ICED13
INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED13
19-22 AUGUST 2013, SUNGKYUNKWAN UNIVERSITY, SEOUL, KOREA

SUPPORTING COMMUNICATION IN THE SUPPLY CHAIN WITH DESIGN RATIONALE MAPS

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ABSTRACT
In modern engineering projects collaboration between organisations is increasingly common for the purpose of sharing expertise, technology, resources, risk and responsibilities. Design communication between collaborating organisations, which is central to the successful development of the design process, takes place over distributed environments, and a range of computer and communication technologies are available to support it. However, none of existing technologies aid engineers in the communication of the nuances and subtleties of engineering design work. This research, in collaboration with the engineering business of a large power system company, argues that for design communication to be effective, stakeholders have to have shared understanding and this is formed by interpreting design rationale. In the paper, this argument is used to explain the success of a software tool, known as DRed, to support the communication between engineers in the collaborating company and those from partner organisations. Case studies of practical application of the DRed tool to support communication with organisations in the supply chain of the partner company are presented and discussed.

Keywords: design communication, shared understanding, design rationale, IBIS

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1 INTRODUCTION

Engineering organisations increasingly operate under the paradigm of concurrent engineering with globally distributed customers, partners and suppliers. The complexity and scope of modern engineering design projects requires constant collaboration between stakeholders. The communication between these stakeholders relies on both synchronous and asynchronous means of information exchange, e.g. audio and video conferencing, as well as email etc. There are several factors affecting collaboration between organisations. These factors are at the level of management, procedures and knowledge (Yang et al, 2011). The latter is particularly linked to the success of communication as during collaborative engineering design tasks, engineers and other experts share and integrate their knowledge about problems to create new knowledge about solutions. The focus of this research is on design communication, which focuses on the engineering issues, assumptions, solutions, evaluations and decisions made during the design process (Wasiak, Hicks, Newnes, Dong and Burrow, 2010). In particular, the research is concerned with communication supported by textual and visual representations. The aim of the research is to understand the role played in communication support by a lightweight software tool for graphical modeling of design knowledge. The research is based on application in a large power system company of an IBIS (Kunz and Rittel, 1970) derivative known as the Decision Rationale editor (DRed) to facilitate communication between its engineers and those from collaborating organisations. The results indicate that the DRed tool has been successfully used by the collaborating company to support communication with a range of organisations including air transport services, aircraft manufacturers, government departments, aviation authorities and sub-contractors. This article is of interest for academics and practitioners interested in understanding how to achieve effective communication of rich knowledge about design processes.

2 BACKGROUND

This sections reviews literature on design communication and tools to support it.

2.1 Design communication and rationale

During engineering design work the knowledge brought to the project by stakeholders is shared and integrated through design communication (Kleinsmann and Valkenburg, 2008). An empirical study of collaborative design reported that 2/3 of communication is based on the content and 1/3 on the process (Stempfle and Badke-Schaub, 2002). Among the content-directed communication, the study found that 90% is focused on the solution space with shifts between analysis and evaluation, and 10% on the goal space (Stempfle and Badke-Schaub, 2002). It is, therefore, evident that a substantial amount of time is spent on design communication about analysis and evaluation of designs.

A key factor influencing the quality of design communication is the creation of shared understanding between stakeholders (Ramesh and Tiwana, 1999; Kleinsmann and Valkenburg, 2008; Yang et al, 2011). Shared understanding has been defined as *a similarity in the perceptions of stakeholders about how the design content is conceptualised or the transactive memory system* (i.e. the memory of the collective) *works* (Kleinsmann and Valkenburg, 2008). Given that a large proportion of design communication concerns analysis and evaluation of solutions, and that understanding how design work is conceptualised necessitates retracing the various steps taken in the design process, it seems that design rationale has an important role in effective communication. The concept has already been reported in the literature for some time (Lee, 1997). Among more recent work, two studies are worth mentioning. The first, an empirical investigation of information exchanged in early design conversations, identified the importance of communicating the reasons underlying view or ideas (Luck and McDonnell, 2006). The second, a review of explicit rules to manage communication in organisations, made a point about ‘focusing communication on the issues that matter most’, ‘distinguishing facts from opinions’ and ‘making the rationale behind positions explicit’ (Mengis and Eppler, 2008).

The next section focuses on tools to support design communication currently adopted in the engineering and manufacturing industry.

