# MANUFACTURING KNOWLEDGE REUSE FOR PRODUCT DESIGN

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## ABSTRACT

In today's world there is ever increasing pressure to bring products to market in a quicker and more time-ly fashion that fulfill customers' needs and are delivered on budget. One way to aid such acceleration of the design and development process is to effectively share and reuse manufacturing knowledge in an ef-fort to bring about product based interoperability. This paper reports upon the work being carried out in the SAMULET research programme that addresses such factors. It focuses upon (i) how the sources of in-formation and knowledge were recognized, (ii) the definition and categorisation of knowledge and (iii) the potential routes for the reuse of manufacturing knowledge. The research approach is currently being developed to help augment a supportive information and knowledge sharing environment and bring about a more integrated development process within a high tech aerospace company.

**Keywords**: Knowledge Reuse, Knowledge Sharing, Knowledge Modelling.

## 1    INTRODUCTION

In today's competitive market place there is the ever growing need to constantly improve products and processes to be able to satisfy and fulfill customer needs. It is imperative that competitive advantage be gained from the acceleration of the design-make process within a manufacturing organization and one such way to do this is to enable and facilitate effective knowledge transfer, sharing and reuse (Baxter 2008).

In high technology manufacturing industry there is a drive towards the application of robust design principles and improvement of product quality. The aim is to reduce product variability so as to maximize the performance of a product and hence improve the ability to produce such a product so that it is right first time. A major facet of enabling robust design is to firstly understand an organization's ability to manufacture products and to then share that understanding. It is crucial that design engineers when creat-ing a product are cognoscente of these manufacturing capabilities to be able to develop a design specifica-tion that can be successfully and effectively manufactured within the current boundaries of the organiza-tion's manufacturing operations. Therefore the issue at hand is one of sharing information and knowledge more effectively, so that it may be accessed when needed in the right manner to enable more informed decision making within the design process.

The academic literature points towards major research efforts focused upon the concepts of sharing and reusing design and manufacturing information and knowledge. These range from document based ap-proaches (Wu 2009), to the more complex knowledge based systems approaches (Cochrane et al. 2008, Young et al. 2007). All of these approaches aim to ameliorate the representation and supply of manufac-turing knowledge to facilitate quicker and better design decisions and therefore enable reuse. One of the

main differences between these approaches is that a document based approach is meant for human interpretation and a knowledge based approach focuses upon machine based interpretation. Whilst pursuing knowledge based systems approaches is worthwhile and extremely valid, such approaches can prove to be complex undertakings, consuming large amounts of time. Moreover they need disproportional amounts of effort to develop the systems that can share knowledge to allow reuse which in turn need time to be developed, tested and validated for use as professional pieces of software within high technology corporate environments. Therefore approaches are still needed that can be developed and applied in short spaces of time, which capture and represent knowledge in a highly structured manner, are simple to use and effectively share knowledge between different engineering functions and multidisciplinary teams of engineers.

The focus of this paper is the development of an approach to structure and represent manufacturing knowledge so that it may be shared with and reused by design engineers. The objective of the research presented herein was threefold. Firstly to determine the information and knowledge needs of the design function. Secondly to determine the types of information and knowledge utilized by the manufacturing function and thirdly to develop a pilot system to allow the information and knowledge to be searched for and supplied to an end user. This paper is set out in the following manner, section two details the research design and methodology applied for the capture and analysis of data. Section three presents the results and describes the purpose of the approach and its intentions and section four draws together the conclusions and outlines future work.

## 2    METHOD

The research was based upon one main question, that being: *Within a commoditized approach how can manufacturing knowledge be captured so that it can be shared across manufacturing and design engineering disciplines ?*

When considering the research, its context and understanding that one research method might not be sufficient to form an answer, the authors chose to apply a mixed methods approach (Creswell 2008) to the question at hand. The exploratory manner of the research lent itself to a case study approach (Yin 2009) and it was deemed useful to utilize a grounded theory method (Glaser and Strauss 1967, Turner 1981) to help refine the research question and propositions as the study progressed.

