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COMMUNICATION, INFORMATION AND KNOWLEDGE PROCESSES OBSERVED DURING ENGINEERING DESIGN REVIEWS

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ABSTRACT

Engineering design review meetings are unique opportunities for all the parties involved to share information about the product and its related engineering processes. For product development teams, the knowledge and information transfer processes that take place during a design review are critically important; key design decisions, design experiences and associated rationale are made explicit. Useful work has been carried out on the design review process, but little has been said about the content of the activity itself. To this effect, an extensive research programme based on case studies in the aerospace engineering domain has been carried out. The research methodology adopted by the authors is based on an "action research" approach which allowed a naturalistic observation of engineering teams. A unique set of tools and methods used to analyse and characterise the design reviews recorded during the case studies is briefly presented in this paper. This meeting analysis "toolbox" includes a Transcript Coding Scheme, a Meeting Capture Template and an Information Mapping Technique. The work reported here focuses on the results generated by these new analytical approaches. They have been compiled according to three complementary perspectives: communication processes, information processes, and knowledge loss. The observations and interpretations made using the aforementioned set of meeting analysis tools have fostered a practical strategy for the knowledge intensive capture of design review contents. These pragmatic findings and their implications in terms of future research activities are discussed in the concluding sections of this paper.

Keywords: aerospace design reviews, unstructured information, discourse analysis, knowledge acquisition, knowledge reuse

1 INTRODUCTION

There have been a number of studies of face-to-face meetings covering many research areas, but interestingly the topic has never, in itself, drawn much attention in the engineering design community. The work presented in this paper focuses on a specific type of meeting, namely design reviews. These meetings are key elements of the design control process and are implemented across product development activities in order to assess progress and verify the quality of the work achieved. Design reviews in the aerospace sector are highly structured to follow precise company guidelines imposed by the international standard IEC 1160:1992 [1] and adopted by national standards institutions.

In practice, they are events in the Product Development Process (PDP) where, amongst other things, key collaborative decisions and their rationale are made explicit [2]. Formal representations (or models) of the PDP can be found in abundance in engineering research literature; for a complete review see [3]. In the widely used Stage-Gate process defined by Cooper [4], a gate is a decision point which divides the PDP into discrete stages. The associated Stage-Gate model therefore explicitly places design reviews, also referred to as gates or milestones, across a stage-based view of the PDP. Of course, the number of milestones varies from one company to another. Design reviews provide a unique "information synchronization" point in the development of a product where the manufacturer and its suppliers can share information about the design and collaboratively evaluate the progress. The storage and archiving of the information and the subsequent knowledge generated during this type of event is increasingly important and has to be considered as a major issue in the development of information and knowledge management tools for engineers [5] [6].

Although the design review process has been studied extensively, as discussed briefly above, little has been done to investigate the efficient capture of the contents of design reviews. From these preliminary observations, the essential issue that stands out in the improvement of information and knowledge management practices for engineers is ***"how is it possible to record aerospace design reviews to capture the important knowledge elements for further reuse?"*** This question has therefore guided the research reported in this paper. The following sections propose a fresh understanding of these formal meetings based on industrial and academic case studies in the aerospace domain, the Design Transaction Monitoring (DTM) case studies, and outline a framework so that design reviews can efficiently support the product development environment described in this introductory section.

2 ENGINEERING DESIGN REVIEWS IN THE AEROSPACE SECTOR

A meeting can be seen as an activity where information elements are communicated, processed and transformed [7]. It is therefore important to build an overall view of the typical information processes that should occur during aerospace design reviews. The following sub-sections will briefly present the communication and information processes expected and outline the key knowledge elements which can be generated during this type of meeting activity.

2.1 Communication and information processes

The communication processes which take place during aerospace design reviews are typically synchronous and the essential communication channel – speech – is a proven knowledge production tool [8], systematically augmented by a visual stimuli (3D models, sketches, documents, gestures, physical parts, etc.) [9]. This event can be categorised as a "decision making" interaction situation [10], where engineers working on the same project are invited to share individual problems in order to achieve consensual solutions. Also, during these formal meetings, project team members are often required to report on their work in front of the review team; this is a typical "justification" interaction situation [10].

Using the information structure definitions outlined by Gardoni [11], spoken information shared during meetings is typically of an unstructured nature, but in the case of design reviews the process is usually structured around formal textual and pictorial information inputs. Figure 1 proposes an $IDEF_0$ parent diagram of the typical information elements related to the aerospace design review activity.

