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Knowledge Management for New Product Development in the Global Manufacturing Era

Professor James Gao

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KNOWLEDGE MANAGEMENT FOR NEW PRODUCT DEVELOPMENT IN THE GLOBAL MANUFACTURING ERA

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Professor James Gao

James Gao was born in Chongqing, China, and now holds British citizenship. James graduated from Dalian Institute of Technology, now Dalian University of Technology, in 1984 with a BSc in design, manufacturing and automation. In the final year of his BSc, he won a highly competitive British Council Technology Co-operation Award, which provided full funding for his MSc and PhD study in the UK. He successfully completed his MSc study in advanced manufacturing technology at the University of Manchester Institute of Science and Technology in 1986, and subsequently obtained a PhD in computer-aided design and manufacturing from the same university in 1989. A paper reporting the result of his PhD work won the Edwin Walker Prize of the Institution of Mechanical Engineers in 1989.

James then moved to Loughborough University of Technology as a research associate working on two projects funded by the Engineering and Physical Sciences Research Council (EPSRC): “Information Support System for Design and Manufacturing” and “Feature Based Design for Process Planning and Equipment Selection”. In November 1993, James took a junior academic position at Cranfield University and was promoted to senior lecturer in 2002. He was the director of the MSc programme in computer-aided design and manufacturing for over six years.

James has directed a large number of research projects funded by EPSRC and industry. Subjects include the unification of design, manufacturing capability and service knowledge in collaborative product development; knowledge representation and re-use for predictive design and manufacturing evaluation; distributed and collaborative product development and manufacturing knowledge management; and functional specification for computer-aided assembly planning.

James was appointed to the Medway Chair in Manufacturing Engineering at the University of Greenwich in September 2006. He provides strategic leadership to the Master’s programmes in the School of Engineering, and the engineering design and management discipline. Since joining Greenwich, He has also established the Centre for Innovative Product Development Research Group, of which he is now the director.

James’s expertise is in computer-aided design and manufacturing, product life cycle management, knowledge management for design, manufacturing and business process improvement. He has published over 140 research papers, has been invited to give plenary keynote speeches at various international conferences and to give lectures to overseas universities and companies. He is a member of the editorial board of a number of international journals and has served on the scientific committee of many international conferences. In his spare time, James enjoys swimming, tennis, golf and walking.

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Introduction

This inaugural lecture note provides a short introduction to the author's research interests and experiences, and also outlines some examples of his most recent research work. The author has been working on projects sponsored by both the EPSRC and industry, since completing his PhD degree in 1989. His early research focused on computer-aided design and manufacturing (CAD/CAM), with the scope gradually expanding to cover information and knowledge management for decision making in both product design and manufacturing functions. The scope has since expanded further to cover product lifecycle management. Most recently, the author has focused his research effort on innovation and knowledge management for the new product development process.

The future plan of the author is to develop and expand the newly established Centre for Innovative Product Development to:

(1) carry out fundamental research in innovation and knowledge management for new product development, and to investigate new methodologies for design optimisation and process modelling;

(2) carry out applied research and consultancy in all aspects of product life cycle including customer requirements, design, manufacturing, service, quality and process improvements;

(3) transfer research outcomes to students though teaching and projects, and develop new programmes based on the research expertise.

Challenges of Manufacturing

A report from the National Association of Manufacturers in the USA claims that more than three-quarters of global trade was in the form of manufactured goods in 2005 [1]. Manufacturing continues to play a significant role in the economic prosperity of Western economies. According to figures cited in the same publication, the USA remains the number one manufacturing nation and accounts for a quarter of global manufacturing output. This report also shows Germany, France, the United Kingdom, Italy and Belgium among the top nine leading exporters of manufactured goods.

In the early 20th century, Henry Ford's innovative use of the assembly line in the automotive industry helped trigger the widespread adoption of mass production, which in turn led to a lower cost of production for many manufactured goods [2]. Products that were previously the preserve of the wealthy became accessible to the less well off and so demand for them grew. In this way, the cost of manufacturing products became a focus of competition for many manufacturers. More recently, the high labour costs of developed countries have encouraged a migration of manufacturing to lower-wage economies. This process has been supported by lower transport costs, the reduction or removal of trade tariffs and developments in communication technologies [3].

In order to address the challenges of increasingly globalised manufacturing business, governments have advocated a shift towards development of value-added products, innovation of new technologies and the management of project and service, while outsourcing manufacturing and assembly of parts to lower-cost countries. This trend has led to the use of the term "extended enterprises" which consists of the original equipment manufacturer (OEM) and its global supply chain and business partners.