2.2 Communication tools in design

Issues of communication and collaboration support have been extensively studied in the field of Computer Supported Cooperative Work (CSCW). Groupware has been defined as *computer-based* *systems that support groups of people engaged in a common task and that provide an interface to a shared environment* (Ellis, Gibbs and Rein, 1991). Available groupware has been characterised through time space and application-level taxonomies (Ellis, Gibbs and Rein, 1991). Typical groupware includes message systems, multiuser editors, group decision support systems, computer conferencing, intelligent agents and coordination systems. The focus of this review is on tools that can support communication through combination of textual and visual information.

Email is an asynchronous medium for information communication, which has become critical to business operation (Wasiak, Hicks, Newnes, Dong and Burrow, 2010). It is used every day to discuss complex engineering problems and communicate possible solutions. However, email is also used for a variety of additional purposes including transferring files, planning meetings and archiving personal data. It has, therefore, little specificity with respect to supporting the communication of engineering design information. Another communication medium frequently used in engineering design is the ubiquitous MS Office suite of applications with Word, Excel and PowerPoint above all for extent of use. The files generated through these applications can be shared through emails or used in face to face and video conferencing meetings to support synchronous communication. Despite having limited specificity to engineering design knowledge their use is standard practice. Current support is, however, not confined to email and MS Office applications. Research work has been undertaken to embed annotation systems in CAD and PDM or PLM systems in order to support communication (Lenne, Thouvenin, Aubry 2009; Hisarciklilar and Boujut 2009). Annotation facilities now exist in most industry-standard CAD packages, in the form of "lightweight" file formats and associated freeware viewers, to which 3D assemblies can be exported for review by stakeholders (Ding et al 2009). Their annotations, linked to geometric features, can then be "round trip" imported into the master CAD files for attention of the designers. The next section introduces the Decision Rationale editor (DRed), which is the subject of this research.

2.3 The DRed tool

DRed is a simple file based software tool (Bracewell and Wallace, 2003; Bracewell et al, 2004; Bracewell et al, 2009a) supporting a derivative of the venerable gIBIS (Conklin and Begeman, 1987) inspired by Rittel's concept (Kunz and Rittel, 1970) of an Issue Based Information System (IBIS), see Figure 1. DRed was developed to address the problem of design rationale capture and was intended as a more functional replacement to the traditional bound designer's notebook.

The rationale is captured in a set of maps, each displaying a graph of nodes linked by directed arcs, and stored in a single file kept in a design folder. DRed elements (nodes) are normally created, positioned, and linked manually by the user, see Figure 2. The user chooses elements from a predefined set of types, namely Issue, Answer, Pro, Con, Text, Task, File, and latterly also Block, Relation and Requirement. The current set is not claimed to be comprehensive for every possible application, but experience has shown that they seem to be a suitable "core set". Any element on a chart can be linked without restriction to any other, and any element can easily be converted from its existing type to another.

Each element type has a predefined set of statuses, signified by changes in colour and geometry of the background shape and/or font style of the text. These statuses are changed by the designer as work progresses, generally from "unresolved" to "resolved".

Unlike most other gIBIS-derived tools, DRed only has a single type of link, a unidirectional arrow, which represents some sort of dependency. The meaning of that dependency is inferred from the types of the elements at each end of the arrow.

Dependencies between elements belonging to different maps are made via tunnelling links, which provide bidirectional hyperlinking. Such links permit the rationale for larger design projects to be distributed across multiple maps, and laid out legibly, while facilitating navigation between them.

Files from any other application used as part of the design process can be linked into the rationale using elements of the File type. If these files are created as part of the design project, they are stored in the design folder and referenced by a relative file path. The default is for the file element to be displayed as a small icon representing the type of the referenced document. However, as an alternative, a screen captured bitmap of the document contents can be displayed on the DRed map.

DRed links anchored to an element normally terminate on the element border, positioned to point at the centre of the element. However, for these bitmap graphical elements, links can be anchored to a specific location in the graphic. This enables, for example, references to CAD files to be displayed within DRed as a view of the screen captured from the tool, with links anchored to the location of individual features, labelling or expressing issues related to them. By double clicking the file element, the referenced document is loaded into its software application and displayed.