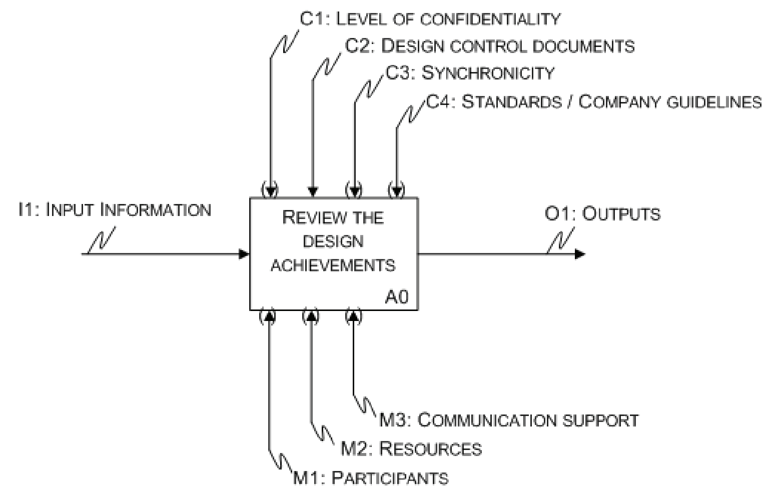


Figure 1. The $IDEF_0$ parent diagram of an aerospace design review process

This information blueprint is a first step towards a generic understanding of the information processes involved in aerospace design reviews. The approach used to represent this model of an aerospace design review follows $IDEF_0$ modelling rules [12], taken from the perspective of the participants.

The $IDEF_0$ approach is well suited to organise information elements related to a process or activity. It is possible to decompose the generic design activity represented by the box A0 in Figure 1 into three sub-activities: ***"share information about the design"***, ***"evaluate the design"***, and ***"manage the***

design". These are based on a general classification of design activities [13] and the theoretical understanding of the communication processes which can take place during the event.

2.2 Key knowledge elements generated during design reviews

Aerospace engineering design deals mainly with redesign or adaptive design activities [14] [15] and has therefore focused on knowledge capture and reuse for an improved evaluation and control of their intellectual capital. Knowledge Management (KM) can effectively be viewed as the management of the specific information elements that take part in the company knowledge process. Company knowledge conversion cycles [16], organizational knowing cycles [17] and learning processes [18] are some of the theories currently guiding KM practitioners. From the analysis of the literature related to KM and the specificities of design review activities, these meetings are predisposed for substantial knowledge creating and decision making. Participants typically update their information about the design, discuss the rationale leading to a collaborative plan of action, and share past experiences. Four key elements – rationale, decisions, actions and lessons learnt – have therefore been singled out for the efficient knowledge-oriented recording of information exchanges during design reviews.

Design rationale can be seen from many different perspectives: it could be the justifications for a designed artefact, a logical representation of the reasons for a designed artefact, a methodology whereby reasons are made explicit throughout the design process, or it could simply relate to the complete historical documentation of a design and its context [19]. The need for efficient methodologies to capture and reuse design rationale is a priority within current KM strategies [20]. The approach to represent engineering design rationale can be split according to whether the rationale relates to process knowledge or product knowledge [21] [22].

Decisions and actions**:** the study of design reviews will give insights on the rationale and the decisions leading to courses of action taken by designers and project managers. All the decisions made during a review will therefore be explicitly or implicitly translated into design definition or design management actions [13]. An organization can effectively be viewed as a network of decision making processes, where compromise frequently takes place within the context of well defined standard procedures [17]. Closer to the practical act of decision making, Badke-Schaub and Gehrlicher [23] have outlined certain patterns that can be found in design teams: cycles which include a reiteration of partial sequences of procedure steps, sequences which strictly follow theoretical decision making models (clarification, search, analysis, evaluation, decision and control), and meta-processes where the decision process is guided by a moderator.

A ***lesson learnt*** can be defined as a formal explanation of the solution to a problem which occurred in a specific context where new knowledge or an adaptation of existing knowledge was employed. In an environment where most of the designer's work involves routine or adaptive design, information concerning past designed products and processes is of great importance. Lloyd [24] distinguished three types of experiences used in engineering to transform a set of requirements into a reality: individual, social, and organisational experiences. Current industrial practices suggest that documenting lessons learnt is essential to help design engineers constrain the design space based on past experiences [25].

3. RESEARCH APPROACH

Research in the field of mechanical engineering design has often focused on studying the act of designing [26]. Because of the empirical nature of the design research field and the way that the act of research may affect and influence the activity being studied, it is of up-most importance for researchers to be clear about their methodology and the context from which the results have been drawn. This section therefore provides a retrospective description of the research methodology employed by the authors, which can be classified as a naturalistic observation approach integrating the "interaction analysis" method [27] but that also focuses on the various facets of in situ observations.