When manufacturing is organised across extended enterprise the engineering knowledge may become fragmented, disconnected, insecure and often difficult to capture and maintain. OEMs own part or all of the product manufacturing knowledge; they will want to own, retain and control product design knowledge and have the opportunity to service and support the products in the market over the full life cycle, including disposal. In complex engineering products such as aero-engines, the service component is a major part of the revenue stream in the product life cycle. To safeguard their intellectual property and competitive market position OEMs need to have access to the knowledge of all the manufacturing process capability (including those across the enterprise) and requirements and feedback from customers. The research challenge is to propose and develop methodologies to facilitate the provision of appropriate engineering knowledge to engineers and managers within the different players in the extended enterprise, while respecting intellectual property agreements and functional requirements. For today's extended and multicultural enterprise, the capture, maintenance, standardisation, definition, retrieval, sharing and reuse of engineering knowledge has become paramount.

Knowledge Management in Manufacturing

In the 1980s and 1990s, it came to be widely realised that information could be used to achieve a competitive advantage [4]. Knowledge, rather than capital, would become the main source of wealth in the new economy and it would seem that this transition is indeed taking place [5]. Some reports claimed that information represented three-quarters of value-added in manufacturing [6], and successful companies will be those that are able to create and disseminate knowledge rapidly and then transfer this knowledge into their new products [7]. These ideas have contributed to an increasing interest in knowledge management, which has therefore become a subject at the top of the product development strategic agenda in large manufacturing firms.

There are many definitions of knowledge management. Recently, Ngai and Chan [8] defined it as “the set process or practice of developing in an organisation the ability to create, capture, store, maintain and disseminate the organisation’s knowledge”. In the *Knowledge Management Handbook* [9], Coleman argued that knowledge cannot really be managed and that knowledge management serves as a blanket term for a number of functions, such as knowledge creation, knowledge valuation and metrics, knowledge mapping and indexing, knowledge transport, storage and distribution and knowledge sharing.

Information and communication technologies (ICT) and the Internet have significantly enhanced functionality, communication and document management within and between enterprises and their customers and business partners. Commercial software vendors are promoting preconfigured solutions to support generic information needs. The availability of these multiple platforms potentially allows the storage and delivery of vast amounts of knowledge. However, with currently employed technology, engineering knowledge workers are not provided with context specific knowledge appropriate to their professional work function. How much information they access and use depends on their individual perception and understanding of what they need for their tasks. Thus there are differences in the quality of the decisions and work, between different players in the extended enterprise. At a technical level, existing systems lack cross-system inter-operability. The prerequisite is to understand the design, manufacturing and service knowledge with respect to specific industrial applications and their needs, and to standardise the knowledge framework so that it can be shared by various knowledge users across the application environment.

Commercial interests may hinder the free flow of knowledge. From a technology point of view, the seamless exchange of knowledge in engineering and manufacture remains a serious research challenge. Despite many years of research in manufacturing, process planning and design knowledge, the most mature international standard, the Standard for the Exchange of Product Data (STEP), has no successful component for knowledge exchange. The Process Specification Language, a US NIST initiative, is developing a robust process ontology for manufacturing systems integration. The international standard initiative, MANDATE, aims to define standard definitions to describe manufacturing equipment features. Manufacturing capability and knowledge is an active field with significant innovation at the international level. However, these initiatives do not meet the requirements of dynamic knowledge in contemporary global manufacturing.

The European Union's Framework Five Programme had several projects that dealt with aspects of engineering knowledge management under the Information Societies Technology Programme. These include CLOCKWORK [10], an ICT tool for collaborative design knowledge sharing and problem solving, and ISTFORCE [11], an ICT tool to enable knowledge-oriented concurrent engineering in the construction industry. P2People [12] developed an open collaborative framework and application for de-decentralised collaboration, but without implementing specific functionality for engineering knowledge management. SMART SME [13] implemented inter-enterprise integration and collaborative knowledge management between manufacturing oriented SMEs. However, integration is at an abstract level that does not sufficiently support collaborative manufacturing engineering. EDIBOLD-SCS similarly developed new tools and methods for manufacturing SMEs to organise inter-enterprise logistics and product management and created best-practice solutions for interaction between enterprises and their customers. KNOW IT was developed as a decision-support system and enterprise collaboration and workflow-based life cycle management system. It is an open enterprise resource planning and customer relationship management solution, that is, in fact, already available in the open-source domain in the form of Compiere ERP [14]. However, these research projects do not fully address the functionality required by the complex product domain.

