The KIM Project: Knowledge and Information Management Through Life

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Engineering firms that make long-lived products are increasingly called upon to sell their products as services. **Alexander Ball** reports on a project that has been investigating the knowledge and information management issues arising from this trend.

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In 1995, power systems manufacturer Rolls Royce registered the phrase "power by the hour" as a trade mark, describing a purchase option for some of their products. The principle is that instead of selling an engine to a customer outright, the customer enters into something more akin to a lease agreement. For a fixed price and term, Rolls Royce provides the customer with an engine, and as many maintenance hours and replacement parts as are needed to maintain its capabilities, even if that means replacing the entire unit. This way of selling products as services is proving popular not only for Rolls Royce, but also for many companies with long-lived products, particularly in industries such as aerospace, defence and construction. Indeed, it has been described as an emerging 'product-service paradigm'.[1]

[1] Rogelio Oliva and Robert Kallenberg. 'Managing the Transition from Products to Services'. In: *International Journal of Service Industry Management* 14.2 (2003), pp. 160–172. ISSN: 0956-4233. DOI: 10.1108/09564230310474138.

The move to a product-service way of working brings with it a wide range of issues. As firms become more involved in the full life cycle of their products, they have more information to deal with, in greater complexity, than ever before. Additionally, as some of the longer-lived products can outlast the engineers that designed them, good knowledge management is becoming increasingly important for ensuring future engineers can still understand the designs and the rationale behind them; this is critical if products are to be adapted to the changing needs of the customer. Of course, the move to product-service also brings with it opportunities for the vendor, such as being able to study how its products perform under real-life usage, in much greater detail than would otherwise be possible.

In 2005, a group of eleven different universities came together to study the strategies and tools that would be needed by both customers and vendors engaging with the product-service paradigm. The KIM Project, short for 'Knowledge and Information Management through life', was funded as a Grand Challenge project by the Engineering and Physical Sciences Research Council (EPSRC) and Economic and Social Research Council (ESRC), and ran between October 2005 and March 2009.[2] A number of industrial collaborators supported the Project, including ABB, Airbus, Balfour Beatty, BAE Systems and the UK Council for electronic Business (UKCeB).

[2] Work on the KIM Project was supported by the EPSRC and ESRC under Grant Numbers EP/C534220/1 and RES-331-27-0006.

The work of the Project had three main themes: improving the ways in which the information about products is recorded; examining how lessons learned from the use of products can be used to improve organizational systems and future products; and considering the implications of product-service provision on governance, contractual incentivization, human resources management and decision making. These issues were considered from a range of perspectives: the engineering environment, the individuals and groups involved, and the practices and tools needed.

The future of the engineering record

Up until the end of the last century, engineering was for the most part paper-based. Design work culminated in the production of two-dimensional blueprints, from which the product would be manufactured or constructed, and against which the finished article would be checked. Around the turn of the Millennium, though, firms started linking their Computer-Aided Design (CAD) systems to their numerically controlled manufacturing robots, simulation tools, enterprise resource planning systems and so on, allowing the CAD data to be used directly and reducing paper versions to something of an ephemeral convenience. CAD software, though, is a rapidly evolving and highly competitive industry in its own right, and with inadequate compatibility even between different versions of the same software, CAD data can become unreadable long before the products they define reach their end of life. While there is an international standard to deal with this problem, nicknamed the Standard for the Exchange of Product Model Data (STEP),[3] it necessarily lags behind the latest advances in CAD software, and with CAD vendors slow to implement the latest features of STEP, information can be lost in the meantime. A team at the University of Bath has therefore developed a way of superimposing additional information over CAD models in any format. The LiMMA system (Lightweight Models with Multilayered Annotations) uses surface identifiers and sets of co-ordinates to link parts of the CAD model with comments held in separate annotation files; as currently implemented, each comment is a structured set of text fields, but may contain links to further files. This means that information that would normally be lost on migrating a CAD file to a simpler, standard format can be rescued as an external annotation. Additionally, since the comments aren't tied to any particular instance of the model, it allows designers to see, layered over their full CAD design, comments made by engineers elsewhere in the enterprise on simplified or approximate versions of the model.[4]

[3] ISO 10303. *Industrial automation systems and integration – Product data representation and exchange*. Multipart standard. International Organization for Standardization.