3.1. A case study based approach to understand design reviews

The overall Design Transaction Monitoring (DTM) project used three case studies to establish the approach and build up the core data. The work focused on the observation of design meetings and the case studies are briefly detailed in the following paragraphs.

Case study 1: observation of a student design team at the University of Bath. The team chosen was composed of four undergraduate students who had the task of redesigning a portable Brinell hardness tester for a small company. Two academic supervisors supported the students. This first case study was specifically an opportunity to organise a simple recording methodology for meetings and outline the foreseeable technical, organisational and human issues linked to the monitoring of design meetings.

Case study 2: design reviews at Airbus UK. Two large design reviews were monitored on site at Airbus UK, namely a Requirement Review (RR) and a Preliminary Design Review (PDR). Although the two meetings involved engineers from the same department, these were related to different aircraft programs. The detailed data collection taken from these two reviews provided a unique insight into the industrial realities of the aerospace design control process. The two Airbus UK design reviews were recorded on audio tapes and transcribed completely by the authors.

Case study 3: the CAMAQ project at the École Polytechnique de Montréal. Fifteen graduate students participating in the "CAMAQ project", a large scale aerospace design effort, were monitored during the whole length of the project in 2004/2005. This hands-on project was developed with the Centre for Aerospace Manpower Activities in Quebec (CAMAQ), IBM, and three large aerospace companies based in the region of Montreal. The project involves the redesign of an aircraft engine pylon to enable the retrofit of a new engine and is controlled by a design review process, in which a team of industrial and academic experts review the design achievements presented by the team [28]. The monitoring of this project resulted in the acquisition of a set of four design reviews: the Requirement Review (RR), the Concept Review (CR), the Preliminary Design Review (PDR), and the Critical Design Review (CDR). These were all videotaped and a complete archive of all the documentation generated during the project was also kept.

Table 1 summarises the role of each case study in the overall DTM research approach by outlining the details of the meetings observed (number of meetings involved per case study, average number of participants, and average duration), the research objectives, and the analytical tools developed and used to acquire the data (TCS: Transcript Coding Scheme; MCT: Meeting Capture Template; IMT: Information Mapping Technique). The analytical tools developed during these case studies are described later in §3.3.

Table 1. Summary of the research objectives for each DTM case study

	No. of Meetings	**No. of participants**	**Duration**	**Research objectives**	**Analytical tools used/ developed**
Case study 1: Observation of student design team meetings	10	5-7	20-45min	Test recording equipment and strategy Acquire awareness of monitoring issues	Transcribing
Case study 2: Airbus UK design reviews	2	9-13	2-3 hrs	Acquire industrial data for detailed analysis Observe industrial practices	TCS IMT
Case study 3: CAMAQ project design reviews	4	20-25	2-3 hrs	Acquire data over the duration of the design phases of a project Test research findings, tools, and methods	MCT

The overall DTM research approach, in which the three aforementioned case studies were involved, effectively integrates the interaction analysis method [27], but also focuses on the various facets of in situ observations.

3.2. Past studies of engineering meetings

Across the literature dealing with meeting analysis, six research teams – the University of Michigan [29], Project Nick [30], Projet Eiffel [31], the Xerox research centre [32], the Knowledge Media institute (KMi) [33], and the International Computer Science Institute (ICSI) [34] – have been studied in detail based on the relevance, completeness, and rigour the work reported. Overall, certain similarities have been noticed; the common goals driving these projects can be summarised as:

- The creation of collaborative tools to enhance meeting facilities.
- Understanding how engineers work / think / operate in a collaborative environment.
- The facilitation of meetings to avoid failure.

A majority of the case studies (University of Michigan, Project Nick, Xerox) were directed towards meetings held in the initial stages of the design process (prior to the specification of the requirements) where exploration and brainstorming are key activities.

Closer to the DTM case studies, Projet EIFFEL studied Technical Review Meetings in the software design domain, with an emphasis on problem solving and decision making. However, these meetings differ from aerospace design reviews in many aspects, e.g. they are not guided by international standards, they do not involve multi-disciplinary teams (only software design engineers), they are relatively short, etc.

The focus of the six research teams was on the development of software tools to support collaborative activities, thus most have concentrated their efforts on a computational approach including variable levels of prescriptive research techniques to validate their prototypes. Nevertheless, most of the teams have spent some time observing meetings in a descriptive approach prior to the development of computer tools, especially in the case of Xerox and ICSI. Protocol analysis has also been a source of data for some of the teams, i.e. University of Michigan and Projet EIFFEL. Because of the objectives of the research and the nature of the case studies, the DTM approach, as described in §3.1, differs from these approaches as it essentially focuses on a naturalistic observation methodology; here, the development of software tools to support design reviews was not the priority.