National programmes outside the UK include the STEPSet [15] research group of the Russian Academy of Sciences, which proposed the construction of enterprise-wide knowledge management solutions around the ISO-STEP standard. The Europe-wide EUREKA programme for market-oriented R&D has financed the TIMESHARE [16] project to enable intelligent, collaborative production management for suppliers. The IKF [17] framework produced generic ontologies and a knowledge-sharing infrastructure within a distributed architecture and has been used for various disciplines, including manufacturing. The international consortium Intelligent Manufacturing Systems has projects such as GLOBEMEN [18] that define open architectures and test systems for global virtual manufacturing enterprises. While these projects are relevant, their primary focus is on the alignment of manufacturing capabilities via the virtual enterprise concept.

In the UK, an EPSRC project [19] aims to develop a range of technologies for knowledge management. The approach is evaluated using testbed applications. Another EPSRC project [20] aims to develop a methodology for the live capture of reusable project knowledge that reflects both the organisational human dimensions of knowledge management and exploits the benefits of web-based technologies. A further EPSRC project [21] deals with collaborative medical problem solving using knowledge services provided via the e-Science Grid. The Managing Knowledge Spaces project [22] includes research with industrial partners from diverse sectors. The primary aim is the development of a taxonomy and diagnostic tool that will help managers to quickly understand the ramifications of differing project team designs and associated knowledge management processes, for project performance in different industrial contexts.

In summary, there is considerable effort in knowledge management, principally devoted to generic business management and the creation of virtual enterprises and networks. There is a clear requirement for solutions to the challenges arising during the global product development process. This is a high-risk process, critical to success in world-class UK manufacturing engineering, especially for products of high complexity and value. The requirements outlined above are the focus of Professor Gao and his research team.

Innovative Product Development

The Department of Trade and Industry (DTI) in the United Kingdom published a strategy document for UK manufacturing in 2002 which identifies innovation as one of the seven “pillars” required to build a successful manufacturing industry [23]. A follow-up report states that innovation is crucial to the future of the UK manufacturing industry [3].

Commercial organisations have sought to increase profits by investing resources in the creation of new products, as well as discovering new methods of manufacturing and delivering existing products [24]. New product development (NPD), defined as "the overall process of strategy, organisation, concept generation, product and marketing plan creation, and evaluation and commercialisation of a new product", is of great interest to manufacturing firms [25]. A benchmarking study of firms in the USA from 2003 conducted by American Productivity and Control reported that in the preceding three years new products had accounted for an average of almost 28 per cent of sales [25]. New products have emerged as a focus of competition for businesses. Furthermore, the process of product development is considered to be a "critical" factor for manufacturing businesses that aspire to prosper in competitive markets.

NPD projects are effectively complex business processes involving individuals from different functions, which will typically include manufacturing, design and marketing [26]. For some years scholars have maintained that project failures are in part caused by the lack of a systematic approach to these complex projects and have encouraged the use of formal process models to support managerial decision making, e.g. Jones and Stevens [27], and Zirger and Maidique [28]. Effectively, these systems serve as methodologies for the application of managerial rigour and discipline to the innovation process. Cooper [29] defined the formal NPD process as "a formal blueprint, roadmap, template or thought process for driving a new product from the idea stage through to market launch and beyond".

A commonly used model today is the cross-functional stage-gate model, which Griffin [30] indicates is employed by almost 60 per cent of firms in the USA. This model divides the NPD process into discrete stages, each of which is followed by a review gate. Each stage can be broken down into a collection of predefined, cross-functional and concurrent tasks, which are executed by cross-functional teams. The importance of such a formal process model and its connection to best practice is well established in the literature. Furthermore, Fredericks [31] showed that cross-functional involvement in product development is dependent on a collective understanding of the tasks required at different phases of the NPD process.

Recent decades have witnessed the emergence of a global manufacturing phenomenon, and product development in the global environment. Respondents to a survey conducted by McDonough et al [32] predicted that a fifth of NPD teams in their firms would be global in nature. They characterised global product development team members as being geographically dispersed, speaking different languages and originating from different cultural backgrounds. This differentiates them from co-located teams who work in a single locale, such as a region of a country or a city, and share a common language. Eppinger and Chitkara [33] stressed that this use of global resources is not, as in previous years, to exploit low labour costs, but rather to exploit globally distributed NPD expertise that cannot be obtained in one locale in order to achieve growth and innovation. McDonagh et al [32] warned that global product development teams will become more prevalent and therefore research is required to develop methods of obtaining levels of performance from NPD teams that match those already available from their co-located counterparts.

