system requirement for implementing a media extraction system against which a more accurate reflection of the current maturity of efforts is able to be compared.

Techniques, Patents and Systems Summary

The review (Carey 2012) has been circulated throughout Airbus UK to inform the direction of knowledge and information management developments, full detailed descriptions of the literature and technology studies can be found in this report. This section has been to provide a summary of the critical findings that impact the research in this thesis directly. In table 5.2 & table 5.3 a complete list of literature reviewed and a literature classification summary are given from the original review (Carey 2012). Brief discussions of the key literature findings have been included in this section for each media extraction literature classification given (techniques, patents and systems). In summary the key outcomes from that review that are *relevant to the research in this thesis* are as follows;

- Patents are available for both software and hardware media extraction solutions, suggesting technologies are available to implement complete systems. However these are few in number and only partial implementations are demonstrated.
- The techniques and implementations for matching and extracting images are not yet mature enough to deploy in software. Those implementations found have limited successful result.
- Performance data is not published or available to enable discernment of the appropriateness or success of techniques for image recognition technologies.
- Literature related to implementations of techniques for limited image sets such as characters is much more prolific and techniques are available that further pre and post process the image data to improve results. This suggests that the techniques have reached a much higher maturity enabling iterative improvements to be made. (The data integrity and quality of results cannot be alluded to utilising the literature alone, thus subsection 5.3, 5.4 & 5.5 address the maturity of such optical character recognition methods, availability of software implementations for industry and the performance of example software).
- The development or application of image recognition for Design Engineering data collections does not appear within literature highlighting a large gap in research in this area.
- Image recognition techniques are developed for highly specific application, thus although literature appears to be generic for media extraction methods, the actual implementation of feature extraction techniques are very different for differing media applications. It has not been possible to elicit the applicability of such techniques for Design Engineering documentation purposes from the literature alone and thus subsection 5.3 considers the overall requirements for design engineering media extraction tools and compares them to those currently available.

Although media extraction or image recognition research is not yet evident in the design engineering domain common themes appear within media extraction literature suggesting requirements for media extraction the same across domains. However, the diversity of media available and the sheer number of different feature extraction

applications suggest that tools and techniques are required to be application or domain specific. Thus commonalities in domain requirements are drawn upon in the next subsection to create a diagram of the media extraction system requirements for processing Design Engineering documents. Each principle is then compared to relevant literature examples from table 5.2 to enable assessment of its suitability and maturity for utilisation for design engineering documents. This enables a complete picture of the research and development overhead that may be required for automating media extraction for the design engineering domain and to synthesise any significant challenges.

Study 2: Media Extraction Tools & Technologies Evaluation

Frequently it is difficult to fully assess the software tools and functionality already developed. In particular where the cost of software applications is costly and any trial products often implement only a fraction of the advertised product capabilities. Assessing the value or implementation of certain techniques is also difficult due to the nature of software applications, the code and algorithms may be tangible to the developer but the complexities are naturally hidden from the user. Little is often disclosed by the developing companies regarding the techniques they employ to implement functionality and the algorithms employed do not necessarily mimic those from recent research. Therefore this appraisal has been based upon in the main trial software applications easily available and the software documentation that could be found together with any publicly available review material. This includes both professional reviews and any informal conversation (on internet forums) alluding to software performance experience.

Technology Evaluation

To evaluate the most relevant systems a sample of 21 systems were summarised and given categories. The categories chosen were; cost; trial availability; advertised functionality; any additional information sources. In table 5.5 below a summary of the 21 systems and their performance characteristics is provided. The table has a column referring to additional sources confirming the quality of the product performance. These were provided in the original report (Carey 2012) but are not included in this thesis, for further information a copy of the original report is available upon request.

Although where possible the product cost and availability of a trial software installation has been noted, often where a trial is advertised, the trial software has not materialised upon request. It has therefore not been possible to include full testing comparison of the software. In many instances the tools available are libraries of usable code not as complete software applications. This would also therefore require considerable development of application software to enable a trial to be possible. However, a more detailed trial of certain methods utilising Adobe software is provided for comparison in subsection 5.5 that follows.

It would have been possible to include a further category for Knowledge Organisation Software (KOS), as referred to by McMahon et al. (2004). However, for the purposes of this thesis it is noted that this particular category of software does not employ extraction techniques but extend the functionality for knowledge purposes, such as organising and classifying readily available data. These technologies are not directly relevant to the extraction of media contents and therefore not part of the comparison given.

Software Name	Cost	Trial Availability	Functionality	Information in Carey E (2012)
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A2ia	Not Advertised	No Response from Quotation Request	OCR for keyword recognition; implements document classification; form processing; address recognition; payment detail recognition	Product guide links and newsletters in references
Leadtools	\$495-\$5995	30 day trial Standard Development Code for application development	Standard Development Libraries of code for user development	Reference links to web pages
javaOCR	Open Source (Freeware)	Open Source requires application development	Trained Optical Character Recognition using Neural Engine	Reference for developers personal blog and user guide; source code link from sourceforge
Adobe OCR	Adobe Professional License Requirement, quotation required	N/A	OCR function and some reorganisation of document formats; limited for certain file types	Multiple user guides in Appendices; Also see detailed discussion in section 7
openCV	Open Source (Freeware)	Open Source C/C++ requires application development		Reference to further resources on web and books
iText	Not Advertised but development only under AGPL license	Some Open Source Libraries for Development; Usage and Costs by Negotiation	Application Programming Interface for PDF and metadata generation and manipulation	Referenced web source for more information
PDFBox	Open Source licensed under Apache License	Open Source Java Libraries for software development	OCR function for PDF text; PDF and metadata generation and manipulation	Referenced web source for more information
GNUjpdf	Open Source Licensed under LGPL	Open Source Java Libraries for software development	Application Programming Interface for PDF and metadata generation and manipulation	Referenced web source for more information

Autosplit	\$49-\$2999	Plug-in Software trial applications for different tasks	Software applications for generation and manipulation of PDF	Referenced web source for more information
CosEdit	OEM License by quotation	N/A	Software applications for OCR, generation and manipulation of PDF	Referenced web source for more information
Gnostice	\$599	Trial Version Available	Application Programming Interface for PDF and metadata generation and manipulation	Referenced web source for more information
Autonomy	Variable by negotiation dependent upon "plugin" requirement	None	Knowledge Organisation System (Multimedia) for IS & R	Referenced web source for more information and extensive product brief
ECDMS	N/A	Academic Test System Only	Knowledge Organisation System (Document Content) for IS & R	See Liu et Al (2007)
Waypoint (theoretical)	N/A	Academic Test System Only	Knowledge Organisation System for IS & R	See McMahon et Al (2004)
Velocity	Quotation upon request	N/A	Knowledge Organisation system (Multimedia) for IS & R	Referenced web source for more information
Adobe SDKScripting	Not advertised, Adobe Software Licence pre-requisite	N/A	Adobe proprietary Application Programmable Interface for PDF and metadata manipulation	Adobe API reference document
Excalibur	SDK	Open Source	Application	Web links for information only