Based on these past research projects in the field of meeting analysis, one of the important practical aspects for an efficient study of spoken discourse is the use of verbatim transcripts. These enable the precise analysis of verbal transactions between participants based on a predetermined coding scheme. The Transcript Coding Scheme (TCS) developed for the purpose of the DTM case studies will be described in the next section.

3.3 The meeting analysis tools developed for the DTM study

Based on the formal understanding of aerospace design review meetings discussed in section 2, a unique set of tools and methods were specifically developed to analyse and characterise design reviews [35]: a Transcript Coding Scheme (TCS), Meeting Capture Templates (MCT), and an Information Mapping Technique (IMT).

The Transcript Coding Scheme (TCS) enables to analyse in depth meeting transcripts, which are documents typically used by a number of research domains in the study of spoken discourse. In the context of the DTM case studies, a specific coding scheme was adopted to produce measures according to 7 research criteria, namely: roles of the participants, intervention types, exchange roles, information types, artefact types, domains of competence involved, origin of the topics of discussion. These coding criteria are the result of a comparative study of the terms used in the engineering domain for meeting analysis presented by the six projects described in §3.2. The comparative study, reported in [2], first exposed the lack of cohesion amongst the pool of concepts used by these research teams to describe and analyse meetings. The results from the coded transcripts yielded a number of interesting results concerning information and communication processes observed during the Airbus UK case study, reported in §4.1 and §4.2. Ultimately, the TCS output tables that include the transcript and their coding were at the basis of the development of two other tools, the MCT and the IMT, which fulfil specific and different needs not covered by the TCS.

The Meeting Capture Template (MCT) enables the user to code the meeting as it is happening, effectively reducing the need for the transcribing process required by the TCS. An MCT presents itself as a table where each entry (or line) corresponds to a new conversation topic. Each entry can then be coded directly by the user; the columns of the MCT relate to a coding criteria derived from the TCS. An MCT can be used to analyse a design meeting according to the following aspects: participant role, exchange roles, information types, and topics of discussions (with their associated actions). The MCT was successfully trialled and developed during the CAMAQ project case study; the data captured with the MCT during the CAMAQ project is analysed in the next section along with the results from the TCS.

The Information Mapping Technique (IMT) was specifically developed to measure levels of knowledge loss from design reviews. This became and important and rather overlooked issue as the research progressed. The 'loss' is based on the comparison of two documents, namely the minutes and the complete transcript of the meeting [36]. The IMT is therefore text-based and requires the user to single out specific information entities in the document under consideration. These information entities are the expression of key knowledge elements – rationale, decisions, lessons learnt, and actions – described in §2.2; these are arguably the essential elements to be captured for both the project's and the company's 'memory'. The information entities are then associated to a specific symbol according to their knowledge type and these are mapped out in a succession of network graphs which follow the topic thread proposed by the document. A detailed description of the technique and illustrations are available in [36]. The IMT was used to map the information contained in the minutes and in the transcript of the Requirement Review from the industrial case study. The results, which will be discussed later in §4.3, illustrate the levels of knowledge loss in minutes of meetings and have fostered a number of empirical hypotheses to counter this problem.

The analytical tools summarised here have been used to help interpret the empirical data generated from the different case studies. The results complement and refine the theoretical findings on design reviews discussed in the previous sections of this paper. The development and use of the TCS, MCT, and IMT has also stimulated the elaboration of a strategy to improve the efficiency of meeting capture practices outlined in §5.2.

4. SELECTED RESULTS FROM THE CASE STUDIES

This section presents selected results from the DTM case studies based on three analytical perspectives: the communication processes observed, the information processes detected, and the knowledge lost from the meeting records. The relevant data was extracted from the recorded case studies using the three meeting analysis tools presented above. The design reviews from case study 2 were analysed with the TCS and the IMT, while the design reviews from case study 3 were studied using the MCT. The selected results illustrate the considerable range of analytical capabilities offered by the tools developed for the purpose of this research. It is important to note that the two case studies (case study 2 and case study 3) involved in this collection of data were not used in a comparative approach but rather in a complementary approach. Indeed, the design reviews in case study 3, which involved the trainee engineers, were considered comparable to industry practices by all the industrial observers invited to the meetings [28].