An Example of a Knowledge Management Framework

The author and his research team have developed a knowledge management framework (emphasising sharing), and carried out an industry-based case study to illustrate and test the functionality of the framework [34]. The company is a multinational manufacturer of physical, electromechanical goods and uses a multifunctional stage-gate business process model to support its new product development projects. Many of the new products produced by the company are variations on previous designs. The model consists of five stages: strategy, conception, development, production and project review. Given that the NPD process consists of dozens of sub-processes and hundreds of tasks, it was decided that the scope of the investigation should be limited to the knowledge inputs and outputs for the tasks in three sub-processes. To demonstrate the multilingual support mechanism, the ontology is presented in English and German versions.

The framework uses an ontology-based tool to address the knowledge sharing problems. An ontology is "a formal, explicit specification of a shared conceptualisation", as defined by Studer et al [35]. A conceptualisation is a simplified view of the world, which is expressed as a model consisting of pertinent concepts in a knowledge domain. In this case, the knowledge domain is the representation of information about knowledge used and generated by tasks in the NPD process. The tool was created using version 3.0 of the Protégé ontology editor and knowledge-base framework software, as well as the Web Protégé browser tool by Stanford Medical Informatics [36]. The knowledge sharing tool system is based on a client-server architecture. On the client side, a web browser such as Microsoft Internet Explorer or Mozilla Firefox is employed to visualise the ontology. The forms for capturing and viewing metaknowledge are created in the Protégé ontology editor and are reproduced in the web browser window. Users are able to navigate their way around the ontology using the familiar "point and click" paradigm.

The method used in the case study consisted of five steps: selection of the three sub-processes; elicitation of information about the tasks from which each sub-process is comprised; elicitation of information about the knowledge required for and generated by these tasks; capture of this information or metaknowledge in the knowledge sharing tool; and translation of the English language concepts and relationships that form the ontology into German and addition of the multilingual labels.

Following a review of the NPD business process, it was decided to select the three sub-processes from the product conception phase. This phase is both knowledge intensive in nature and exploits knowledge from a range of disciplines. Table 1 lists the selected processes, accompanied by a brief description. The "generate product proposal" process is mostly of a technical nature, while "product validation" involves the use of knowledge from a broad range of functional domains. In contrast, the tasks in the "project performance" process use and generate knowledge associated with the end-of-phase stage-gate review. This includes technical, cost and project management knowledge. As a result, the two selection criteria are satisfied.

Table 1 Selected sub-processes

Process title	Description
Generate product proposal	Create initial product specification and prototypes from marketing proposal
Product validation	Test product concept and assess reliability
Project performance	Verify that NPD project is running to the agreed time, cost and process

For reasons of brevity, only one of these processes, “project performance”, will be discussed here. However, the example should prove sufficient to illustrate the key functionalities of the tool. Information about the sub-processes and tasks was transferred to the knowledge sharing tool using the Protégé ontology editor.

Selecting a task allows the tool user to add its input and output knowledge items. Once this exercise is complete, the actual knowledge may be added to each knowledge item, which includes the priority assigned to the knowledge item and expert contributions to the knowledge item made in previous projects. Such contributions might include the rationale behind a decision taken during a project review meeting. All of this information may then be viewed remotely through a web browser interface, making it accessible to NPD project team members irrespective of their geographical location.

In summary, this framework provides mechanisms to prioritise knowledge and supports a multilingual ontology interface, in addition to a web-based dissemination mechanism. The ontology explicitly defines the relationships between various concepts in the NPD process knowledge domain, including the knowledge required or generated by NPD process tasks, the meta-knowledge which provides a range of contextual information about this knowledge, and the NPD business process itself. By linking NPD knowledge to tasks in the NPD business process, project team members are provided with a common reference point for accessing knowledge relevant to their needs. The case study has shown how the tool might facilitate knowledge sharing in a global product development environment. Furthermore, given the close adherence of the case study company’s NPD process model to generic stage-gate models in the literature, it is proposed that the ontology employed in the tool could be adapted to suit the needs of other multinational manufacturing companies using a cross-functional stage-gate model.

Knowledge Reuse

Engineering design in mature domains is increasingly competitive in today’s globalised manufacturing environment. One approach to assist in this competitive cycle is to reuse previous knowledge, to enable the creation of robust designs in less time, with lower production costs. Although the design process output or solutions can be directly reused, they cannot be expected to function in the same way if they are directly scaled or if elements of them are reused in different systems. Knowledge relating to geometry can otherwise be reused through the formalisation of associations between product parameters. This enables optimisation of functionality where products are scaled up or down within certain limits. Parametric associations that are embedded in CAD models help to speed up product development, reducing the time required to reproduce well-known components. Most knowledge-based engineering (KBE) tools provide solutions that interact with product data, particularly geometry. However, there are a wealth of non-geometric knowledge elements that could be reused but are missing from current KBE systems. These include problem resolution methods, solution generation strategies, design intent and project knowledge.