[4] Manjula Patel, Alexander Ball and Lian Ding. 'Strategies for the Curation of CAD Engineering Models'. In: *4th International Digital Curation Conference*. Edinburgh. 1–3 December 2008. Digital Curation Centre. URL: http://www.dcc.ac.uk/events/dcc-2008/programme/papers/Strategies%20for%20the%20Curation%20of%20CAD%20Engineering%20Models.pdf.

The integration of CAD models into wider enterprise systems is just the first step towards a more efficient and effective engineering record. There are times when a design has to be revisited: perhaps to adapt it to a new customer requirement, or to discover why a product isn't working as expected. In such cases, it is important to know not just the finished design of the product, but also how and why the designers settled on that design. Currently this information is locked up in an aggregation of reports, spreadsheets, databases and catalogues: a nightmare for anyone not already familiar with the process to assimilate. In order to make things easier, new records, tools and processes are needed.

A team at Cambridge University have produced a Design Rational Editor (DRed) for recording how decisions were reached. The tool produces a sort of highly structured mind map that allows one to see at a glance what questions were asked, which answers were considered, and what evidence was given for and against each answer. DRed also supports two-way links with documents and spreadsheets, allowing one to see within both the rationale map and the documents themselves how the facts and figures were used to make decisions.[5]

[5] Rob Bracewell et al. 'Capturing Design Rationale'. In: *Computer-Aided Design* 41 (2008), pp. 173–186. DOI: 10.1016/j.cad.2008.10.005.

Exposing how information in one document is used in others is useful not only for tracing rationale but also for understanding the entire design process. Teams at the Universities of Bath and Loughborough have shown topic maps to be ideal for this task. Topic maps identify where topics (activities, methods, resources, concepts) occur and specify what relationships exist between them. This information can be used to generate eye-friendly visualizations of the design process, showing how initial designs, data and information sources are used and transformed by activities to produce more refined designs or more pertinent information. Typically, topic maps are created for only a small number of topics (say, a single activity and its inputs and outputs) but as topic maps may be joined together, in theory one could reconstruct the entire process by which the final design was developed. Of course, for this to work, special records need to be generated for each topic. The teams have therefore been looking at ways this can be done as a side effect of other documentation efforts.[6]

[6] Alastair Conway et al. 'Holistic Engineering Design: A Combined Synchronous and Asynchronous Approach'. In: *Proceedings of the ASME 2008 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (IDETC 2008)*. New York. 3–6 August 2008. American Society of Mechanical Engineers, 2009. ISBN: 0-7918-4327-0.

One approach involves designers filling out an electronic form to record what they are doing as they go along. The form creates a specially marked up record that can be transformed in various ways, producing a topic record, a process diagram or a written report for later review. A team at Heriot-Watt University have made the process even easier by generating process and rationale information simply from the way in which the designer interacts with CAD or virtual reality design tools. Part of this research involved using a customized version of the BBC's BAMZOOKi™ software, essentially a simplified CAD system for rapidly developing virtual mechanical creatures called 'Zooks' that compete in trials such as sprinting or pushing blocks.[7]

[7] James M. Ritchie et al. 'Automated Knowledge Capture in 2D and 3D Design Environments'. In: *INTUITION 2008 Conference: Virtual Reality in Industry and Society – From Research to Application. VIRMAN Workshop*. Torino, Italy. 6–8 October 2008. URL: http://www.costar.hw.ac.uk/publications/2008_VIRMAN_Workshop.pdf.

A team at Strathclyde University developed a media-enhanced minuting system called KEN (Knowledge Enhanced Notes): a sophisticated wiki-like environment for recording what goes on in design meetings. For each meeting, a page with appropriate metadata is generated on the system, complete with the agenda and a timeline. The timeline records when each item is discussed, and allows copies of documents used in the discussion – as well as scans or photographs of notes and sketches made – to be uploaded in real time. After the meeting, audiovisual recordings can also be uploaded and synchronized with the timeline. The result is a set of media-enhanced minutes far more comprehensive than regular written minutes.