4.1. Design reviews – *a communication process perspective*

The observed communication structure of the recorded design reviews has been analysed at different levels. The study of the role of the participants in both case studies illustrates specific communication patterns for the meeting as a whole; the results also show the predominance of interface negotiation scenarios such as "justifications" and "information requests" [10] during design reviews. In order to analyse the underlying communication intent, the results from the "exchange roles" coding element in the TCS and the MCT have been further studied. Overall, the striking aspect common to all the design reviews monitored is the importance of "informing" and "clarification" exchange roles (these roles occupied 60-70% of the conversations). These results suggest that the simple act of "sharing information about the design" is an essential part of the overall design review process. In addition "decision-making", "exploring", and "evaluating" are also key exchange roles observed during design reviews. Their variation in percentage of conversation time across different design reviews, as observed during case study 3, can easily be related to specific objectives of each design review type.

In the study of communication processes for case study 2, a specific process has been chosen for detailed analysis, namely decision making patterns. The data generated from the "exchange role" criterion in the TCS, enabled to outline typical sequences of exchange roles prior to decision making; six main sequences of decision making have been unveiled and illustrated in Figure 2. These sequence patterns ultimately reflect a rational course of decision making with few conflicts of interest between participants [23].

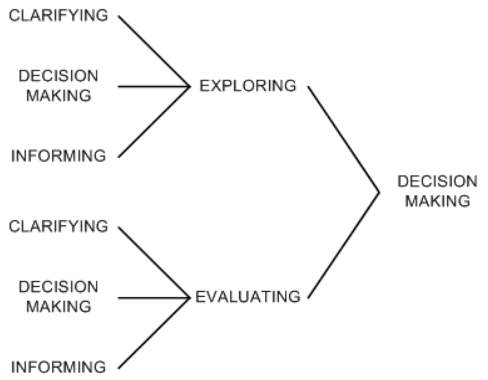


Figure 2. The essential decision making patterns observed during case study 2

4.2. Design reviews – *an information process perspective*

This section will now characterise the information processes observed during case studies 2 and 3, using respectively the TCS and the MCT.

The "origin of the topic of conversation" coding criterion in the TCS has further supported the qualification of the structure of the information exchanged during design reviews. In effect, the measures resulting from case study 2 indicate that 60-70% of the conversation topics are predetermined by the meeting agenda and the remaining topics of discussion are directly derived from these. From this study, the authors would also have expected a higher percentage of totally unexpected conversation topics in the early stages of the product development process, but the influence of the artefacts used in the conversations seems to play an important role in the structure of the information process.

The content of the information shared between participants, in case study 3, were very much in line with Concurrent Engineering practices. Design issues were at the heart of most conversations throughout the four design reviews monitored, with a peak at PDR. Management issues were dealt with early in the project (peak at RR), while manufacturing issues were only the true concern of the participants at CDR (with a critical low point at CR).

The study of the types of information exchanged during the design reviews of case study 3 has provided a unique illustration of the shift in balance between process and product information that occurs during the evolution of a design project, as shown in Figure 3. It might be argued that this was to be expected, but this research provides detailed evidence of its occurrence.