Information access, design reusability and retrieval are all fundamental issues enabling design reuse [37]. Around 20 per cent of the designer's time is spent searching for and absorbing information. This figure is even higher for technical specialists [38]. Furthermore, around 40 per cent of all design information requirements are met by personal stores, despite the fact that more appropriate information may be available from other sources. Early in the design process, textual information is most important. Later, geometry becomes more important and the importance of textual information declines [39]. Some important factors to enable reuse include a method to first make design reusable, then to store the reusable elements so that they can be found. If knowledge stored in computer-based systems is accessed, and is to be reused, several additional requirements must be met: reusability, availability, and relevance. Efficient exploitation of past designs has been prohibited by the lack of a methodology to structure past designs and information [40]. With a well-structured library of reusable past designs, and a method to make new designs reusable, the issue of design reuse is greatly simplified. This would provide support to the aim of enabling both design for reuse and design by reuse to be applied during new projects.

Design reuse systems, which are based on a knowledge model and are normally not associated with a process model, are referred to as the "classic" approach here, such as the well-known "finding the (best) previous solution to a new design problem". A typical example is the case-based reasoning (CBR) approach, which has been applied in a variety of ways to enable design knowledge reuse. Essentially, it involves creating an index of the problem area, then applying artificial intelligence (AI) techniques to find similar cases. These "similar cases" are then further analysed and the best "match" case is used as the basis for new product development. Another type of design knowledge reuse approach is the rule-based approach. For example, the CADET system uses as text for easy understanding and editing of the rules used to select and evaluate concepts [41]. The axiomatic design can be regarded as a design reuse method [42], in which fundamental principles are reused to systematise the design effort. Based on a formulation of the design requirement (which is cited as the most important and difficult task in engineering) alternative solutions can be tested against the principles, or design axioms.

Most computer-aided engineering (CAE) systems (such as Unigraphics, Catia, Pro-Engineer and I-CAD) provide parameter-driven knowledge modelling capabilities which are normally based on a geometric model. These systems have design rules embedded in the parameters, and are used for very specific engineering calculations. They are very well suited to solving complex, highly structured problems in which a level of optimisation is required. KBE is generally regarded as an umbrella term describing the application of knowledge to automate or assist in the engineering task. KBE can be applied to a wide range of design tasks. Knowledge embedded in KBE systems has a short life. To make this knowledge reusable, the MOKA (Methodology and tools Oriented to Knowledge-based engineering Applications) project provides a standard methodology for developing KBE applications, enabling reuse of the captured knowledge through a modified-Unified Mark-up Language knowledge representation method [43].

It has been suggested that the design process is a driver of design reuse for decision making at all stages of product development. Design reuse tools should support the project (or design process) as a means to reuse knowledge, either through guidance to reapply knowledge at the most effective time or through the capture and application of the knowledge embedded in the process itself. If these factors can be combined, the process can be used as a basis for design knowledge reuse [44]. The following reported research has, to different extent, considered the design process as the basis for knowledge reuse.

Signposting [45] is a parameter-driven task model of the design process. Design knowledge is represented in a flexible task model. The task model does not have strong precedence links; instead the method uses the level of confidence in key design and performance parameters as the basis for identifying, or signposting, the next design task. The signposting method is well suited to the development of new technologies in well understood application areas.

The FIPER (Federated Intelligent Product EnviRonment) project defined an environment within which a variety of distributed services can be applied to the problem of design through the use of the intelligent master model (product geometry). Software tools act as distributed service providers and service requestors [46]. A workflow model has been developed to manage process definition, execution and resources. The intelligent master model is most suitable for variant design in well-known areas, where extensive product knowledge has been built up over many years and the next generation will share much of the same geometrical relationships.

The design roadmap (DR) method provides a formal method to represent the design process [47]. The method enables the representation of feedback and feedforward processes, which are common in design yet uncommon in other representations. The data model enables a variety of graphical representations, or views. Graph, matrix, tree and list views are supported. Additional functions, including resource management, document attachment and notification functions were added to the DR framework. The method mainly addresses project management issues, which implicitly applies product knowledge.

An Example of a Knowledge Reuse System

The underlying principle of the developed knowledge reuse system is based on the interaction between a design process model and a product data model through a set of parameters to meet the particular needs of the application area: mature engineering design. In the early stage of new or developing designs, a great deal of details underlie (and can be extracted from) a description of a product that includes only a small number of parameters. These parameters may relate to size, performance, or other technical characteristics. The parameterised model of the product is then extended to include parameters that are calculated, or inferred, from the original specification. These parameters form a key element in the creation of a product development process describing the best approach to the design of that product within the organisation concerned.