SDK	unobtainable commercially	SDK requires application development	development kit and digital image manipulation libraries in C++ and Java	JISC review paper details in references for content based image retrieval methods
Matlab	£1,600 + additional and numerous toolboxes as required (approx £800-£2,400 each) student version	Requires Application Development	Fourth generation programming for image (signal) processing, numerical computations and visualisation of data sets	Widely used within academic environments for testing theoretical principles some application development
Bolide – Image Comparer	\$34.95- \$59.95	N/A	Image Comparison Metric Provision (no access to algorithm performance)	Review details poor and user forum questions list link
IMMI Rapidminer	Open Source IMMI (Freeware) and RapidMiner community edition (Freeware unsupported)	Open Source SDK requires application development	Trainable Image Segmentation or Object detection, other image processing and mining	Reviews from website and cited paper using the tools for academic development, see references and www.rapid-i.com
Mathematica	Not advertised, by negotiation with sales team.	Requires application development	Fourth generation programming for image (signal) processing, numerical computations, data analysis and visualisation simulation for data sets. CDF document format creation	Widely used within academic environments for testing theoretical principles some application development

Table 5.5: Tools & Application Evaluation

Summary of the Technology Sample

The differing systems summarised in table 5.5 are designed to perform functionality relating to one or more parts of the feature extraction process. In most cases this

either relates to manipulation of documents (parsing and reorganisation), image matching or feature detection (including specialist optical character image recognition) or more comprehensive tasks including full image data mining capability.

The tools also offer functionality for a broad spectrum of purposes but are all related to the extraction of media content from image documents. The table contains summaries for 21 technologies, offering functions such as image matching techniques, OCR functions, knowledge classification and organisation and feature extraction. There are 8 complete applications reviewed and 13 technologies supporting feature extraction development.

Half of the 8 complete solutions are designed to offer OCR functionality (4), only 1 offers image matching functionality, 1 advertises PDF document manipulation techniques and 2 are designed for the organisation of knowledge to support Information Search and Retrieval systems. This confirms that OCR is embedded within a higher proportion of software applications suggesting that tools for this purpose are more mature than generalised image recognition or manipulation.

Review of Technology Capability

The tools readily available for some automatic document content analysis and extraction functionality are many. A majority of the applications reviewed relate implement OCR functionality for the extraction of text from document images. However, fewer advertise image extraction functionality. In addition to this software development kits provide software code libraries to enable a proficient developer to implement their own OCR or image recognition functionality. This however, has significant development cost overheads.

Prolific software solutions are advertised commercially to provide OCR capability. Examples found include Adobe Professional, PDF Box, CosEdit, iText and A2ia. These tools while readily available suggest that they are accurate in output result but have not been tested as part of this report for viability. Reviews on the website for each application are worth reading (see references section for website details) as indication as to the performance of some of these applications is available from users.

The SDK or software library solutions such as JavaOCR or OpenCV offer the inclusion of some artificial intelligence methods for OCR but require algorithms, development and image training sets. These would be developed for individual purpose as opposed to generic implementations suitable for all extraction purposes. The potential for this type of development is considered in 5.4 & 5.6 however, the development of software application is not primarily the objective for this research.

In the literature there are examples of *pre and post processing of image data* to improve the results of algorithms, in particular for OCR. Within the technologies reviewed there is only one example of functions that either pre or post process data for a similar purpose, unless this additional functionality is not advertised (this is unlikely as it would be a significant selling point). The A2ia software is available commercially demonstrates the potential of post processing and pre-processing techniques for handwriting OCR and IWR (intelligent word recognition) for word recognition solutions. More details are available in the A2ia documents detailed in the references. This suggests that some of the literature techniques are now mature enough to be embedded within software applications. However, this is a cautious statement as details are not transparent enough about their implementation to compare directly.

There are few *image matching software tools* identified as commercially available. The JISC review for content based image retrieval Eakins & Graham (1999) identifies Excalibur software as having potential. In practice it has not been possible to obtain the actual software or much detail regarding its use and thus it has not been possible to ascertain its technology capabilities.

An alternative is Bolide software, advertised as a powerful personal software application implementing image matching for a number of purposes. In particular it is advertised that matching photograph images can automatically be searched for and eliminated within digital photograph collections. However, in practice the reviews on the website for Bolide suggest that in practice the tools do not perform well.

Other technologies fall into *additional categories* such as information and knowledge classification systems such as Velocity or knowledge organisation systems such as EDCMS and Waypoint. However, currently these methods rely upon either the extracted media or media metadata to be readily available describing the document or file content (concept-based image retrieval) as opposed to extracting features from the information media elements themselves (content-based image retrieval). Concept-based image retrieval would potentially require a manual annotation element for design engineering documents prior to the elements being organised as little metadata currently exists within image data files. The potential for this method is explored in the software capabilities in 5.4 and PDF file bookmarking subsection 5.6. The integration of media feature extraction to increase the descriptive value of the media elements being mined could much improve the retrieval methods a software is capable of implementing.

The *developmental and theoretical systems* available appear to offer incredible potential and current capability for implementing image matching techniques. However, many of these technologies are not yet complete software applications for commercial use and thus limit their usefulness for industrial purposes. Due to the incomplete nature of some of the software applications reviewed it necessary to consider the research and developments that would still be required to advance technologies for the automation of document media extraction for design engineering. The section below highlights the potential application of such tools. These routes for technological advancement offer increased potential but require large developmental costs in expertise and time.

Opportunities for Development with Technologies

The academic tools such as Matlab or Rapid Miner for use with Mathematica are tools that integrate image processing techniques with powerful image data mining potential. Their integration capability with other academic resources such as artificial intelligence analysis techniques are a place to begin the image matching for engineering design and image PDF files.

The academic use of tools such as Matlab or Rapidminer should be used to test the implementation of engineering text and image mining for raster image files. The open source developmental SDK's (OpenCV) could be used to implement resulting algorithms for producing engineering image matching software. The use of current OCR technologies with pre and post processing (A2ia) capability is possible either standalone or to facilitate intelligent combined image and text content mining. While Adobe software and OCR is already a PDF standard within design engineering technologies and could be used for basic OCR subject to licensing and performance tests (the performance of Adobe software functions is tested in section 5.4).

Summary of Technologies

In this section a number of broadly available technologies have been reviewed with a view to their potential for developing the support provision for design engineers to reuse document contents more effectively. The findings in respect of design engineering documents are follows;

- The performance of any software has not been possible to evaluate.
- A large part of the software or code libraries are designed for expert users and require significant further developments to implement effectively. Only 8 complete systems were observed.

