Institution:
University of Cambridge

Unit of Assessment:
UoA15

Title of case study:
The Decision Rationale Editor (DRed)

1. Summary of the impact (indicative maximum 100 words)

Fundamental research undertaken by the University of Cambridge Department of Engineering (DoEng) on the decision-making process in design led to the creation of a software package called DRed. DRed was initially aimed at capturing design rationale, but subsequently broadened in its capability to become a 'problem management' tool. DRed has been formally embedded in the Generic System Design Process at Rolls-Royce (R-R), which applies across the whole company such that all R-R engineering staff, including designers and service engineers, have access to DRed. During the period 2008 to 2013, DRed has played a key role in the understanding and resolution of two major aerospace incident investigations, and in the design and development of the Trent XWB engine for the Airbus A350 commercial aircraft.

2. Underpinning research (indicative maximum 500 words)

Professor Ken Wallace was the Director of the Engineering Design Centre (EDC) at the University of Cambridge Department of Engineering (DoEng), where he was appointed as a Lecturer in 1978 and promoted to Professor in 2001 (retiring in 2007). In the early 1990s, he initiated observational studies into decision-making and the use of information in engineering design.

Results from experiments in 1993 by Wallace's team, investigating how designers make decisions, showed that they frequently overlooked or forgot arguments addressed earlier in their design processes and repeated previous steps. Wallace's team saw that there was a clear need for a decision-support tool that could capture their reasoning and present it back to them when required (Ref 1).

Results from an observational study by Wallace's team within Rolls Royce (R-R) in 1996, investigating where designers source their information, showed that: the majority of their information needs were met by asking colleagues; reference was made to documents only as a last resort; and around a quarter of the working day was spent acquiring information.

A key research question then emerged: How can design rationale be captured without undue imposition on designers?

In 1998, Wallace secured long-term funding to focus on this question. The DoEng established the University Technology Partnership (UTP) for Design with academic partners Sheffield and Southampton. The UTP was sponsored by R-R and BAE Systems. Wallace was one of the three Co-Directors and led the research into Engineering Knowledge Management.

The UTP won an IMI (Innovative Manufacturing Initiative) grant, "Knowledge Capture, Sharing and Reuse" (KCSR), in 1999. This additional funding enabled a detailed investigation into the knowledge needs of designers. A survey confirmed the pressing need to capture design rationale. A parallel study revealed that R-R's traditional Design Definition Reports (DDRs) were poorly structured and difficult to interpret.

Wallace's team systematically analysed the shortcomings of existing rationale capture tools based on the well-established Issue-Based Information System (IBIS). Wallace's Senior Research Associate, Dr Rob Bracewell (in post at the DoEng from 1997 to 2013), a key member of his team, successfully found novel ways to overcome these shortcomings and produced a prototype graphical tool using his results to capture design rationale, originally called DRed (Design Rationale editor). New features included nodes on DRed charts automatically resizing to present all the pertinent information and, behind each node, coloured graphics to signify its type and its status. The advantage was that nothing was hidden, as in previous tools such as Questmap, making DRed charts much easier to scan and to interpret.

Wallace and Bracewell analysed a number of DDRs and presented their argument flow graphically using DRed. After seeing the clarity of these DRed charts at the UTP's Annual Spring Conference in 2002, R-R became an enthusiastic supporter of DRed. Wallace and Bracewell first reported on DRed and how it was developed in 2003 (Ref 2).

Wallace and his team, in a related research project that started in 1997, addressed the knowledge needs of novice designers and how to support them. The aim was to provide insights into what knowledge to capture and the best way to train young designers. Due to increased staff mobility and retirements, it was no longer always possible to consult experts with the required knowledge. The main finding was that novice designers were only aware of their specific information needs in about a third of their queries, so simply supplying a knowledge database was not sufficient; they also needed guidance on what questions to ask. This resulted in DRed being introduced to R-R's graduates as part of their training programme and also influenced the design of R-R's emerging intranet (Ref 3).

Wallace's team continued to work closely with a small group of designers to research the principles underpinning DRed. There was a need to capture increasingly large rationales, in response to which Bracewell invented tunnel links to allow easy navigation; the largest rationale captured to date covers 190 charts. The use of DRed within R-R expanded rapidly. Wallace undertook studies to understand the nature of how capturing and retrieving information using DRed charts compared to using conventional reports. The results indicated that DRed's graphical presentation: increased the speed with which recorded information could be retrieved; and resulted in more complete answers to questions requiring wide-ranging information searches (Ref 4).