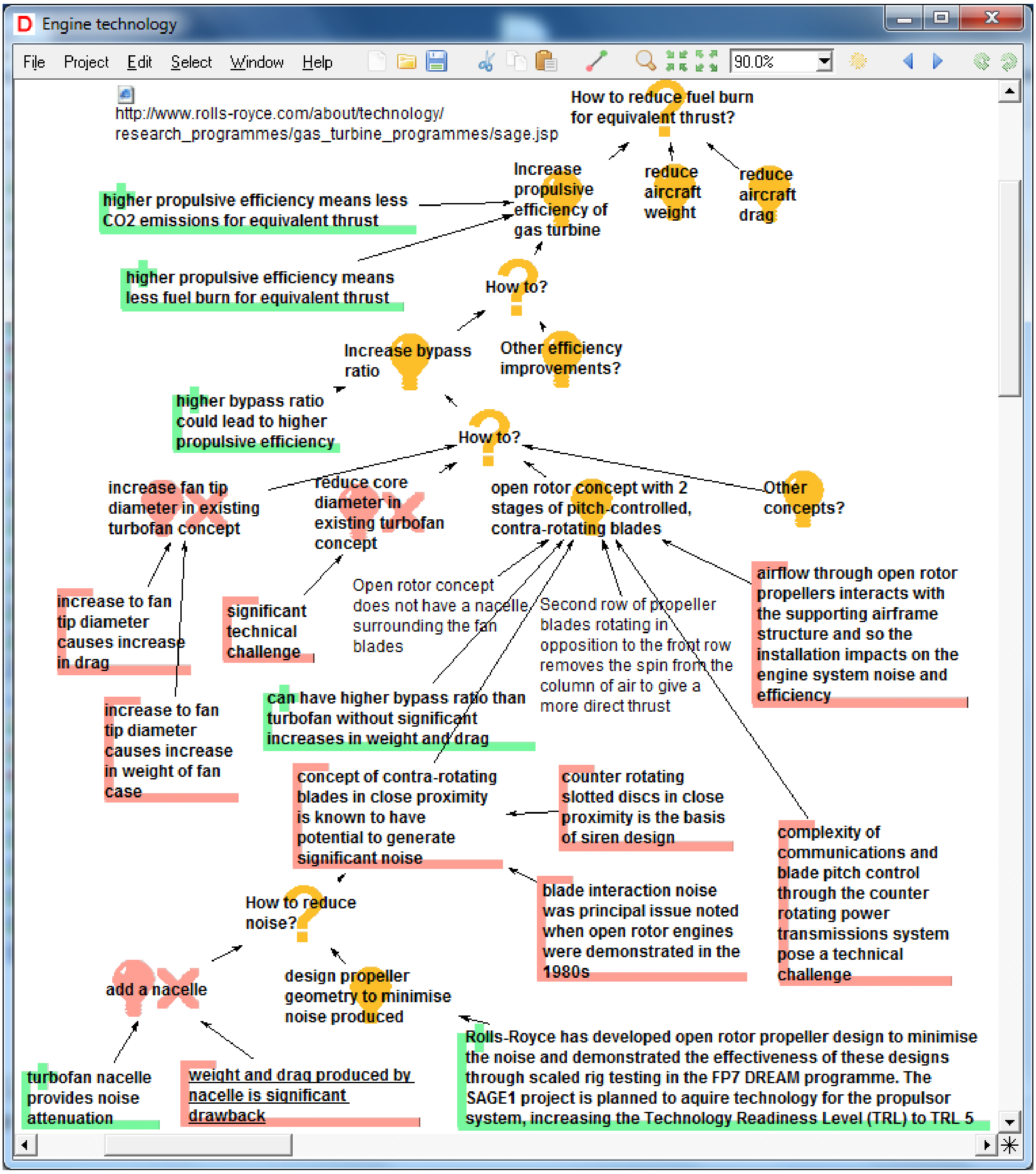

Figure 1. DRed map example

The DRed tool, after its initial introduction in Rolls-Royce, has seen a steady increase in use leading to its acceptance as part of the standard Product Lifecycle Management (PLM) toolset, and deployment across the company worldwide. The ability of the tool to capture design information without needing its own dedicated database, which make it compatible with existing document management practices, was found to be a critical factor in its success.