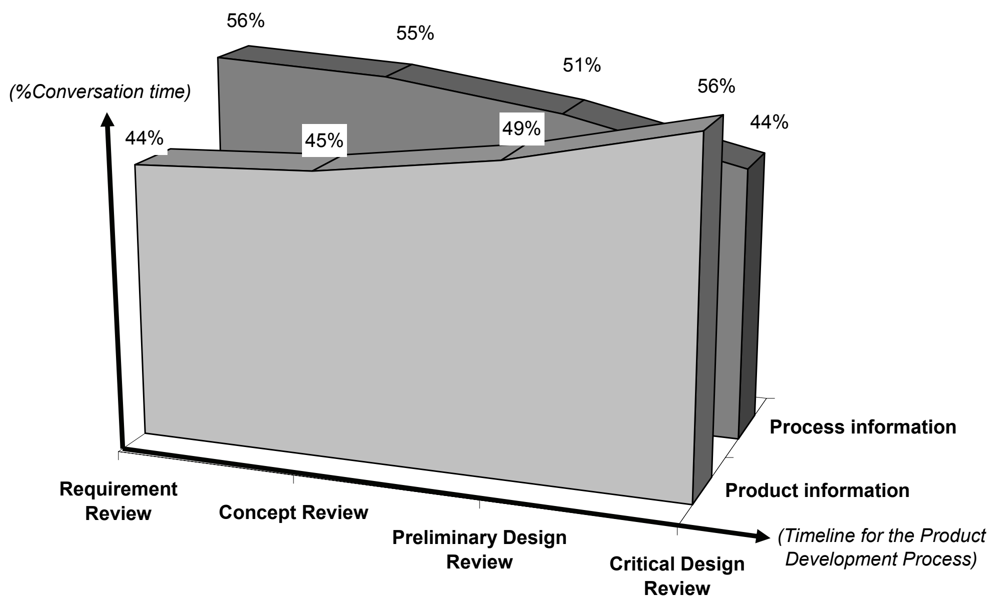
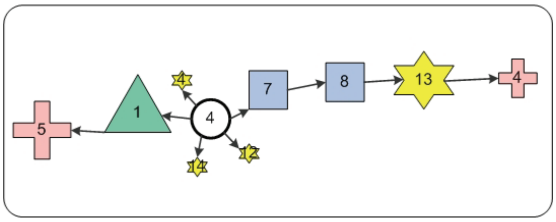
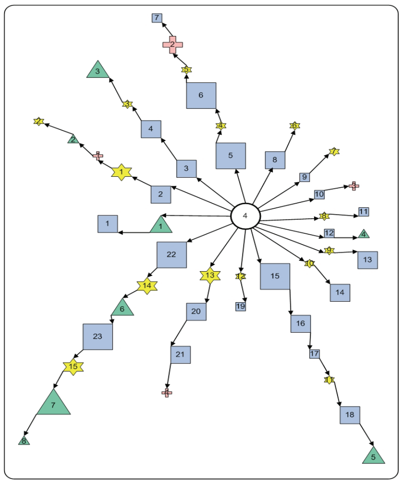
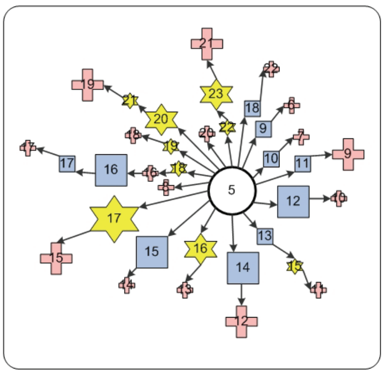
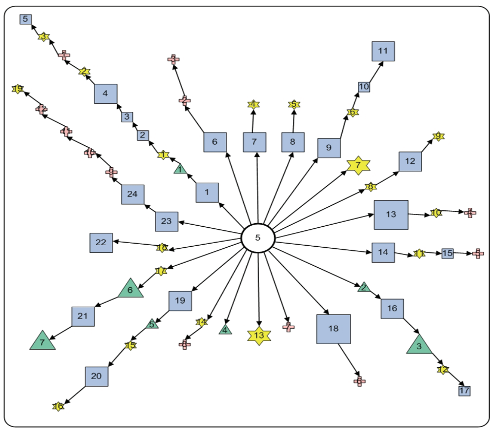


Figure 3. Evolution of product vs. process information across case study 3

Process information dominates the topics of conversation in the early stages of the project and then slowly diminishes, while product information gradually increases to dominate the topics of conversation at CDR. This study is unique in the sense that it actually provides figures based on case studies to support claims on the shift between process knowledge and product knowledge across the life of a project [21]. Nevertheless, the overall results from the DTM case studies (case study 2 and 3) show that the balance between product and process information remains within a 40%-60% bracket.
Finally, the study of the types of artefacts used during both design reviews of case study 2 clearly suggests that they are important elements which structure and focus to a certain point both the communication intent and the type of information exchanged between the participants. Artefacts used during a design review have definitely a key role to play in the elaboration of improved techniques for the efficient capture of meeting contents.

4.3. Design reviews – *measuring knowledge loss*
This section will interpret the findings from the Requirement Review monitored during case study 2 to highlight the implications in terms of knowledge loss based on the use of the IMT [36].
In the map for the "minutes" document, the most important topic of conversation in terms of number of words involved and highlighted information elements was "topic 5". However in the transcript, the two most important topics based on the same criteria were "topic 5" and "topic 4". This was quite a surprise as the minutes' map suggested that "topic 4" was not of great importance. Table 2 compares both maps (transcript map and minutes map) for "topic 4" and "topic 5".

Table 2. Comparative table of the information maps for "topics 4 and 5" [36]

Topic #	Maps from the minutes	Maps from the transcript
4		
5		

The maps presented in Table 2 follow a specific coding scheme [36]: rationale is represented by a square, a decision by a star, an action by a cross, a lesson learnt by a triangle, and the topic of conversation is the central circle. An information map of a meeting is therefore a sequence of conversation threads clustered around each major conversation topic, i.e. a circle. Based on the maps shown in Table 2, "topic 4" appears to have been badly recorded by the secretary. In the transcript map for "topic 4" a high number of threads, many rationale, decisions and lessons learnt elements appear, but with few actions associated to these. On the other hand, when comparing the maps for "topic 5" it seems that the minutes give an accurate account of the discussions which took place. Looking at "topic 5", a different observation can be made immediately: it seems that when writing up the minutes, the secretary "transformed" some of the decisions into actions. This is perfectly understandable as decisions can always be interpreted as actions.