Assuming that the organisation has developed similar products in the past, a large amount of product knowledge can be applied to the creation of the design process. During enactment of the design process, the parameter-based product model is applied. As the process model is carried out, the product model is populated. Computational methods are applied through the creation of relationships between the process task model and the parameterised product model. This architecture enables a variety of analysis methods to use the same data set. The resulting product and process model together can be regarded as a project model or project template, and can be extended for specific products. The project model is created in such a way that the data sets are populated at the most appropriate time – and so any product analysis is scheduled to take place when the data is available.

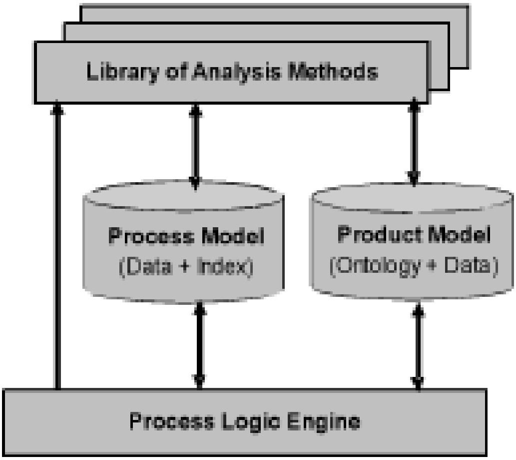
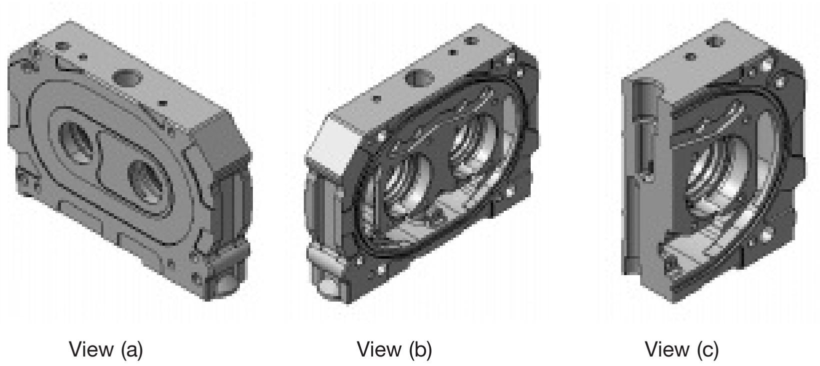


Figure 1 Knowledge reuse system architecture

The design knowledge reuse system therefore has two key elements (see Figure 1): a process model and a product model. The process model itself provides a detailed structure that can be applied to the indexing and retrieval of additional information. The product model is a combination of product data and ontology. The product ontology in this case is a formal vocabulary defining the product objects. The product data can be directly manipulated within the system or externally. The product ontology enables reasoning relating to product concepts, and retrieval of similar concepts. The process logic engine is the interface with the process model, which manages the assignment and updating of tasks. The process logic engine also interacts with the product model, through the assignment of product data in the form of features. The process logic engine serves as a trigger for the library of analysis methods. These methods use the product data as input, carry out their function, and store the result in the product model database. There is also a link between the process model and the library of analysis methods to allow dynamic management of the process itself.

A major contribution of the method is derived from creating it. The method requires an investigation to capture the design process, followed by in-depth analysis to create the project model (template). This exercise will allow the organisation to formalise and improve their methods in advance of applying the tool, which itself will provide benefits. The industrial partners supporting the research project that this paper is reporting on are involved in mature engineering domains. A detailed design process model has been developed, and the supporting knowledge has been captured and added to the model. The component selected for the knowledge capture exercise is the head-plate, shown in Figure 2. The head-plate serves several critical functions for the operation of the vacuum pump: to seal, support and lubricate. Internal, or shaft, seals prevent oil from crossing from the bearing cavity to the process chamber. External seals prevent transfer of atmospheric gas. Bearings support the shaft under load. They are lubricated with a single charge of oil for the service life of the pump.

The head-plate is designed as a common item for a range of pump types. Side view (a) shows that the head-plate forms part of the pump stator. Critical elements include stator tolerances, the shaft seal and the atmosphere seal. Side view (b) supports the shaft bearings, and critical elements include the bearing bore geometrical and positional tolerances and the bearing lubrication system. The dynamic seal system, including gas flow channels for purge and pressure balancing, also play a major role in pump reliability. One of the gas flow channels can be seen in the cross-section view (c).