- OCR is observed frequently within functionality, suggesting it is becoming a standard tool (Half of the complete solutions offer OCR functionality).
- Pre and post processing techniques for improving OCR functionality are not yet standard provisions (only one implementation found embedded within software).
- Image matching software implementation performance reviews indicate that this technology is not yet a commercially available function. Performance is not yet of a required standard for industry (only one implementation illustrated).
- Licences for software of this type are costly and functional trials are very limited, limiting the possibilities of direct performance comparison (ranging from \$34.95 - \$5995, freeware is designed for developers).
- More sophisticated knowledge or media organisation tools are still being researched thus not yet available commercially. This suggests that considerable developments could be required.
- Text extraction could potentially be combined with other methods to improve media extraction and utilisation.

Summary of implications

These findings suggest that technologies illustrate potential for being used for manipulating design engineering document contents and media. They do not however offer complete solutions to enable automatic extraction of relevant media for its reuse in informing design engineers. It is also evident that the utilisation of such technologies is subject to a level of programming development if further methods or algorithms for post and pre processing techniques are to be utilised, this could be costly in terms of development resources. It also requires the validation of the performance of such techniques or software to enable its utilisation in an industrial setting. The next section uses an example of software that is readily available that has some of the main media extraction functionality discussed so far in this chapter. It uses the Adobe software to evaluate the current potential for utilisation of software applications within industry.

Study 3: Adobe Document Software Testing

It is important to understand the media content of the documents being analysed to ensure that appropriate extraction methods are chosen. It is equally important to understand the format of the PDF documents, the media storage formats and to understand how to manipulate the files and content using current analysis tools. Adobe PDF- A is the current standard being used in industrial teams and is a document standard developed to be suitable for archiving; other versions are now available for secure web publishing. Adobe provides a software suite to enable creating and processing PDF documents, namely Adobe Professional. This software offers multiple functionality such as optical character recognition, although the implementation differs dependent upon the software version, thus changes in performance are noted.

Testing using the archived PDF files has therefore been conducted for analysis of current software capabilities. The purpose of this is to get an understanding of the efficacy of automatic media extraction from these large, complex and varied data sources that are archived as a single scanned PDF image file.

A number of considerations are of note influencing the choice of Adobe software for testing the capability of Adobe software as a performance indicator. They include the availability of functioning trial software and the cost of performing the trials, hence Adobe software applications was thus both available and free from cost. It is also one of the current applications being utilised for PDF compilation in design engineering.

Hence, it is of interest to this thesis to ascertain the current capabilities and potential of a sample software application. A trial has been conducted with this popular software application to scope the current potential of software applications.

Testing Conducted

Tests conducted using the Adobe Professional software is explained in the following sections. Each of the tests conducted is a function enabled within the software user interface. Development of additional testing using the Adobe API has not been conducted but is discussed as future potential in this section. A descriptive explanation of each of the tests is provided below. This is followed by a summary of the tests and results in table 5.6. The tests conducted are to be used as illustrative examples and not exhaustive for software testing purposes.

The PDF historic case file tested was 50 pages in length containing a variety of media types. A copy of this file is provided as an example historic case appended to Carey (2012). The first test conducted was the extraction of text media using the Adobe OCR function. As is discussed below this test impacts upon the results of all other testing, hence this test is dealt with separately from others.

Adobe OCR and Image Integrity

One of the techniques developed and offered within the Adobe Professional software version 8.0 is optical character recognition. This is a standard integrated function proprietary to Adobe and offers no further additional facility to train the software for recognition of handwriting or alternative character fonts.

The results are provided in Carey (2012) and are a comparison of results before and after the OCR function is conducted. Performing the function of OCR for an example 50 page PDF file takes several minutes to process, the output includes error messages that frustratingly if not supervised during processing can result in the abort of processing of one or more files. The error messages provided are not easy to interpret where the processing issue results from. Although not significant for processing one PDF document, performing OCR for multiple files could take human effort due to the time and error corrections and dedicated computer processing resource.

The outcomes from each of the tests listed in table 5.8 differ for an OCR processed PDF file than for a traditional image PDF file. This result in unusable and partial images without further processing, example results are provided below from the processing of 777 historic case files. This is particularly significant when extracting images from PDF documents and without comprehensive understanding of the underlying document PDF encoding are complex to resolve and potentially require further image processing. This appears to be due to the changes in PDF file structure that occur as a result of the text extraction process. For this reason a pre and post OCR result is provided in table 5.8 after a brief description of each test in the following sections. The Adobe website provides more detail regarding the Adobe OCR function and associated file structure changes that take place, details of the Adobe supporting resources and document are referenced in Carey (2012).

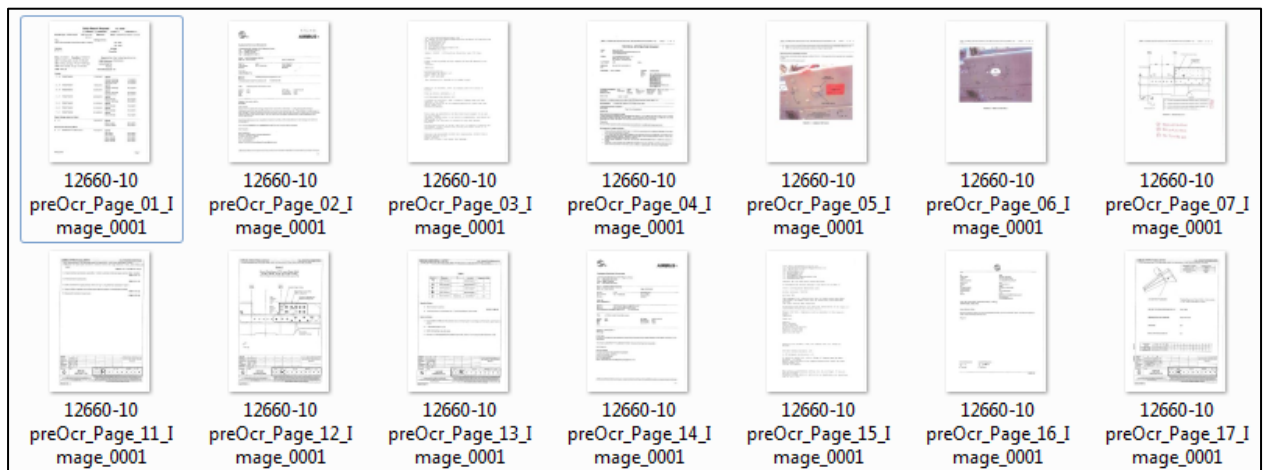


Figure 5.6: Illustration of Images Extracted (PreOCR)