### 2.1    Context Discovery

The first aspect to understand was the context within which products are designed and manufactured. To fully understand the products made by the sponsor company, their complexity and scale, two modeling techniques were chosen so as to formalize and represent both the design and manufacturing function and thus appreciate the variety of different relationships and interactions that take place in a multidisciplinary environment. These were (i) the IDEF0 method which is a widely accepted and used technique for the modeling of processes, activities and information flows and (ii) the Business Process Modelling Notation method was chosen to augment the approach by assessing time based actions and decisions.

The resultant functional models were verified and validated by a process of individual feedback and assessment from engineers and two half day workshops to review and assess the models for completeness, precision, clarity and fidelity. These were used to deduce the main information flows that were of major consequence and importance to the design-make process allowing the research to focus upon what was valuable to the engineers and what would have to be elicited and captured to achieve the goal of feeding it back into the design process for reuse.

### 2.2    Case Study

After careful consideration, the best approach that fitted the context was that of a case study. Following Yin's (2009) well established methodology for setting up a case study; a number of steps were taken (Neale, Thapa and Boyce 2006). Accordingly two propositions were stipulated to help focus the case study, these being (i) Design Engineers can reduce product variation by understanding the organization's

manufacturing capabilities, (ii) Design Engineers can maximize product performance by understanding how products are manufactured, with what and the workings of their environment. Accordingly a unit of analysis was ascribed, that being the organization's knowledge sharing mechanisms. The case has been designed as single case, which is holistic and has a single unit of analysis. This is because the case being studied is considered crucial by the domain experts. To understand the data collected from the case study, two analysis techniques are being employed, grounded theory (Glaser and Strauss 1967, Turner 1981) and a logic model. These work well together as they are highly iterative approaches and suit the exploratory research.

Planning for the case study identified the stakeholders whose involvement was considered to be instrumental. A specific instance of a new product was identified for reasons relating to the most advanced methods used both by design and manufacturing to produce such a product. Aligned with this a number of information sources were stipulated so as to enable convergence of evidence (Yin, 2009) and triangulation of data. This would counter any problems with construct validity. The sources were documents and drawings, interviews, observations and physical artifacts. The development phase of the case study set out an initial open ended interview, utilizing the knowledge elicitation techniques set out by Cordingley (1989) and the naturalistic knowledge engineer (NKE) method of Bell and Hardiman (1989). This enabled the effective capture of knowledge held by the participants during the interview. To support this, a list of the issues to be explored was set out to ensure that each of the relevant aspects covering the subject matter was addressed in each interview.

As data was collected, analyzed and reflected upon, the grounded theory and NKE methods brought about a semi-structured interview that is currently being used to collect data. A logic model is also being used to analyze the collected data, results of which are yet to be forthcoming. All of these outputs are subject to a teach-back process with the interviewed engineers and the review of a community of domain experts, so as to verify and validate what has been captured and the research that is being developed.

## 3    RESULTS

Two mains items have been derived from the analysis of the data collected by the context modeling and case study. These are presented herein:

### 3.1    Feature Knowledge Relationship Structure

One of the key aspects of knowledge management is to understand the relationships between different items within a specific context, providing this allows different disciplines to be able to relate their viewpoints to others disciplines' viewpoints (Cochrane et al. 2008, Young et al. 2007). The preliminary output of the case study was a draft feature knowledge relationship structure (FKRS) which was modeled utilizing the unified modeling language so as to formalize it as illustrated in Fig. 1.
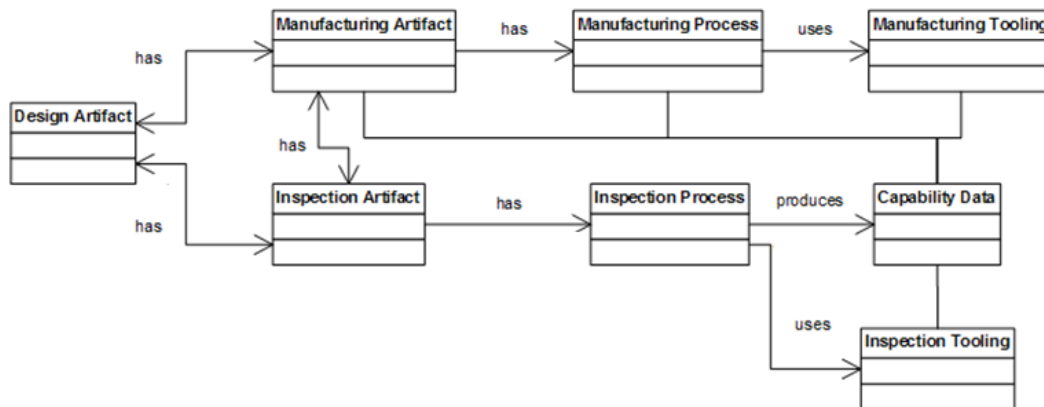


**Fig. 1:** UML Feature Knowledge Relationship Structure

The FKRS sets out the derived relationship view between a design artifact, a manufacturing artifact and an inspection artifact. Moreover there are different types of information and knowledge that can be associated against each of these. Hence by explicitly modeling and stating these relationships the FKRS allows the information and knowledge to be linked between entities. The first of these entities is the design artifact, this is the product part that is being developed and represents the design engineering point of view. The second is the manufacturing artifact, this is part of the manufacturing perspective about the product that is being manufactured. Related to this are the manufacturing process and the associated tooling used to produce the artifact. The third is the inspection artifact, which again has an associated inspection process, tooling and resultant capability data. Each design artifact has a number of dimensions that need to be measured, these constitute inspection artifacts. Measurements are taken to validate that the manufacturing operations are capably producing the specified design artifact for a given tolerance. A design artifact to inspection artifact relationship is one to many, whilst the design artifact to manufacturing artifact relationship is a many to many relationship. Aligned with a manufacturing artifact is a manufacturing process which is employed to realize the artifact which in turn uses manufacturing tooling. Accordingly an inspection artifact employs an Inspection process to generated Capability Data and uses Inspection Tooling. The Capability Data relates to the Manufacturing Artifact, Manufacturing Process, Manufacturing Tooling and Inspection Tooling.

### 3.2 Knowledge Document Templates and Queries

The second key item generated from the research approach was a set of knowledge document templates and the understanding that queries will be needed to access them by way of a search engine. These templates were created to explicitly represent manufacturing information and knowledge so that they may be fed back to design engineers for reuse. There are two specific templates, one for the representation of manufacturing knowledge and one for inspection knowledge. Both of these templates have been created utilizing the feature knowledge relationship structure thereby allowing relevant items to be represented and explicitly state the relationships between the different artifacts.
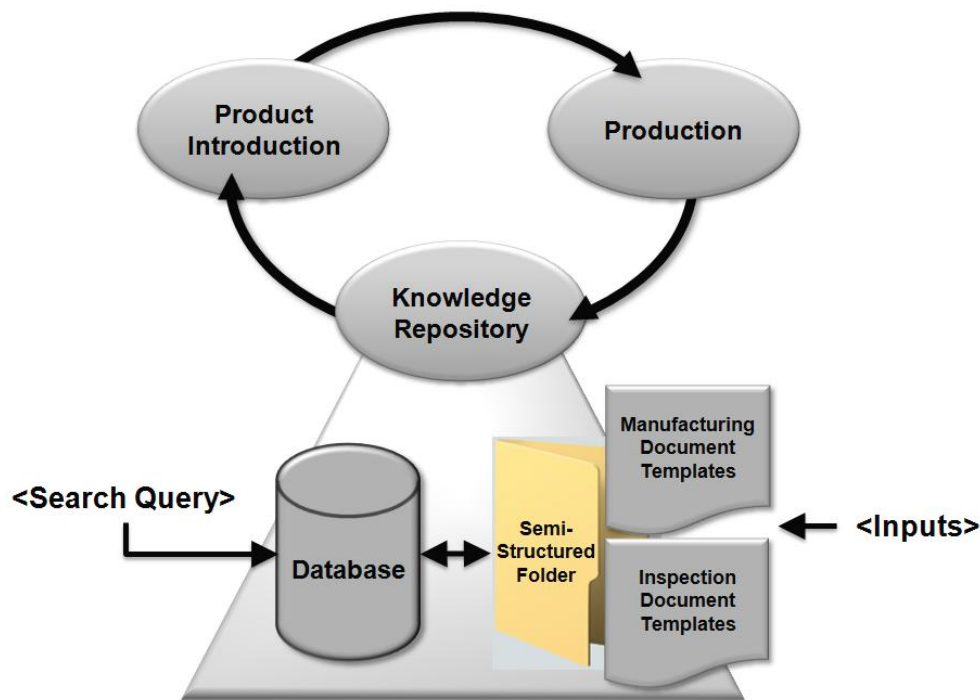