View (a) View (b) View (c)

Figure 2 Images of the head-plate showing different functional features

The design process for the head-plate component was captured and modelled using the DR framework [47]. The DR representation consists of two node types, “task” (the task itself to be enacted) and “feature” (which contains data required by the task, also produced by subsequent tasks). Link types include precedence, abstraction and constraints. Precedence shows order of task execution and likely iteration. Abstraction relates to the capability for a sequence of elements to be represented by a single element. Constraint links connect feature nodes and show that a constraint exists.

Figure 3 shows a view of head-plate design tasks, modelled using the DR framework, with some of the features and their attribute slots visible. Iterations, feedback and side effects have been omitted for simplicity. Within the head-plate design task, both sequential and concurrent activities take place. Data that is required by later tasks is recorded in the features. For example, the bearing bore feature contains data (size and tolerance) that will be used in the lubrication system design task (see top of Figure 3). This same data set could also be used as an input to a manufacturability analysis task, i.e., data sets can be called by any task object. The main objective of the features shown in this diagram is to provide data required by subsequent tasks. It is the feature that triggers the task. If a data set is required but not complete, the task will not be initiated.

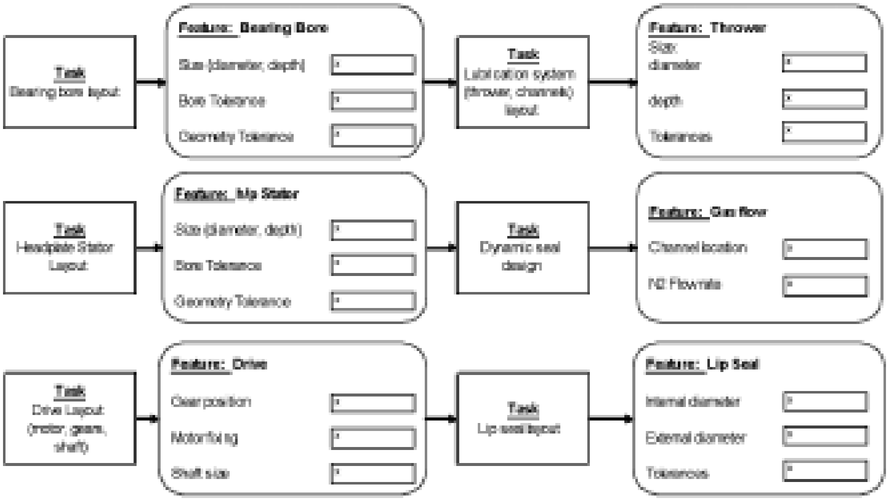


Figure 3 The head-plate design tasks modelled using the design roadmap framework

The data handling provided by the process model enables the parameters of the product to be created through the enactment of the design process. An implicit method for the handling of the data set is embedded in the design process, i.e. what the parameters are, where they are created, and where they are used. The explicit methods applied to the storage and manipulation of the data set are not made clear, so must be defined. A full implementation of this method may involve several thousand parameters. In this case, grouping them into sets (objects) could ease the retrieval and reuse process. Rather than call an individual parameter, an object could be called. These objects are called by the features in the process model. Using an inheritance model, it will be possible to treat the parameter set as a hierarchy of objects. The attributes of the objects are populated through the product design process.

The product model and process model together enable effective distributed collaboration on the product design. Supporting information is also available, to support the designer in completing the task. This may include general notes, formal design documentation, images, tables, catalogues, and algorithms or knowledge-based methods to manipulate the product data (further details are given in the next section). In the test example, the product model is stored in a Microsoft Excel spreadsheet. Excel is used to implement the process representation, i.e. clickable process and feature nodes, process pages, feature contents, and product model parameters. Knowledge reuse is achieved through two distinct elements: data analysis carried out using the library of analysis methods, and the application of knowledge stored in the product model. A section of the process is shown in Figure 4 (the last task, head-plate design, is detailed in Figure 3).