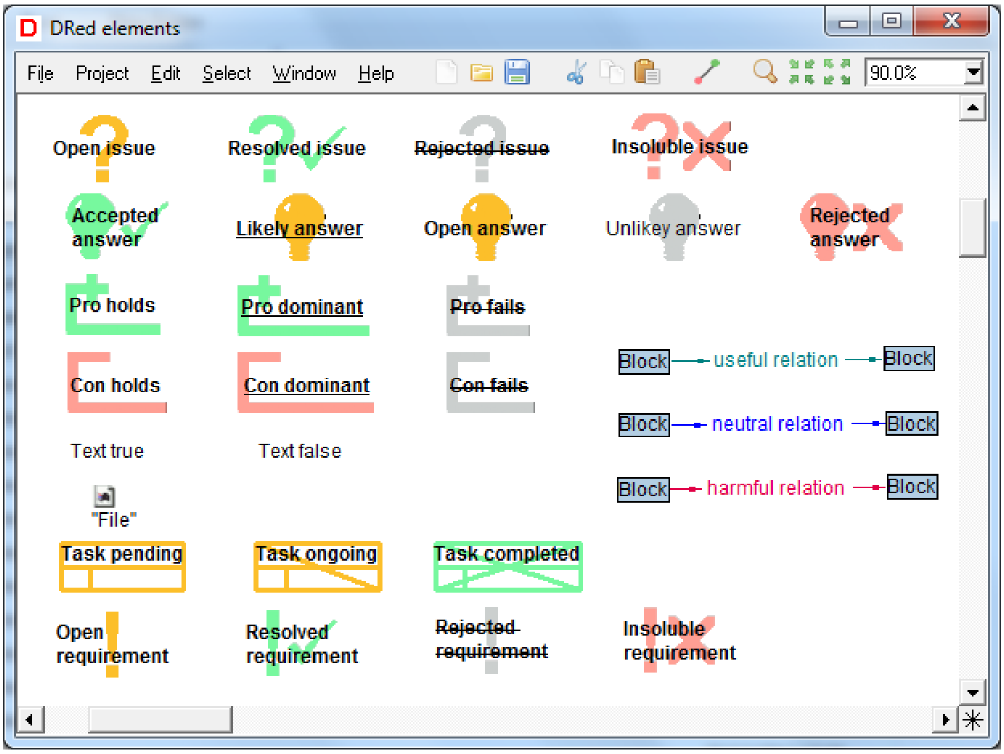

Figure 2. DRed elements

3 RESEARCH METHODOLOGY

The approach taken in this research to investigate use of the Decision Rationale editor (DRed) for communication support followed the Design Research Methodology (DRM) (Blessing and Chakrabarti, 2009). The methodology consists of four stages namely, *research clarification*, *descriptive study I*, *prescriptive study* and *descriptive study II*. According to the proponents of the methodology, research can start from any of these stages. In this work, we began from the *descriptive study II* stage. This is because the research aims to understand the role of a computer aided engineering tool previously developed by the authors and already in use in industry. In this context it is worth mentioning that the DRed tool, initially in a very early form, has been in use by engineers in the collaborating company since 2002, i.e. six months after the commencement of the research project. Going back to the methodology, the work did not limit its self to research within the *descriptive study II* stage. Rather, requirements for software development were extracted from the understanding emerged during this stage and implemented, therefore moving the research into the *prescriptive study* stage. An example of a software feature closely related to communication support is the set of graphical representations of the DRed node types and statuses, which are instrumental to read and to comprehend the maps. A key requirement was that the maps would effectively communicate design rationales both from computer screen and paper print out. Based on users' feedback the icons went through iterative phases of design improvement until they reached the current look. Rather than isolated work, research between the *descriptive study II* and *prescriptive study* stages consisted of a continuous process of moving back and forth, and involved constant contact with practitioners from the collaboration company.

3.1 Data collection and analysis

This research has made use of three data sets collected employing multiple methods. The first data set consists of semi-structured interviews with fourteen engineers in the collaborating company. These interviews were conducted by the authors as part of a study to understand DRed use. The second data set consists of brief interviews with fifteen engineers in the collaborating company. These interviews were run by DRed specialists in the partner company to develop a case for DRed's participation in the company's 'Director of Engineering Quality Awards 2006' (the result was a "highly commended" runner-up place in the finals). The third data set consists of emails exchanges between the authors and DRed users. The data were analysed to undertand the types of: organisation involved in the communication, communication system employed, communication subject discussed, and communication aids.

4 DESIGN RATIONALE MAPS FOR COMMUNICATION SUPPORT

This section presents the results of the research using three example cases.