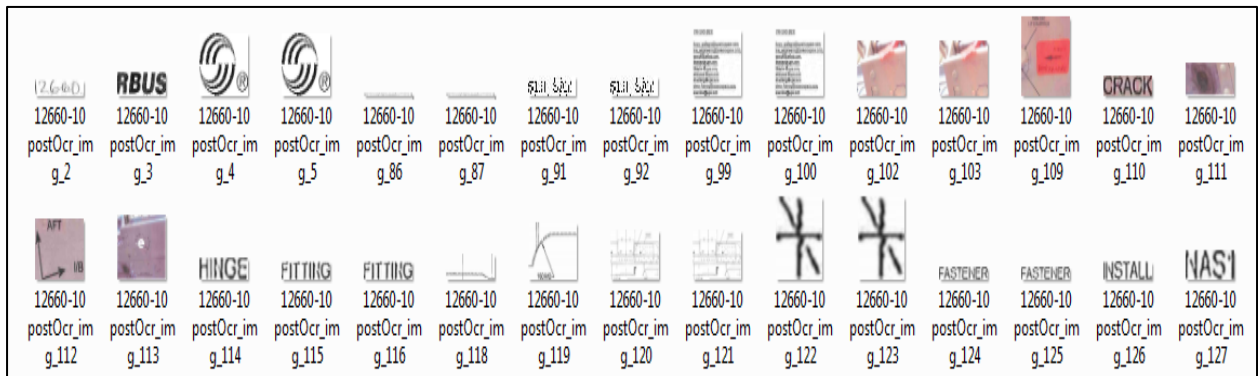


Figure 5.7: Illustration of Image Extracted (Post OCR)

It is evident from the results that the underlying format plays a huge role in the image functions available and that considerable understanding of these formats is required. The first example in 5.6 illustrates that an image PDF file is simply parsed page by page irrespective of the text contents, this would be an unsuitable solution if attempting to automate the understanding of the text or if attempting to utilise the value of the images separate from the text. In Figure 5.7, the file has been processed with OCR but it remains that photographs are parsed due to the extraction of text making them difficult to understand visually. This is small sample of the illustrations extracted, the images extracted from the entirety of the file are prolific, many of which have little meaning but illustrate the poor recognition of characters in logos or handwritten text. This type of extraction would require significant further processing to be of value in automating media extraction such as processing to discriminate the valuable images. This would also require investigation into the most valuable contents for design engineering process and document understanding. In

Test Descriptions

Test a – Preflight Test: The Preflight Test function is offered within the Adobe software. The output from this function is a short report offering insight into the file content and objects. However, as illustrated in the table the output prior to or after the OCR function provided similar results. The detection of images within the PDF file is evident in both results.

Test b – Export of All File Images: The export of all images function results in the output of images from a PDF file being copied into another folder with a naming convention identical to the original file name. The input PDF file is itself an image and therefore the Adobe definition of an image feature is of interest and being tested.

There are significant differences before and after the OCR processing of a PDF file. The contents of the pre OCR image folder is each and every page is extracted as a complete image and exported singularly into the folder as a separate image file.

The result for a file pre-processed using the OCR function differs. The content of the output image folder contains individual images as extracted from the PDF file. Figure 5.6 and Figure 5.7 are example is an illustration of the images output from the image extraction process. This is an example of the image features that the Adobe software uses for extraction purposes.

Test c – Export of All XML: The use of the Export of XML function produces a formatted XML document as output. The XML descriptions of the PDF file are provided within the XML. The significance of this test is the extraction of descriptive metadata regarding the PDF file content that could be utilised by other programs.

The resulting XML file descriptions differ for a pre and post OCR PDF file. The pre OCR output XML file although formatted as an XML document provides information regarding the file content in hexadecimal and binary format. The XML descriptions for a post OCR PDF file alter and contain information regarding objects and formatting. Appendix 8 of Carey (2012) provides an example of the XML file output for each of the files processed for comparison.

Test d – Object Data Tool for Object Selection: There is no product output from this result for further analysis. This function allows for the processing of a PDF file on a computer screen to select the possible objects that may be encoded as part of the PDF file. The result of attempting to select an object both pre and post OCR function are the same. The software suggests that objects do not exist within the PDF file as no objects can be selected.

Test e – Export as HTML: The HTML Export function is useful to illustrate the format of the PDF file if viewed in a web browser. The differences are output to a folder for viewing. Comparison is not provided within this report as the results are similar to those of the export of images or XML. This could be a useful function to demonstrate file formatting if web browsing were to be implemented.

Test f – Document Page Comparison Report : The output result of this function is a print preview report for the PDF file. Example results are provided the full review.

Testing Summary

In table 5.9 shown below is a collective summary of the testing results obtained from the tests described in 5.4.3 explained above. The following sub-sections highlight some common issues that arose from the testing process.

Test Performed	Pre OCR file format	Post OCR file format	Results Appendix
a) Pre-flight Test	Images only are detected within the file	Images are detected within the file	N/A
b) Export of All File Images	Each of 50 pages extracted into a folder of images (compressed JPG files created for each individual page)	Images separated and extracted into folders, (compressed JPG images created). Not all images remain intact; some image data appears lost, images parsed in irregular places. Some text images remain in interpretation of image is questionable.	Original Report Appendix
c) Export of associated XML	Processing time appears significant in length; file produced is approximately 9KB.	Immediate processing but file produced significant at 37KB.	Original Report Appendix

d) Object Data Tool for Object Selection	Fails not allowing object selection	Fails not allowing object selection	N/A
e) Export as HTML 4.2 with CSS 1.0	Processing time appears significant but completes successfully.	Creates images folder; some images appear duplicated from previous experiments.	N/A
f) Document Page Comparison Report	Print preview comparison	Print preview comparison	Original Report Appendix

Table 5.8: Initial Testing Results

The Processing Issues

A number of issues arose as a result of the extraction testing discussed individually below in the processing issues. The overall extraction functionality and the potential for further testing using the Adobe API is discussed below.

Processing Issue 1- OCR performance: The performance of the OCR function results in a processing delay. Although not significant upon processing individual files it could be a significant processing issue for multiple files.

A pre and post comparison file is included for in the original report demonstrate the output result. The results illustrate one of the performance limitations of commercial OCR solutions. The accuracy of the interpreted data is still somewhat limited in its success. This is evidenced by the approximate 14 errors in text conversion found on the second documented page of the document alone.

The errors found relate to the performance of the software when converting emblem image characters or hand annotated characters. Even in the instance of the logo the characters "RBUS" is not recognised and remains in image format. On another page the logo is converted correctly other than the character "S" is replaced for the \$ symbol. In instances of chunks of text being converted errors character conversion errors include "e" being recognised as "a" or a "/" being recognised as the digit "1". Numerous errors are identified and the consistency of performance differs throughout the document. This raises integrity and performance issues that would be required to be addressed before further using the converted file text. The inconsistent performance could also be indication that sections of the document image are clearer than others or due to consistency errors within the image matching algorithms.