Bringing all this together, a team at the University of Leeds have worked on integrating product, process and rationale information into a single metamodel. The metamodel uses the DRed ideas of issues, proposed answers and arguments, and relates them to requirements placed on the product design, such as a part needing to be a certain size, or a pair of parts needing to be a certain distance apart. Context for these requirements are provided by both a hierarchy of parts and a flow of process steps. The point of this is that it allows not only easy analysis of how a product was meant to function, but also the addition of emergent uses as they are discovered, and assessing the impact on the product design of any changes to requirements.[8]

[8] Alison McKay et al. 'Product development and the transition to product service systems'. In: *Knowledge and Information Management Through-Life Seminar*. London. 24 June 2008. Institute of Mechanical Engineers. 2008. URL: http://www.engineering.leeds.ac.uk/iesd/research/documents/Leeds-IMechE-KIM08--V-Final.pdf.

Learning from use

Experience from working with a product during its in-service phase is a valuable resource for designers when they come to adapt designs for new requirements, and create new designs fulfilling long-standing requirements. Systems that provide the capability to add this information to the engineering record – without altering what is already there, for legal reasons – are particularly helpful in this regard, but the task of codifying that experience in the first place is not a trivial task.

Perhaps the main obstacle facing a designer trying to learn from the manufacture of previous products is that there is rarely a one-to-one correspondence between how something is designed and how it is manufactured. A part with a certain set of geometric features may be manufactured in a number of different ways, and the same manufacturing technique will be suitable for many different types of parts. This difference in viewpoint between functional design and manufacturing process causes a real problem when it comes to sorting and filtering information in a way suitable for both sets of engineers. A team from the University of Loughborough has explored the implications of this on recording manufacturing best practice. The solution they have developed involves modelling aspects of parts as design and/or manufacturing 'features' and the parts themselves as belonging to a particular design part family and a particular manufacturing part family. The relationships between part families, between features, and between part families and features, are also modelled. Best practices may be modelled using constraints on these relationships; for example, whether a groove needs to be milled or cold-rolled depends on its size relative to the size of the milling cutter available. These models and constraints are implemented in a knowledge base connected to the CAD and Product Lifecycle Management systems, allowing designers to see the manufacturing implications of their work.[9]

[9] A. George Gunendran and Robert I. M. Young. 'Methods for the Capture and Reuse of Manufacturing Best Practice in Product Lifecycle Management'. In: *Proceedings of the 5th International Conference on Product Lifecycle Management (PLM-08)*. Seoul, Korea. 9 July 2008.

There are further information organization challenges to face when collecting evidence about product performance from inspections and maintenance performed by service engineers. Here the problem is less about conceptual differences between groups of engineers, and more about the natural human differences in the way service engineers document their activities. Research by the University of Bath has shown that the semi-structured reports commonly used by service engineers do not constrain their entries sufficiently to allow analytic techniques to reliably detect systematic faults and so on. Ideally, firms need to employ rather more managed systems, where engineers receive proper training on entering records in an objective and consistent manner, and where each record is checked for compliance.

Even so, there is a certain amount that can be done to reveal patterns in semi-structured reports. The team at Bath experimented with using faceted classification to organize a corpus of such reports – or rather, nearly faceted, as insisting on true orthogonality between each of the facets would have excluded some useful access points. The parts of the reports that used controlled vocabularies were simple to turn into facets, whereas text mining techniques were needed to extract useful facets from the free text portions. The resulting classification was used to present the reports in a faceted browse interface, with some degree of success.[10]

[10] Yee Mey Goh et al. 'From Faceted Classification to Knowledge Discovery of Semi-structured Text Records'. In: *Studies in Computational Intelligence*. Vol. 206: *Foundations of Computational Intelligence Volume 6. Data Mining: Theoretical Foundations and Applications*. Ed. by Ajith Abraham et al. 2009, pp. 151–170. ISBN: 978-3-642-01090-3.

The Project was not solely concerned with designers learning from the experiences of engineers later in the life cycle, however. A number of case studies were performed in order to gain insight into more general issues in organizational learning. For example, a team from Imperial College London looked at knowledge flows between a UK-based construction firm and its subsidiaries in India and China, and found few mechanisms for overcoming the significant cultural, geographical and technological barriers to learning. The practice of temporarily embedding individuals from the subsidiary companies in the headquarters, however, had a particularly positive impact. A team from the University of Liverpool looked at how communities of practice were used in a multinational construction company, and found two very different types. Role-based communities of practice tended to be set up deliberately by the company, and were therefore stable and suited to top-down dissemination, but lacking in innovation. Interest-based communities of practice tended to arise naturally, and were more suited to developing expertise and innovative solutions to problems; however, they were rather more fragile and only survived when given technological, administrative and organizational support. Meanwhile, a team from the University of Bath School of Management compared two Private Finance Initiative (PFI) construction projects, and found in both cases that the (private sector) contractor was rather better set up for organizational learning, with meeting structures, knowledge databases and so on already in place, than the (public sector) customer.