The single most important difference between "topic 4" and "topic 5" lays in the actions: in the discourse, most of the threads linked to "topic 4" do not contain actions, whereas it is quite the opposite in the case of "topic 5". The resulting difference in the minutes' maps suggests that it is easier for the minute taker to record the meeting when actions are set out following the decisions. A number of meeting management strategies, e.g. [37] [38], suggest that certain meetings need to be action-oriented to become effective.

Another factor which might have an influence on the difference in the way minutes were taken for "topic 4 and 5" is the "distance" observed between the conversations and the artefacts under review. Although none of the meeting analysis tools presented in this thesis are capable of providing data for this type of measurement, the observations made by the authors suggest that the participants held discussions closely related to the document under review in the case of "topic 5". This most definitely facilitated the secretary's work as he had an explicit reference to action any decision made.

The essential finding that has emerged from the knowledge loss study is the importance of turning actions into decisions. Indeed, the secretary seems more capable of recoding the associated rationale, lessons learnt, and decisions based on an explicit expression of the action to be taken. There are some important lessons to be learnt here as a result of this research in terms of establishing how gaps in "corporate memory", particularly recorded "corporate memory" can and do occur.

5. AN ACTION-ORIENTED STRATEGY TO RECORD DESIGN REVIEWS

The results reported so far in this paper have enabled to refine a conceptual understanding of aerospace design reviews, to characterise them in terms of communication and information processes, and also to evaluate the knowledge lost. Before discussing a strategy for improving the capture of knowledge from design reviews, §5.1 will outline current practices observed in industry based on a review of meeting minutes exemplars and on a survey carried out in 2005.

5.1. Current practices for recording design review contents

Four documents were collected at Airbus UK for a study of their structure and communication intent: 3 design review minutes and a design review report template. The template is effectively used to insert the minutes along with other meeting artefacts (e.g. agenda, copy of presentation slides, list of actions, list of attendees, list of reviewed documents, etc.). Overall, this study has highlighted that rationale and lessons learnt are not explicitly recorded in these documents, and although they propose a similar structure, the resulting contents are formatted in an inconsistent manner even within the same document. Comparing the 3 design review minutes with the design review report template has enabled the authors to single out a major concern: the template generates significant information overload by recalling information which is already present in the minutes and in the same format.

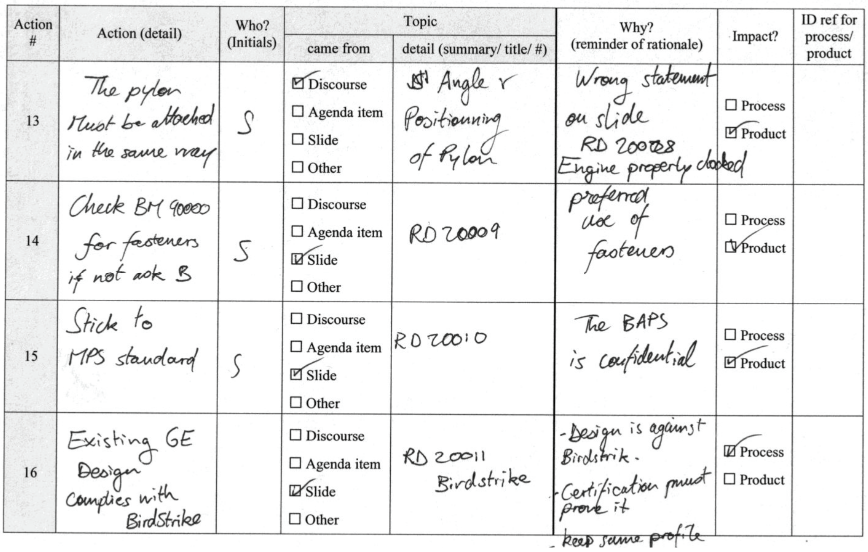
The study of a few examples of design review minutes limits the extent of the conclusions that can be drawn, and therefore a more precise understanding of minute taking practices in the aerospace industry was therefore sought via a survey. The questionnaire was distributed in 2005 to aerospace companies and suppliers based in Canada and in Europe. The investigation covered the following topics related to minute taking: "company guidelines and practices for meeting minutes", "typical structure of design review records", and "the respondents' perception of meeting minutes". The results of the survey are unequivocal: engineers learn to take minutes by experience and only truly value the actions list, the practical side of traditional minute taking [36]. These findings resonate with the study of design review minutes at Airbus UK and with meeting management guidelines [37] [38]; meeting minutes must be "action-driven" in order to be productive.