These issues would be required to be investigated in full before further use of the converted text as the impact upon performance of information search and retrieval methods using text terms could be profound. It is however possible to post-process the strings of text output using an additional program script to identify, manipulate and correct some of the error. This would require the definition and spelling for a library of "Airbus" associated In-Service engineering design terms (or frequently used acronyms). The results of this post-processing could improve errors minor misspellings; this will not remove all error due to the unpredictable nature of those errors.

Processing Issue 2 – Image Integrity Loss: Another processing issue identified upon the extraction of sub-images from the image PDF's. The result of extracting images before the OCR process simply resulted in the conversion of the large PDF image into a "lossy" image compression format such JPG. This does not immediately support the parsing of the PDF file into meaningful media but converts the original file into an alternative document media form.

The performance of image extraction post OCR processing was more effective, as the remaining file after the removal of text conveniently resulted in sub-sections relating more directly to the sub-images required to be extracted. However, whilst appearing promising this process was not without its integral issues. Extraction of the sub-images from the original file leaves still leaves each image stored as a compressed image file, in a folder for each document (this reformatting of the image loses some integrity of the original data format due to compression).

A more significant issue relates to the extraction of the image after OCR processing, leaving some images, where text or annotation was present, parsed in irregular places. The images present within the folders were in some cases partial Airbus logo text that had not been converted using OCR and in others it was complete photographs that contained textual features for OCR comparison.

It is possible but not conducted in the testing described above to perform OCR upon a copy of the PDF file and retain the original file for alternative purposes, thus removing the issue of image integrity. However, the images in this case would not be extracted but only text from the OCR output. This does limit the use of textual information within images that could be of particular relevance to the location of a repair (Hunter 2010).

Processing Issue 3 – Post Processing Programming Requirement: The testing conducted illustrates individual functions of the Adobe software. It does not however provide for the restructuring of the information elements or clear extraction of individual media features. The files concerned have multiple formats of media of interest that the Adobe extraction methods do not attempt to address. Additional programming would be required to implement the file restructuring and testing comprehensively.

Processing Issue 4 – Result Dependence upon File Structure and Format: The results of the tests appear to be dependent upon the PDF sub structure and file type as the performance of each test differs both before and after the processing of the document using OCR. The Adobe User Guide (Appendix 5, Carey 2012) suggests that processing of a PDF image file using the OCR function results in a new layered document with created PDF objects. Some of those objects contain binary image data and some of those objects are the ASCII coded text, together with associated file layout or format data. This could explain the result differences.

The test differences between the output both before and after the OCR processing is significant and therefore required to be understood. Differences in testing output and the supporting Adobe documentation, regarding the OCR functionality (Appendix 5 of Carey 2012), indicates that OCR processing performs transformations to the PDF storage formats. It appears to convert the image data within the file into PDF object data where it is feasible to do so, with the addition of XML file data or metadata. This renders the new output file format into more useful forms for further processing using the XML data, encoded text data and the new parsed sub image data.

Processing Issue 5 – Objects (Object Interpretation Issue): Object data extraction doesn't work either pre or post OCR suggested limited object understanding and further testing may be required.

It is possible that the reformatting of PDF file data by OCR processing appears not to be true PDF object data as the object selection tool does not perform in either pre or post OCR processed files. It is possible that this result is incorrect and further analysis and deeper understanding of the file formats and storage types would be required.

Processing Issue 6 – Testing Sample Limitations: The sample file tested may not be exhaustive enough to provide accurate results from each of the tests and should be used as an example of possibilities only. Additional comparison and comprehensive testing would be required to make accurate inference as to the performance of the Adobe Professional software for feature extraction. In particular, the resolution of file images and file media content for the OCR processing could provide significant differences in results.

Additional Testing Possibilities

It is possible to further process the documents utilising the Adobe software and an application programming interface (additional libraries of code for developers to implement further function). An example would be the manual annotation of pages or features within the documents with Adobe bookmarks. These bookmarks create background metadata to support further programming of functions for extracting selected document pages or manual but accelerated file navigation functions by providing metadata for additional navigation structures (these are observed once a file is opened by a user and accessed by clicking upon document navigation hyperlinks). The potential benefits for applying this technique to design engineering documents for the extraction of media contents is considered further in subsection 5.6.

Adobe provides a proprietary scripting language for the PDF file to enable the programming of some file transformations or manipulations using file scripts. The transformations available are limited by the PDF file type and the existing meta-data. This is similar to writing a macro script using Visual Basic within excel file types to increase the programmed functionality.

In the case of PDF/X formats the PDF file is stored as a series of linked objects, thus facilitating the reorganisation of the data using programming techniques in a meaningful manner. The utilisation of differing PDF standardised formats alters the low level encoding of a document and thus alters the functionality provided or the performance of such techniques and this would need to be considered further for industrial repurposing. For the image formats considered in this study this document discusses the manual book marking that would be required and is the only additional file meta-data that can be used for programming transformations without the implementation of image processing techniques.

Summary of Adobe Document Media Extraction Performance

A number of tests have been undertaken utilising the Adobe software. It is advertised to include functionality to extract text or images from the PDF files and automation suggested to be possible using the additional scripting facility for batch processing of files. There are a number of findings to highlight from the results that are relevant when considering if the Adobe software is an appropriate solution for implementing automated extraction of the media content for design engineering documents;

- The file format prior to processing using Adobe software determines the images output from the function. Results are also affected by the OCR processing. In practice the output is potentially parsed up images where the OCR function attempts to recognise characters, or the images appear in small slices rather than complete. If little information is given before processing and standard Adobe functions utilised the output image results in entire pages being output as each image.
- The images extracted post-OCR function relate closer to the individual images within the original file. The OCR processing function while appearing useful has some issues with the integrity of the output text and the images retained within

the file. This is particularly difficult to predict the output due to the complex encoding PDF supports and the differences this relates to in document data structures.

- OCR performance would need to be measured more accurately before determining if it is an appropriate tool as there are a number of characters that are misinterpreted frequently. This could be particularly troublesome for acronyms or critical reference fields for subsequent identification. The result of further text extraction methods are detailed in section 5.7.
- Duplication of document resources due to processing issues is evident within industry. In more recent industrial utilisation of OCR it has been necessary to process batches of files with a dedicated computing resource taking several weeks to complete. Due to processing issues (see 5.4.5) this has required duplicate document resources to be retained as the original file pre-OCR is required to be retrieved for the image integrity and the post-OCR version being utilised for programming purposes. This risks the integrity of any information if the files are updated, takes huge additional network storage capacity and poses security risk for sensitive data.