4.1 The role of the DRed tool in communication support

Data analysis showed that the DRed tool has already been used in several occasions to support communication with external organisations. Figure 3 provides an overview of the types of organisations which were exposed to the DRed tool as part of communication processes. It can be seen that the spectrum of organisations covered includes both upstream and downstream players in the aviation supply chain. Although the model in Figure 3 presents generalised types, it is worth mentioning that the organisations involved in decision rationale-supported communication were both larger and smaller players in the industry.

The DRed tool was found to be used to support both synchronous and asynchronous communication with engineers and experts from other organisations. With respect to synchronous communication there is evidence that DRed maps have been used to support face to face conversations of technical work as well as discussions over the telephone. In the case of asynchronous communication DRed maps were found to be attached to emails.

The subject of the communication with these organisations was found to range from studies to investigate future power systems to detailed design of engines to failure investigations. The participants to the communication episodes varied from small to large groups. There are cases in which more than one organisation, among those listed in Figure 3, was simultaneously involved in information exchanges with the collaborating company.

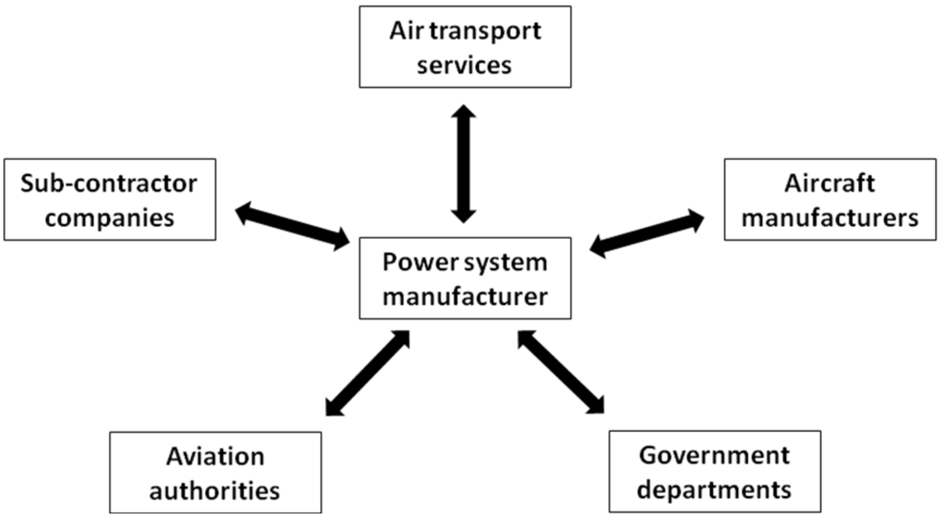

Figure 3. Organisations exposed to DRed as part of communication with the collaborating company

Five communication aids offered by the DRed tool are presented in Table 1. At the top of the table, there is recognition for the role that DRed maps have in quickly informing on the status of current work. As indicated by the participants to this research the maps have been found effective at presenting the main aspects of the design routes investigated by an engineer or a team. The second type of aid refers to the ability of the tool to clarify a logical deliberation of potential solutions. This was described by the participants as the thought process followed to develop a piece of design work and the reasons to choose the final solution. The third type of aid relates to support in the discussion of alternative solutions. The fourth type of aid, related to the previous one, concerns the provision of support in agreeing the final solution. Finally, the tool was described as useful in overcoming communication barrier between engineers from diverse cultures and therefore with different level of proficiency in the communication language (which in this context was English).

Table 1 Communications aids

Communication aids offered by the DRed tool
Help quickly inform on current work status
Help clarify a logical deliberation of potential solutions
Help discuss alternative solutions
Help agree the chosen solution
Help overcome cultural and lingual barriers

The next sections introduce three cases from our datasets to provide examples of how the DRed tool supported communication. The cases were chosen to illustrate a variety of issues and situations in which the tool offered support.

4.1.1 Case study 1: Conceptual design of a future propulsion system

This case reports on use of the DRed tool to support communication of conceptual design work for a future gas turbine. The work involved face to face communication between engineers from the collaborating company and those from a large aircraft manufacturer. As reported in the interview, engineers from the external organsiation were taken through DRed maps to show them accomplished work. The session was described as a good success resulting in the visitors gaining a thorough understanding the issues. An engineer from the collaborating company stated that he struggles to imagine how they could have shown the same story from zero to full without use of the DRed tool.