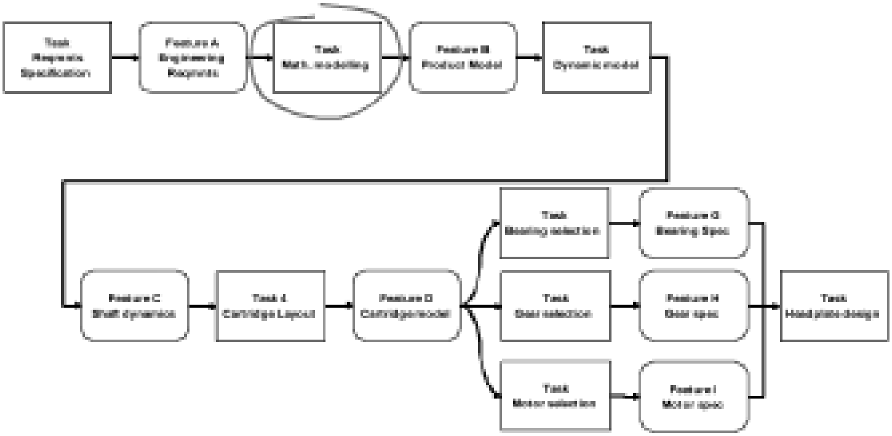
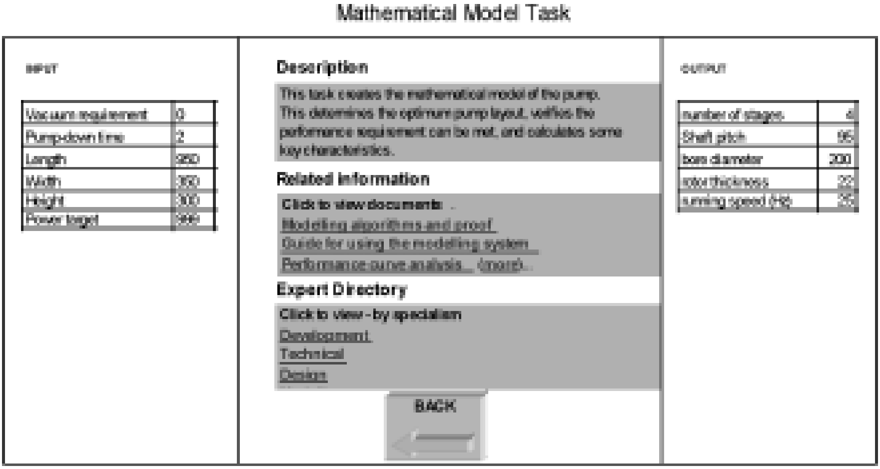


Figure 4 Design task overview showing precedence relationships

Each element of the process (both task and feature objects) contains a hyperlink (a clickable link in text or graphics). The task objects link to a page containing a task description, additional information and an expert directory. The task page also shows the data inherited from the input feature, which consists of a description and the data (generally a string and a short, although a range of data field types are acceptable). Each task and feature in the process model has an associated detail page. In figure 4, the mathematical modelling task is highlighted. The detail of the page of engineering requirements is shown in Figure 5.



Mathematical Model Task

INPUT

Vacuum requirement	0
Pump-down time	2
Length	950
Width	350
Height	300
Power target	999

Description

This task creates the mathematical model of the pump. This determines the optimum pump layout, verifies the performance requirement can be met, and calculates some key characteristics.

Related information

Click to view documents

Modelling algorithms and proof

Guide for using the modelling system

Performance curve analysis (more)..

Expert Directory

Click to view - by specialism

Development

Technical

Design

OUTPUT

number of stages	4
Shaft pitch	95
bore diameter	200
rotor thickness	22
running speed (Hz)	25

Figure 5 Mathematical modelling task page

It can be seen that the description header shows the first section of a more detailed description document. The related information section contains links to other documents, images, or files. The expert directory section is arranged by specialism, in which each link links to another page containing information about individuals, their experience and their contact details.

The method described above addresses the need to reuse product and project knowledge, particularly of a non-geometrical nature. The underlying principle of the methodology is the interaction between a product model and a process template through a set of parameters to meet the particular needs of an application domain. The proposed system will provide project guidance and monitoring, a framework to organise information and knowledge retrieval and a central repository of product data. These elements can be brought together through the use of a combined method to represent the design process, provide data support, and to form relationships between the process model and product concepts. The system has been tested with an industrial sponsor on a major component. The next challenge is to build additional components, with the longer-term aim being to capture and represent knowledge for an entire product family.

Summary and Future Work

New product development and services are becoming increasingly important in the global manufacturing business. The efficient management of innovation and the knowledge of enterprises, and their supply chains and partners across the world, is a challenge to both business and academia. The author has been working in this area for many years and the two example projects described above reflected part of his most recent work.

Subjects of other on-going projects supervised by the author include: a requirement driven product introduction based on an enterprise architecture; a multi-agent knowledge search framework for product development; product innovation and optimisation using the Triz methodology; and a tolerance advisory system for product design and optimisation.

It is hoped that the Centre for Innovative Product Development will now expand rapidly. Five full-time PhD students and one part-time PhD student have been recruited or transferred from Cranfield, and a new lecturer/senior lecturer will join the group. Two new research projects will start very soon in new design process modelling methodologies and cost engineering for the early design process. The group also plans to address the environmental issues that are becoming of major importance to new product introduction.

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