After DRed had been in use within R-R for several years, Wallace's team and staff in R-R undertook further research of its use and effectiveness. They concluded that DRed's underlying logic and flexible interface helped designers to: clarify their design thinking; manage design tasks; capture design rationales easily as they are created; reduce the need for written reports; and improve communication during meetings (Ref 5).

3. References to the research (indicative maximum of six references)

1. *Dwarakanath, S. and Wallace, K.M. (1995). Decision making in engineering design: Observations from design experiments. In Journal of Engineering Design, 6 (3), 191-206, DOI: 10.1080/09544829508907913
2. *Bracewell, R.H. and Wallace, K.M. (2003). A tool for capturing design rationale. In Proceedings of ICED 03, the 14th International Conference on Engineering Design, Stockholm, Editors: Folkeson, A., Gralen, K., Norell, M. and Sellgren, U., ISBN 1-904670-00-8
3. Ahmed, S. and Wallace, K.M. (2004). Understanding the knowledge needs of novice designers in the aerospace industry. In Design Studies, 25 (2), 155-173, DOI: 10.1080/095448208410001708430
4. Aurisicchio, M., Gourtovaia, M., Bracewell, R.H. and Wallace, K.M. (2008). How to evaluate reading and interpretation of differently structured engineering design rationales. In Artificial Intelligence for Engineering Design, Analysis and Manufacturing (AI EDAM), 22 (4), 345-358, DOI: 10.1017/S0890060408000231
5. *Bracewell, R.H., Wallace, K.M., Moss, M. and Knott, D. (2009). Capturing design rationale. In Computer-Aided Design, 41 (3), 173-186, DOI: 10.1016/j.cad.2008.10.005

*Research outputs that best represent the quality of the research.

In 2004, DRed won the R-R Director of Research and Technology's Award for Creativity.

4. Details of the impact (indicative maximum 750 words)

The possession of an effective, robust and technologically innovative design process is a key success factor for R-R and a direct contributor to the performance and safe operation of its high-integrity power systems. The 1990s were a decade when R-R started and accelerated its journey from a largely paper-based to a wholly computer-based design system. This context drove R-R to become an industrial sponsor of the UTP formed in 1998. Wallace's research and DRed in particular were significant outputs for R-R.

DRed has achieved specific major impacts in the period from 2008 to 2013, as follows:

- The use of **DRed was recommended for 19 of 33 design process steps for the new Trent XWB engine** by R-R's Global Head of Power Systems Design in a manual for designers entitled, "Generic System Design Process - overview of steps, process and tools proposed for the Trent XWB". This was released formally to the designers in October 2008 and updated in 2009. The design teams applied this process from 2008 to 2010, producing approximately 700 schemes that defined approximately 30,000 engine components of the engine. After the first successful engine run in 2010, DRed continued to be used within the process for a further 2 years of engine development, problem diagnosis and re-design, during which the number of schemes, including re-issues, rose to approximately 2,000. The use of DRed, having being embedded at the start, has continued throughout the period of initial flight aboard the Airbus A380 Flying Test Bed on 18 February 2012 and the first flight of the Airbus A350 itself on 14 June 2013. (Ref 6)
  As at 31 July 2013, Rolls-Royce has an order book for the Trent XWB of more than 1400 engines (Ref 7). Although the company does not publish the value of this order book, an estimate can be made using announcements on the value of specific orders. For example, the order for 25 aircraft from Air Lease Corporation on 4 February 2013 cited a list-price order value of USD1.1 billion for 50 engines (Ref 8). This suggests that the whole Trent XWB order book, at list price, is worth approximately GBP20 billion.
- **In 2009, DRed became a significant tool in the R-R Engineering System (RRES),** as the Generic System Design Process brochure was incorporated into RRES. The methods and guidelines in RRES are used by all R-R's engineers (approximately 14,500 in 2013, which is an increase from approximately 10,000 in 2008), who work in all R-R's businesses across the world - i.e. aerospace, marine, energy, and nuclear. (Ref 6)
- **DRed was adopted as the standard tool for incident investigations** by the 80-person Service Engineering Department in Civil Aerospace at R-R, following its successful use during 2004 in a real incident, and has been used for the following major incidents between 2008 and 2013:
  - British Airways Flight 38 with 152 passengers and crew on board crash-landed at Heathrow Airport on 17 January 2008. It was a Boeing 777 with 2 R-R Trent 800 engines. The engines had not responded to the power demands on final approach at an altitude of 600ft and a distance 2 miles from touchdown. At the outset, the cause could have been a failure in any of the engine, airframe, maintenance, control and/or operational systems. The incident was unique and high-profile. DRed was the tool of choice in the root cause analysis by the Civil Aerospace Engineering team. A large network of DRed charts was gradually developed, printed out and displayed at meetings where stakeholders from multiple organisations participated in identifying and eliminating causes over the course of a year. DRed enabled the narrowing of potential causes to a single, testable hypothesis. (Ref 9)
  - One of the four Trent 900 engines on QF32, a Qantas Airbus A380, suffered an uncontained intermediate pressure disc failure on 4 November 2010. The aircraft was climbing through 7,000ft after departure from Singapore Changi Airport with 469 passengers and crew on board. The incident again was high-profile with the potential for significant business consequences for R-R, Airbus and Qantas. It threatened to ground the aircraft type (indeed, Qantas initially did so for a short period). The R-R Chief Engineer and Chief Design Engineer of the Trent 900 at the time, and their team of approximately 300 engineers, made extensive use of DRed in conducting the root cause analysis. Once the root cause was established beyond reasonable doubt, DRed was used again to evaluate the design solution. The Chief Engineer said; *"We used DRed in the first weeks of the QF32 investigation to explore possible failure scenarios and to formally capture evidence from hardware and data analysis. This was our structured, systematic approach to the problem understanding and it proved valuable for the Engineering team, also helping with reporting at the end of the process."* (Ref 10).

The impacts above were born of knowledge transfer and process improvements that started before 2008 and that continued throughout the period from 2008 to 2013, for example:

- From 2003, Wallace's research (particularly Ref 3) and DRed have been a core element of the Graduate Training Programme, which is an important programme in R-R because R-R principally targets newly qualified graduates in its recruitment. From 2008 to 2013, over 1,000 graduate trainees have been recruited worldwide, attended this programme and used the training in their work (Ref 11)

- In 2005, R-R established a subsidiary, Rolls-Royce Operations India Pvt Limited (RROIPL), to build a robust engineering services platform. RROIPL grew to employ over 800 engineers by 2012 and has continued to grow, supporting the delivery of engineering solutions across multiple R-R business sectors. DRed was built into operations from the start and it is still an integral tool in 2013. A Technical Operations Manager at RROPIPL has observed that *"…using DRed with the local engineers is fantastic. It helps to achieve a common technical understanding and overcome the communications barriers"* between engineering teams in the UK and India. (Ref 12).

The impacts of DRed were primarily founded on the quality of the research by Wallace's team, but they would not have been achieved so quickly or so widely at R-R if the team and its counterparts at R-R had not invested time in knowledge transfer activities. Key success factors included:

- close engagement of Wallace's research team with the Design Methods team at R-R with endorsement and encouragement from the Chief Designer at R-R;
- involvement of front-line designers and service engineers in studies and trials;
- the professional attention given to the structuring of DRed and its user interface to win acceptance among designers as being easy to use.

5. Sources to corroborate the impact (indicative maximum of 10 references)

6. Chief of R&T, Design Systems Engineering, R-R
7. Civil Aerospace section of the R-R Holdings plc Half-year Results, 25 July 2013, http://www.rolls-royce.com/Images/civil_aerospace_tcm92-50015.pdf
8. "Rolls-Royce wins $1.1bn Trent XWB order from Air Lease Corporation", R-R press release, 4 February 2013, http://www.rolls-royce.com/news/press_releases/2013/040213_air_lease_corporation.jsp
9. Statement by Chief Engineer (Trent 800 and RB211), R-R
10. Statement by Chief Engineer R&T - Civil Aerospace, R-R
11. Statement by Design Training Specialist, R-R (and Royal Academy of Engineering Visiting Design Professor at the University of Leicester)
12. Statement by Head of Engineering Strategic Resourcing that includes a quote from a Technical Operations Manager at RROPIPL