4.1.2 Case study 2: Outsourced detailed design work

This case concerns collaboration over detailed design work between the sponsoring company and a subsidiary in the Asian continent, which specialises in the delivery of engineering solutions for the holding. The work consisted of investigating a range of issues linked to the applicability of a new design to a turbofan engine in service for defense application.

The collaboration between the two companies is such that engineers in the subsidiary are trained to use DRed as part of their tasks as much as those in the partner company. This is obviously an important precondition to stimulate use of the tool for communication support at the boundary between the two businesses. A typical scenario of collaboration involves technical discussions over the telephone. In this context DRed maps were found to be systematically used to support telephone communication, see Figure 4 for an example of a shared map. Engineers involved in this collaboration indicated that DRed maps are easy to refer to and provide a framework for discussion. More so, the maps were described by engineers in the partner company as useful to understand outsourced work and build confidence in it. Another type of aid, reported as part of this case, points to the ability of the DRed tool to help overcome communication barriers due to cultural and lingual differences.

4.1.3 Case study 3: In-service investigation

This case deals with a multi-party investigation on an aircraft from a large airline company. The investigation involved engineers and experts from the collaborating company, a large aircraft manufacturer and the Department of Transport. Engineers in the collaborating company routinely use DRed maps to facilitate comprehension and improvement of system behaviours, and the tool was adopted also in this situation. By the end of the investigation, a linked information space of more than ten DRed maps had been produced to record and portray the developed understanding of the system behaviour. Over an eight-month period, meetings with external parties were facilitated by the use of DRed maps, see Figure 5 for an example of a shared map. In this context engineers from the aircraft manufacturer and the Department of Transport were introduced to DRed maps and the underlying methodology for root cause analysis. As far as the interviewees reported it was easy for the partner engineers to visualise the maps and follow the lines of investigation. As part of the meetings DRed maps were used to provide a visual guide both on screen and hanging from the wall printed in large size.