It is possible that with further post or pre-processing of the image documents that result could become more accurate, in particular with regard to the OCR processing issues. However, it is not possible to suggest how much time or cost in development that this would require without considerable more investigation. Hence this could be a useful tool for implementing the automation of OCR for design engineering documents, although processing the large number of files required could present additional time challenges.

Summary of Implications

The Adobe software does not provide a comprehensive image feature extraction facility for the definition of heterogeneous media contents as is required by to automate the extraction of media from design engineering documents. Hence this would not be an “off the shelf” solution and would require part automation and significant developments to be useful.

However, utilising the text extraction alone ignores the value of the rich image media elements prevalent within design engineering resources. Thus solutions that combine text extraction with manual image annotation and browsing strategies may be more appropriate for developing solutions. This is similar to the methods employed for concept-based image retrieval research using a manual implementation. Exploring the benefits of book marking of key media elements and additional tool development for extracting media elements using programming libraries (discussed in subsection 5.6 and 5.7) could provide a powerful extraction method for the manipulation of documented information and the extraction of key media elements.

Overall Summary: Review of Potential Developments

In this chapter thus far subsection 5.2 has summarised the challenges and potential for media extraction developments from a theoretical perspective and 5.3 and 5.4 have further investigated this by considering the tools and technologies currently available to implement or develop support for the reuse of media from design engineering documents. In this section the key findings in respect of this research so far are highlighted below and then potential developments utilising what has been learned are synthesised and their challenges discussed in the subsequent subsections.

The significant findings from literature and technology explorations thus far are;

- OCR pattern recognition techniques are the most mature (some additional processing to improve) and many software applications implement some of this functionality. The performance although difficult to measure illustrates

processing issues in time and integrity of the text, however, with further development this could be useful for design engineering document text extraction.

- Image recognition techniques are much less mature in particular for the heterogeneous nature of design engineering document contents. The software implementations are few and require considerable specialist development skills, thus this is not suitable for current support developments.
- Extraction of text alone does not support the reuse of heterogeneous media content of design engineering documents. Thus to investigate the value of support for reusing their contents requires methods that combine some automated text extraction and manual image extraction and browsing support. Section 5.6 explores further Adobe software functionality to investigate this possibility (concept-based image annotation).
- Dealing with image data files such as design engineering documents requires specialist knowledge and competencies in low level document encoding and programming with application programming interfaces or libraries of proprietary development code (API's & SDK's). This type of development is time consuming and costly with little measure of performance of any resulting solutions.
- There is a significant gap in application of media extraction research for design engineering documents as this is not yet within literature. This is also evident in little research into the techniques for the extraction of heterogeneous media from documents.

The gaps in media software and poor performance for the extraction of heterogeneous content from image documents represent the immaturity of current tools and methods are summarised in the comments in Eakins & Graham (1999), where they identify levels of image query capability for image recognition technologies. He suggests that "level 3 queries relating to the actual contents of images" are unlikely to be resolved for many years to come. This is seconded in its lack of application to design engineering research. To make research thus manageable it is necessary to combine manual efforts for image interpretation and annotation with some automatic technology support for text extraction and understanding. However, this should be further focussed in efforts by understanding the respective value of the informative contents to concentrate developments upon those resources most significant for design engineering in-service documents. From a data driven perspective this has been identified as a gap in the design engineering literature (see section 2.3) as little has yet been done to understand knowledge support needs from a data perspective for design engineers (Vijaykumar & Chakrabarti 2008).

It is evident from the media extraction literature reviewed in 5.2 that there are many techniques being applied in a wider context that could be useful for exploration; many of these relate to making the human judgement of any resulting information queries easier by minimising the results, these are listed below with examples of their application;

- (Steimann 1998) uses text extraction methods for medical documents to create concepts of importance to support search. This is also applied in the facet analysis and ontology creation work conducted in McMahon et al. (2004) and Liu et al. (2007) for engineering design documents.
- (Krowne & Halbert 2005), (Kwasnik & Crowston 2004) and (Tang 2012) utilise the content of document metadata to facilitate intelligent browsing of document collections. Xie (2013) demonstrates how this can be further utilised to create semantic libraries to information search and retrieval tools using context to improve text based retrieval results. Artificial intelligence methods further explore the possibilities in this area.

- Image content recognition methods such as the patient repositioning system developed in (Hirasawa et al. 2014). The work by Eakins & Graham (1999) utilises the recognisable content of images and a review of content-based image recognition is found in (Venters & Cooper 2000), (Eakins 1996) and Eakins & Graham (1999). This is one of the strategies demonstrated in wider research.
- Pattern recognition principles could be applied to the contents of design engineering documents to create key feature summaries of document contents that are required to be “reused”. This could potentially support the assessment of information quality, the needed presentations or push of relevant information for design engineering documents (Nixon et al. 2012).

However, there are a number of practical methods that could be employed in research now to support understanding of design engineering knowledge needs from a data perspective. Related research exploring the potential of these solutions is detailed in the following sections 5.6 to 5.7 of this chapter but relate to the following potential opportunities;

- The manual annotation of images within Adobe documents to support the semantic metadata content of documents and to create mechanisms to develop further document content browsing and navigation techniques.
- The automatic extraction of text for further processing and available visualisation tools and methods to support the browsing and navigation of documents and identification of their contents.
- Automated summarisation techniques for the extraction and processing of document text to represent its contents for browsing (Hunter 2010).
- Content-Based images matching for the automated recognition of image contents in design engineering documents (This option is identified as a potential solution but not further explored due to the immaturity of feature extraction tools identified in section 5.3.5).

The sections that follow describe the related research and its findings that are applicable to direct the research possibilities for this thesis. It is deemed that the first two points for initial processing or pre and post processing of data for feature extraction and image recognition have been considered in the first three scoping studies described in sections 5.2 – 5.4. With the exception of optical character recognition that is currently already software implemented these techniques are not considered as useful for the further utilisation in this research due to their complexity and the current limitations of these techniques in their current application for design engineering applications. However the latter points are further considered in the final three scoping studies that follow below in 5.6 - 5.8 of this chapter.

Study 4: Adobe Document Bookmarking

The section above summarises a number of strategies that could be employed along with their limitations. However one potential benefit that could be achieved by enhancing document metadata and thus facilitating the combined image and text extraction, thus enabling further browsing presentations. This study aims to explore the processing required and the potential for Adobe Software and PDF document formats to be utilised to implement this technique.

This study utilises the historic case documents within industry that are described in 4.3.4, the adobe software application (also used in 5.4) and an exploration of the possibilities of the iText (see table 5.5) java processing libraries. The exploration in this study can be likened to the context-based image retrieval methods illustrated in Table 5.2.