**Fig. 2:** Proposed knowledge reuse approach.

There are four key sections for the manufacturing template. The first section states the version number of the document and the date created. The second states the manufacturing artifact that the document relates to along with the relationships to the design and inspection artifacts. The third section denotes the specific factory and machines that are used to produce the artifact. Whilst the fourth and final section of the document sets out the manufacturing rules and considerations to be understood by design engineers. The second template is the inspection knowledge template, which possesses five key sections. The first four sections of the template are the same as the manufacturing template, stating the inspection feature the relationships to the manufacturing and design artifacts and the factory and machine that are being used to inspect the artifact. Where it differs are the two last sections. These are used to present capability information in a number of different formats, rules that are to be applied to the information to help interpret it and inspection tooling knowledge. Fig.2 shows that these knowledge templates are to be stored within a semi-structured folder on a server and it is planned for these to be accessed via queries from a search engine. A number of search terms and basic queries have been elicited from design engineers so as to set up the planning and testing of the system to assess application, integrity and usage.

## 4    CONCLUSIONS

Our investigations with design and manufacturing engineers into their activities and information requirements brought about a strong foundation with which to evaluate their working environment. The resultant IDEF0 and BPMN models helped identify and understand the types of information and knowledge utilized in day-to-day activities. From these a set of information and knowledge requirements were deduced, along with a comprehension of the engineers' accessibility needs.

A feature knowledge relationship structure (FKRS) has been developed by way of using the models and conducting a case study around a specific product. What has been produced is a structure that formalizes the relationships between a design viewpoint of a product, a manufacturing viewpoint and an inspection viewpoint and ultimately the underlying knowledge and information. This has been focused upon tooling knowledge and process capability knowledge. From this it has been possible to build document templates to represent each of the aspects within the FKRS that are founded upon sound knowledge modeling techniques.

Pursuing a document based approach allows for a much quicker and simpler manner in which to represent and share knowledge than a knowledge based approach. Part of the appeal of the presented knowledge document template approach is the FKRS upon which it is built. It has the potential at some point in the future to be developed into a database or even a knowledge base for the sharing and reuse of such knowledge. Hence versatility is an applicable characteristic that one might ascribe to such an approach. Moreover each instantiation of the document templates is a document object which is universally recognized and one which is usually supported by an organization's information systems.

What is needed to partner such an approach is a well designed and developed search engine capability that is able to highlight the applicable documents for an end user and present them in a rational manner for access to facilitate knowledge sharing. This is currently being developed with a view to creating a pilot system. Testing and assessment of the pilot system will be part of the appraisal process to gauge how easy to use and applicable the approach is.

Other aspects of future work pertain to the verification of the FKRS by studying other areas of manufacturing and inspection to deduce whether or not it is applicable to different commodities. Additionally there is the question of broadening the scope of the FKRS to address other areas of manufacturing knowledge and moving beyond commodities to include systems.

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