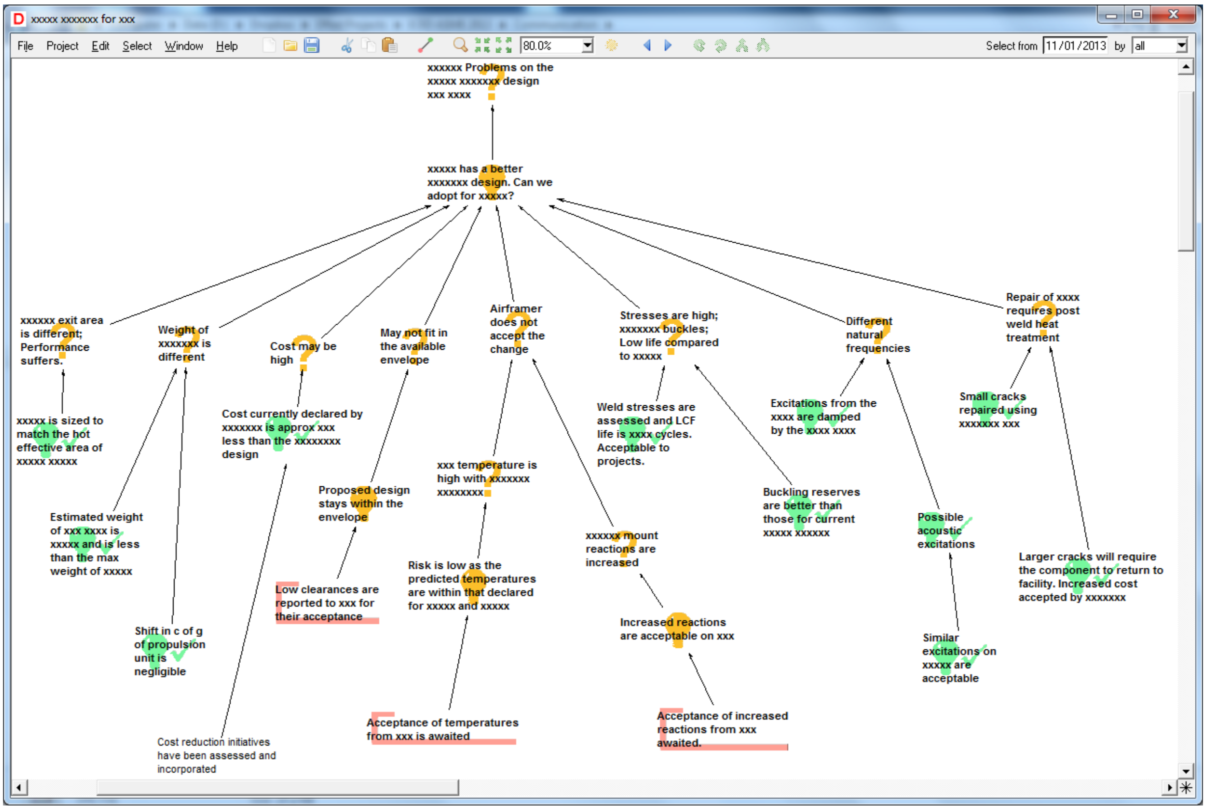

Figure 4. Example of DRed map shared to collaborate over outsourced detail design work

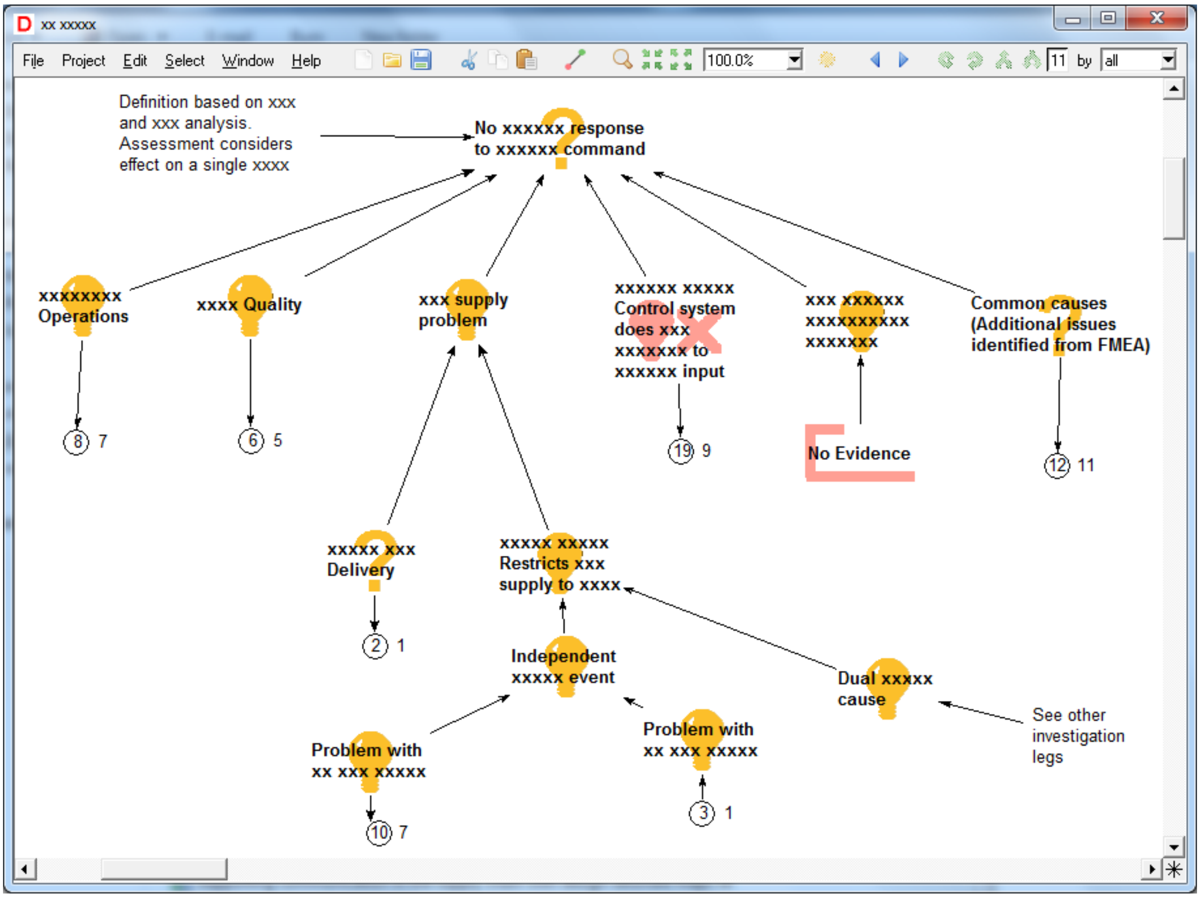

Figure 5. Example of DRed map shared to collaborate over an in-service investigation