The next section describes the work undertaken in respect of this study within the industrial case.

PDF Bookmarking in Practice

The industrial historic case collection described in Chapter 4.3 and the Adobe Software application were utilised to explore the potential for bookmarks to serve the purpose of additional document metadata. The schema 5 in the work by Darlington (2005) was used as a basis for deconstructing the media within these documents that would require demarking. The study was exploratory and was in part an observation of current practice combined with the additional bookmarking of a number of documents.

The schema shown in Figure 5.9 is an example of the bookmarking that was created within one historic case document. The schema shown is a combination of the schema by Darlington (2005a) and the constructs already demarked within the historic cases. It is evident from the acronyms that are already demarked that local terminology and further standard resources would be needed to be included in any bookmarking scheme for the design engineers to find the exercise truly useful in current working practice.

In observing the current administrative practice and in the addition of additional bookmarks it has become evident that the application of metadata has not been a consistent process for the design engineering team, with limited administrators being contracted in for the role. It has quickly become apparent that in practice bookmarking document collections of this scale and keeping them updated would not be a viable option.

However, it is possible that for some PDF file formats the automated addition of bookmarks is an option. The Adobe API (Application Programming Interface) and the iText Java libraries were explored to consider the applicability of such an approach. Due to the complexity and variety of low level encoding involved in PDF formats it is considered that such an approach is beyond the scope of this research. However, it is possible that for future studies involving a subset of the document contents to be extracted it could be a valid approach.

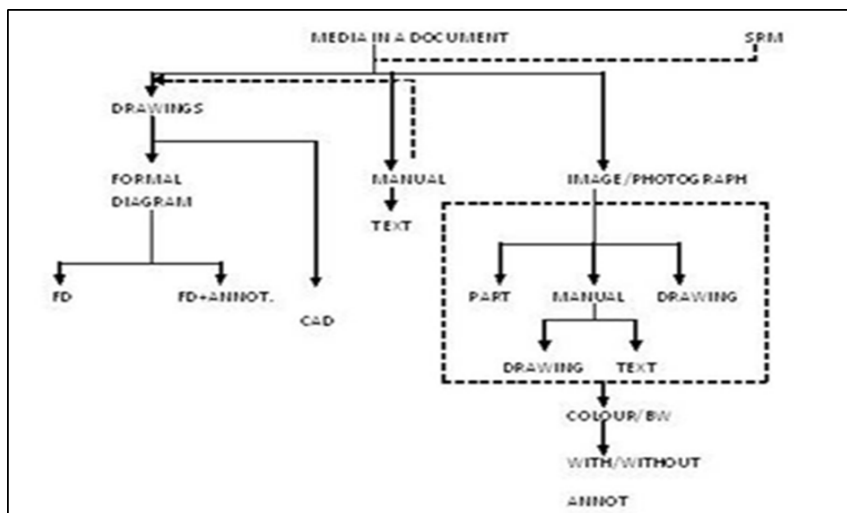


Figure 5.9: Example Bookmarking Media Schema for Historic Case

The maturation of technologies within industry is ongoing and the findings above could change rapidly with the advent of newer technologies for processing and utilising document contents. This is evident in the application of developments in in-service design engineering teams of automated collation of electronic subdocuments to create digital "e-pack" documents. In practice this currently results in part image PDF and part electronic PDF document collections. The research conducted in this thesis

demonstrates an awareness that supporting technologies are rapidly changing and this influence has been relevant in this example.

Summary of Adobe Bookmarking Challenges

In this section the potential for enhancing the metadata of design engineering documents to enable further context-based image retrieval techniques to be applied to the historic case documents has been explored.

It is evident from the administrative work being conducted already within in-service departments that even without further application programming this is deemed to be a useful tool for enabling better navigation of large and cumbersome documents. That said there are limits imposed to the usefulness of such methods due to the manual effort required to perform bookmark annotation to the historic case documents. The issues that arise are as follows;

- The previous efforts of administrator for the team are on an ad-hoc basis, meaning the reliability of the percentage of files containing additional bookmarks and thus facilitating metadata is low. This is due to the share nature of the role and the lack of industrial funding for such a position.
- The schema by Darlington (2005a), did not match the content of the design engineering document sample and thus needed considerable adaptation.
- The limited time available and the huge number of documents within the historic case collection mean that conducting this scale of bookmarking and keeping it up to date is not a feasible option.
- The lack of metadata currently available and the detailed understanding and programming overhead required to utilise Adobe API's and the iText java libraries are thus beyond the scope of this project.

In the next section a number of related studies to the design engineering historic case collection are described to scope their usefulness for this thesis.

Study 5: Related Design Engineering Document Studies

The studies explored in this section relate to additional research projects that have been conducted by students of the University of Bath as part of Masters Research projects. Each of these studies explores one or more aspects pertaining to the in-service information need. The works carried out for three research projects are described that contribute findings to the explorations for this section. These are conducted by Hunter (2010), McMullen (2011) and Humphrey (2013) in attempts to better transfer design engineering knowledge from explicit assets.

These are considered to be important supplementary work to the research work dealt with in this thesis. The projects were used to supplement it and to explore some other areas. They are included for completeness.

Supporting In-Service Operations

Hunter (2010), aimed to develop methods in support of the In-Service operation with a particular focus upon the historic case document collections. One of his initial objectives was to develop automated systems for the purposes of providing technological support for document content utilisation.

Hunter's experiments were exploratory in nature and reviewed the potential methods and tools that could support the extraction and summarisation of document contents. These also included the mining of text data for the purpose of further processing such as document clustering. In particular he identifies the difficulties in mining data from PDF document forms as a substantial limitation, citing Hassan & Baumgartner (2007). He also experiences technical difficulty when using the Adobe software application for exploring the document processing functionality.

The document processing and summarisation that he conducts is in the main limited to the textual elements for these documents. This is likely due to the availability of software application for text extraction and summarisation. Other than for the Adobe Software application he finds that it is not possible to extract the text from images. He also suggests that the images are possible to extract from the PDF files using the Adobe Software, this result is questionable given the results illustrated in section 5.4 and the resulting images are not shown. This could be related to the format of the original files that were processed, indicating the complexity of the PDF formats or due to his classification of image media. It is not clear if this includes handwritten notes, sketches, testing results etc. He also suggests the potential for the semantic annotation of images to support their reuse. However, he suggests this is not possible, this may be overcome by using further programming techniques as explained in section 5.6.

The findings of significance to this research are;

- A by-product of the use of OCR is the document size is dramatically reduced.
- The automated extraction of images using Adobe Software for some PDF encodings may be possible but would require further processing to be useful (approximates 10% to be currently useful).
- The processing of extracted text is useful to create summaries and to cluster similar results.
- It is not yet possible to automate the semantic annotation of PDF images.