While dealing specifically with an engineering context, these case studies provide useful insights into organizational learning that could be applicable in a wide variety of settings. This is also true of the research performed into knowledge and information itself.

Handling knowledge and information

Teams at the Universities of Bath and Cambridge have been considering the role that the maturity of information plays in the design embodiment process. This is the stage in the design work where a basic concept is fleshed out into something that can be produced, and therefore the point at which designers calculate what properties the design must have in order to fulfil the design requirements. If the information on which these calculations are based is incorrect, there is a real risk of the finished product being unfit for its intended purpose. In order to manage this risk, one must first be aware of the likelihood of the underlying information being incorrect, and then the likely impact that any inaccuracies, imprecisions, or late changes to the information would have. Maturity in this context measures resilience to such uncertainties in the information; indicators of maturity include passing data quality and validity checks, and having low mathematical sensitivity to variations in the contributing data. By taking the likelihood and impact of the risk together, one can judge the relative importance of a risk, and whether the risk needs to be reduced before design work can continue.[11]

The Universities of Bath and Loughborough have also been considering metrics for determining the value of information, and mechanisms for using these evaluations in organizing information. This work has strong links with the idea of appraisal in records management: how does an engineering firm decide what information to keep in live storage, what to keep in low-cost storage, and what to delete? As well as theoretical work on a Bayesian network model of information evaluation, a case study was performed to see how information was evaluated at different managerial levels and in different functional contexts. The team discovered that the latter was the more significant differentiator, with document managers mostly concerned with accuracy and relevance, project managers mostly concerned with accuracy and novolescence, and directors only concerned with accuracy.[12]

A typology of knowledge, and the interactions and entanglements between the different types in practice, was the concern of a team at the University of Lancaster. While many studies of knowledge management concentrate on the distinction between tacit and explicit knowledge, there are other distinctions or tensions that are just as relevant; for example, the distinction between knowledge held by individuals and socially-held knowledge, between intellectual knowledge and acquired skill, and between prescribed procedure and actual practice. A case study of how engineers use knowledge to solve problems revealed that a whole range of different forms of knowledge were brought to bear: written documents, familiarity with information systems, experience-based instincts of how to solve particular types of problem, understanding what had been attempted previously, and so on.[13]

[11] Khadidja Grebici, Yee Mey Goh and Chris McMahon. 'Uncertainty and Risk Reduction in Engineering Design Embodiment Processes'. In: *Proceedings of the 10th International Design Conference (Design 2008)*. Dubrovnik, Croatia. Ed. by D. Marjanovic et al. 19-22 May 2008, pp. 143 –156.

[12] Llewellyn C.M. Tang et al. 'A characteristic based information evaluation model'. In: *Proceedings of the 2nd ACM Workshop on Information Credibility on the Web*. Napa Valley, CA. 2008, pp. 89–92. ISBN: 978-1-60558-259-7. DOI: 10.1145/1458527.1458549.

[13] Jon E. Lervik et al. 'Knowledge for Theory and Practice: Balancing Commitments in Collaborative Research'. In: *British Academy of Management Conference*. Harrogate. 9-11 September 2008.

Improving the present to improve the future

The work of the KIM Project has not only broadened academic understanding of key management issues in a new industrial context – and despite the Project's name, not just in the fields of knowledge and information management either – but also proved the concept of some highly practical tools to help engineering firms to make the most of their information resources now and long into the future. Indeed, a theme that has run through the Project is that the strategies needed to ensure efficient and effective information flows in contemporary systems are often the same ones needed to provide future systems with the usable legacy information resources they will require.

Presented here is just a selection of the many strands of research undertaken by a Project that will continue to have an impact for some time. Even though the Project has now concluded, parts of the research will continue under separate funding arrangements, ensuring the momentum set by this collaboration is not lost. The various threads of the Project will also be drawn together in a set of final reports, and there are plans to publish two books summarizing the outcomes.