5 DISCUSSION

This work has brought to the attention of the research community the role in communication support played by the DRed tool. DRed is a light-weight software tool implementing an extended IBIS ontology to capture and communicate the nuances and subtleties of engineering design work. The research has shown that the tool is used to support communication of design work between the collaborating company and its partners in the aviation industry. In addition to use requiring introduction of the tool and its methods to external engineers, the research has revealed that the tool has crossed the boundaries of the collaborating company to become a practice in other organisations. This is in line with a strategy by the collaborating company to make the tool available to collaborators in order to fully harvest its benefits. The results have also shown that the DRed tool, with its simple and generic ontology, is suitable to support both synchronous (face to face and remote) and asynchronous communication (email-based) as well as to discuss diverse subjects including design and diagnosis. These two aspects confirm empirically the flexibility and versatility of the tool long advocated by the authors. The types of communication aid identified in this research are at different level and point to the various stages of the communication process. The ability to quickly inform on current work status and to clarify the logical deliberation of potential solutions can be interpreted as provision of support in the creation of shared understanding between stakeholders (Kleinsmann and Valkenburg, 2008). It is clear that the IBIS ontology and the DRed-specific innovations in its implementation have an important role in this context. In particular, it can be argued that the structure provided by the diagramming presentation, and the reading and comprehension support offered by the multi-status graphical node representations (Aurisicchio, Gourtovaia, Bracewell and Wallace, 2008) are instrumental to inform and make work clear to stakeholders during communication processes. Other aids such as discussion of alternative solutions and agreement on the direction to choose can be explained by the emphasis posed by the tool on capturing argumentation-based rationale. Finally, the DRed tool has been perceived as a *lingua franca* of structured discourse (De Liddo and Buckingham Shum 2010) bridging communication barriers between multicultural engineering communities. This has the potential to provide a very important form of support in the increasingly international context of current engineering design work.

In modern engineering organisations, information such as that captured in DRed maps is predominantly communicated through MS Word, MS PowerPoint and emails. However, these offer little help in structuring information and as a result the conveyance of a message depends heavily on the ability of an engineer. In engineering, maps as a form of analysis and communication of design information have long existed. Mind-mapping (Buzan 1996) is an example of a method used in industry. Other typical examples of engineering design methods adopting map-like representations are Fault Tree Analysis (Mearns 1965) and FAST (Miles 1989). However, maps and computer tools to support their generation have always been confined to the good will and preference of the individual without ever becoming standard practice. Systems to annotate CAD geometry can be seen as maps rooted to product structure. They offer a promising direction to enhance communication but they have two major limitations. The first is that their usefulness seems to be confined to parametric design and the second is that they lead to heavy-weight computational support. Overall, the results of this research suggest that the DRed tool fills in a gap in communication support. It provides a simple, fast and effective means of communicating design issues, solutions and their rationales.

5.1 Limitations, contributions and implications

The main limitation of this research is that the three data sets have different depth. This did not pose a problem during data analysis as overall the research is based on a large amount of industrial data, which have allowed validation of the findings.

The theoretical benefits of design rationale capture for communication support have long been advocated (Lee, 1997). However, until now practical evidence of effective support in engineering design work has not emerged. This work contributes to design research by demonstrating systematic and beneficial use of design rationale maps in a large power systems company to support communication with organisations in its supply chain.

The research presented in this article is based on a tool owned and controlled by the collaborating company. Engineering and manufacturing organisations interested in exploring the opportunities of design rationale mapping for communication support can look at other tools implementing the IBIS ontology. Among this, designVUE, an open-source tool developed by the Design Engineering group in the Department of Mechanical Engineering at Imperial College, is recommended as it has commonalities with DRed in terms of software implementation approach and notation implemented to support the IBIS ontology.

6 CONCLUSIONS

Communication of design work between collaborating organisations is increasingly common. Design communication was shown to consist primarily of analysis and evaluation of designs. *Shared understanding* between stakeholders was discussed as an enabler of effective communication and its link to *design rationale* explained. State of the art communication tools were shown to offer limited support in the communication of the nuances and subtleties of engineering design work. Within this context the Decision Rationale editor (DRed), a light-weight software tool for design rationale capture, was introduced and its role in supporting communication between the sponsoring company and its collaborators was described and discussed.

ACKNOWLEDGMENTS

The authors acknowledge the support of the Technology Strategy Board (TSB) and Rolls-Royce plc through the SILOET project.

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