The most significant weakness of these findings for the reuse of in-service document contents is that little focus is placed upon the design engineering requirement to utilise the document elements explored. It does not suggest if these text summaries are in fact the reduced features within the document contents that support the utilisation of information and documents for design engineers.

Understanding Aircraft Damage Context

McMullen (2011) seeks to explore the ways that improvements could be made to improve the document search facilities for similar in-service design engineering document collections. The objectives for his research included investigating the activities of design engineers to profile their search requirements and to "understand aircraft damage" with a view to being able to develop new strategies for data categorisation.

McMullen (2011) observed the current practices for retrieving document information within the industrial team and analysed this to outline the process undertaken. He also informally discussed with the design engineers their perspectives on the current search challenges.

The main findings of significance are;

- The textual terms for categorisation of damage within the historic case documents and the potential additional textual terms indicative of damage differences.
- Highlighting the scale of annual historic case amassment per aircraft programme.
- Highlighting that each design engineers has different search processes/strategies.
- Identifies useful information contents and subdocuments as diagrams, photos, RAS, ISQ & calculations. (This requires further understanding and clarification).
- Concludes that the current systems do not the most suitable documents.
- Suggests that to overcome the issues case (or document) summaries, visualisation and standardisation of historic case and search metrics to elicit similarity would all reduce the design engineer workload.

One of the strengths of the work by McMullen (2011) is that he sought to understand the design engineering users' needs to further characterise the key challenges they

face. This is important for the success of any technological developments or human interaction studies (Shneiderman & Plaisant 2004).

The explorations carried out also begin to scope the potential requirements for design engineers in documents, such as preference for certain sub-documents or visual media such as photographs. It is also evident that other document summaries show potential for benefit but McMullen (2011) does not identify the browse "use case" for document information. However, this is by no means substantiated by design engineering user testing and any summaries would require thorough evaluation of the value of any document contents to ensure useful content was not eliminated.

Visualising Aircraft Damage Context

Humphrey (2013) identifies a number of pressing challenges facing engineering designers including the increasing number of aircraft in-service and thus increasing historic case documents (Hunter 2010; McMullen 2011; Xie 2013 & Chapter 4 & Chapter 2), the extent and distribution of novice design engineers and the reduction in expertise due to retirements. Hence there is an increasing demand for effective communication to transfer experiential knowledge from existing resources. He suggests that existing research has addressed the problem of capturing knowledge and thus focusses upon the need to communicate that knowledge.

A number of visualisation tools and techniques were explored in a state of the art study and the textual contents of the historic case documents were utilised for visualisation sampling. There are many techniques showing promise but the coding requirements for creating visualisations was a limitation for this research, hence it is possible devoting further time to this cause could produce more significant results. Humphrey (2013) also identifies the need to match the visualisation characteristics with the needs of the design engineering users but does not find a solution that is completely suitable.

The relevant findings of this research are;

- A suitable visualisation for design engineering documents does not yet exist without proprietary development.
- It is possible from the document text alone to create visual search summaries for the collective cases.
- The visualisation of collective cases was potentially more useful for management purposes than for viewing individual document contents.
- Clarity and consistency in the visual method are key requirements, but user preference is varies significantly.
- Visualisation does not solve the case content and context issues.
- Identifying three further search requirements as archive browsing, context search and case content search.

The use of visualisations show promise for the management purposes of design engineering teams, however for viewing the informative relevance of individual documents other strategies are required. This research did not explore the potential for "reusing" the visual contents of documents as an alternative to visualising its collective contents. This is something that is critical to investigate to understand the relative value of information. For the purpose of this study it was assumed that the utilisation of the historic case documents was for "case based reasoning", this potentially excludes other "reuse" scenarios for the information collections and also needs to be investigated further.

Overall Summary of Findings

In this chapter it has been necessary to review the appropriateness of media extraction and utilisation technologies in particular for the purpose of reusing document information collections and content. These have been investigated in a series of detailed studies to assess their suitability to support the research in this thesis and for facilitating the reuse of document information. A number of

outcomes that contribute to the scope of the research in this project have come from these preliminary investigations. These are summarised with their implications below;

- Heterogeneous document information media reuse requires the image and text extraction and thus the available OCR software implementations available and thus software implementations are not yet suitable to support reuse of design engineering document collections (section 5.5 discussed the limitations in more detail).
- Performance of current combined text and image extraction software applications such as Adobe for extracting media from documents is not yet possible without considerable additional specialist low level document encoding knowledge and software development and thus is not suitable for this research.
- Automated extraction of heterogeneous media and images from design engineering documents such as described in Chapter 4.6 is not yet possible with the required level of accuracy and thus methods for this research will require manual preparation of any required resources and document representation solutions. However, this manual preparation could be supported by the design engineering document schemas (section 5.6 & Darlington 2005a) and content audits of Chapter 4, section 4.6.
- The developmental costs, integrity and security issues highlighted in 5.4 suggest that it is likely to be costly to develop technical solutions and thus the grounding for any technical developments need to be well established (see sections 5.4 & 5.6-5.7) requiring research into those document information contents most useful to design engineers. Hence the focus of this thesis is first upon the respective value of document information contents before embarking upon any technical solution implementation.
- Eliciting critical but reduced key document features (or reduced document features vector from utilisation patterns) for design engineering document contents is the required first step for this research to support the development of efficient to reuse document information representations.
- Traditional visualisation methods are not the most suitable for the design engineering document information collections (Humphrey 2013), this would support how information should be encoded for reuse and minimises document storage overheads, thus speed and accuracy of information retrieval methods could potentially improve significantly.
- The automated extraction and utilisation of text from documents is possible and useful to some extent (Hunter 2010). This alone however does not facilitate exploration of the contents of visual media in documents and thus must be employed with other research methods (McMullen 2011).

As has been discussed previously the awareness of the prevalence and value of visual representations for design engineering information (Henderson, 1991: Wild et al. 2009: McAlpine et al. 2006: Rotter 2012) suggests that priority should be made to investigate the value and utilisation of any visual representations within design engineering documents. In the next Chapter 6 a framework to enable the analysis of the experiments in Chapter 8 are grounded in the decision making theory that supports its creation.

The studies that follow describe the research investigations and design engineering experiments that have been conducted to enable the critical document contents for understanding design engineering information to be synthesised and to elicit their relative importance in the "information relevance" decisions of design engineers. This involves a shallower understanding of some of the concerns for human information interaction as applied to conducting research studies but application of any principles left to the exploratory demonstrations in the in-service interventions suggested in the discussion of chapter 10. Any relevant methods from human information interaction

research are discussed in Chapter 3 and in Chapter 7, describing the experiment for which they are employed.