5.2. Discussion: towards an action-oriented strategy to record design reviews

A number of results from the analysis of the case studies and the survey on minute taking practices in the aerospace industry have helped the authors to establish an action-oriented strategy to improve the capture of key knowledge elements from design reviews. The strategy proposed can be summarised from the secretary's perspective using the following three phases:

1. ***Knowledge acquisition phase.*** During the meeting, the secretary should focus on keeping track of the actions with their associated rationale or lessons learnt. This knowledge acquisition phase of the strategy would see the secretary turn decision points into actions whenever possible, and at the end of the meeting sufficient time should be allowed so that each action can be reviewed in detail and agreed by all participants.
2. ***Knowledge representation and encoding phase.*** At the end of the meeting, each action (noted on a customised form) needs to be detailed and tagged according to the type of information it contains (product or process). After the meeting, the secretary would finalise the formal meeting minutes by seeking the approval of the authorities responsible for the design review.
3. ***Knowledge implementation and reuse phase.*** Once all the "action forms" are approved, these can be linked to one of the two engineering tools typically used to manage product and process information in a Product Lifecycle Management (PLM) environment. Actions tagged as "product information" could be inserted in the product structure tree managed by Product Data Management (PDM) systems, while those tagged as "process information" could be included in workflow management systems.

To date, this strategy has not been completely tested. The authors have essentially focused on the knowledge acquisition stage of the process. The 3 analytical approaches, i.e. the TCS, the MCT, and the IMT, have enabled a number of high level views to be taken but also a pragmatic approach to minute taking to be developed. The solution is embodied in a "design review capture template" that uses a format based on the MCT. A preliminary version of the template is shown in Figure 4.



Action #	Action (detail)	Who? (Initials)	Topic: came from	Topic: detail (summary/ title/ #)	Why? (reminder of rationale)	Impact?	ID ref for process/ product
13	The pylon must be attached in the same way	S	☑ Discourse ☐ Agenda item ☐ Slide ☐ Other	Angle r Positioning of Pylon	Wrong statement on slide RD 20008 Engine properly docked	☐ Process ☑ Product	
14	Check BM 90000 for fasteners if not ask B	S	☐ Discourse ☐ Agenda item ☑ Slide ☐ Other	RD 20009	preferred use of fasteners	☐ Process ☑ Product	
15	Stick to MPS standard	S	☐ Discourse ☐ Agenda item ☑ Slide ☐ Other	RD 20010	The BAPS is confidential	☐ Process ☑ Product	
16	Existing GE Design Complies with BirdStrike		☐ Discourse ☐ Agenda item ☑ Slide ☐ Other	RD 20011 Birdstrike	- Design is against Birdstrik. - Certification must prove it - keep same profile	☑ Process ☐ Product	

Figure 4. An extract of the preliminary version of the "design review capture template"

The feedback from the participants who used the MCT encouraged the application of the same format for the capture of actions during meetings. This new template was trialled by the authors, and subsequent improvements and guidelines for its usage have been established. The template fulfils most of the requirements outlined in the strategy, and is currently being tested in industry.

6. CONCLUSION AND FUTURE WORK

Computer support for the action-oriented strategy has been investigated and a conceptual solution is also currently under development. The approach seeks to build a software solution based on the "design review capture template" illustrated in Figure 4, but with added digital functionalities such as: hyperlinks, digital artefact annotation, and automatic summarisation tables. The main advantage of this computer-based prototype over its paper-based counterpart is its integration to the digital environment in which design engineers work. Indeed, most of the artefacts discussed during a design review are nowadays available in a digital format. All the functionalities envisaged are already available in various software solutions (not necessarily for meeting capture), which adds credit to the scenario under development.

Only a limited number of observational studies in engineering have focused on a clearly identifiable type of meeting. The DTM case studies, however, chose to use a very specific and widely occurring meeting event that takes place in the aerospace industry, namely design reviews. Companies, using the standard Stage-Gate approach to control their product development activities, implement design reviews with similarly constructed guidelines based on industrial standards. In particular they are guided by a number of formalised constraints, they follow a clear set of predefined objectives, they are a unique "information synchronization" point for all stakeholders involved in the development of a product, they are visible activities in business planning tools and documents across projects and companies, and they are at the heart of the collaborative decision making cycle inherent to any product development process.

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