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ORIGINAL ARTICLE

Knowledge management to support product development in cold roll-forming environment

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Abstract Knowledge and information management has focused on how available knowledge is exploited to enhance organisational performance especially in marketing, costing, design, and manufacturing activities; however, there is limited information on how knowledge acquired during product development can be utilised to provide decision support throughout the product life cycle. Existing knowledge management systems do not seem to provide information on well-known manufacturing constraints and product attributes identified during product development. Secondly, such systems do not provide the means to identify, capture, formalise, present and utilise tacit knowledge which have a major impact on overall product development process. Consequently, knowledge and experiences gained from existing projects are sometimes poorly documented and therefore are not available for reuse in future projects. An organised transfer of knowledge from previous projects will no doubt enhance the quality, efficiency, cost, and time to market of new products and processes. The study carried out here has developed a knowledge management framework to support product development in a cold roll-forming manufacturing environment. Process modelling supported by Integrated Definition for Function Modeling methodology was applied to guide the identification of information and knowledge required to support product development and also for effective decision making in routine cold roll forming.

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1 Introduction

Global business enterprises are aware that accesses to essential information for business operations will enable them maintain competitive advantage and thereby stay one step ahead of other businesses. They therefore need to develop an effective knowledge management strategy both for the benefit of their employees and customers in order to support decision-making process and thereby remain sustainable. Knowledge management concept has increasingly become fashionable; however, many organisations are still unable to develop and leverage knowledge to enhance business performance. In most cases, organisational knowledge is fragmented, sometimes difficult to locate and therefore to leverage, share and reuse. Tacit knowledge exists in the minds of employees and therefore may not be available to process customer queries and enquiries. There is a need therefore to develop robust decision support systems to capture, store, share and leverage data, information and knowledge. Decision support systems will enable the transformation of tacit to implicit knowledge to be shared and leveraged for improved decision making. They will also enable the conversion of explicit to implicit knowledge a process of internalisation.

Figure 1 shows the concept of knowledge derived from theory, information and experience and extended to include wisdom—which is tacit in nature and could be described as successfully applied knowledge. For instance when an enterprise faces an order enquiry from customer, it should

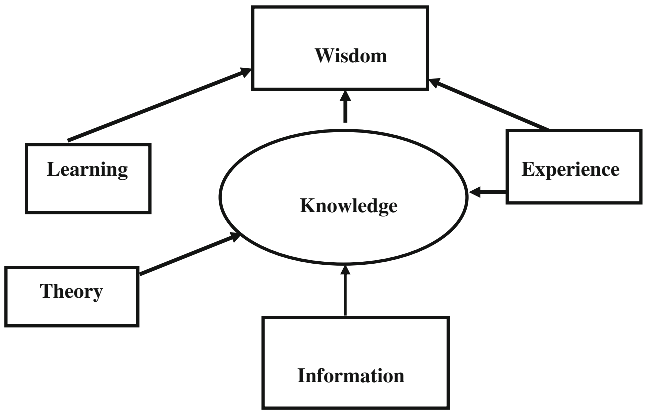

Fig. 1 Knowledge derived from theory, information and experience

be able to respond to the enquiry based on available information, theory and experience. When there is a repeat enquiry in the future, the enterprise should now be able to respond promptly based on what it has previously learned and also from a previous successfully applied knowledge

2 The significance of knowledge management in decision making

Experimental data is classed as raw or discerned elements and when these elements are patterned in a certain way, data becomes transformed into information. When rules or heuristics are applied to information, knowledge is then created as actionable information for producing some value-added benefit. The knowledge that is created and shared amongst organisational members can be categorised into two typical forms of knowledge—tacit and explicit [1].

Tacit knowledge is highly personal, context-specific, and therefore hard to formalise and communicate, this type of knowledge is stored in the human brain, such as in personal belief, expertise, perspective and values formed as a result of experience. On the other hand, explicit knowledge is defined as public knowledge and covers those aspects of knowledge that can be articulated in formal language and can be easily transmitted among individuals using information technology. Hansen [2] and Swan et al. [3] have outlined two basic strategies for managing knowledge as follows;

Codification strategy is based on codifying the knowledge and storing it in artefacts and databases where it can be accessed.

Personalisation strategy is where the knowledge is tied up to the persons who develop the knowledge and the sharing of that knowledge is achieved only by personal interactions.

Vast amounts of work have been carried out on how knowledge is utilised in each organisational activity; especially in marketing, costing, design, manufacture, etc.; however, there is limited research available on how knowledge from all the activities within product development can be collected and utilised to provide decision support throughout the product life cycle. Harris [4] recognises that knowledge in product development environment is considered to consist of four different activities;

Identification; the identification of knowledge required to develop new products, including product specifications, process, tooling, and material capabilities

Capture; how the knowledge is captured stored and retrieved.

Formalise and present; how knowledge can be formalised and presented to ensure its use in existing and future projects.

Utilisation; how the knowledge identified, captured and formalised can be integrated into products and decisions, and applied in other projects.

There are various perspectives of knowledge management; strategic knowledge management—deals with pinpointing opportunities to find, distribute and transfer knowledge related to long term goals of an organisation; tactical knowledge management finds, distributes and transfers knowledge for the medium term organisational goals; operational knowledge management is associated with daily or short-term operations [5]. The researchers developed a knowledge management framework demonstrating how design information and knowledge, manufacturing information and knowledge, operations information and knowledge and disposal information and knowledge all add up to shape the total product information for the product life cycle

Mustafa and Robert [6] have also developed a knowledge-based decision support system suitable for short-term scheduling in flexible manufacturing systems and strongly influenced by the tool management concept to provide a significant operational control tool for a wide range of machining cells, where a high level of flexibility is demanded. The benefits are more efficient cell utilisation, greater tool flow control and a dependable way of rapidly adjusting short-term production requirements. Development of a robust knowledge-based system to support the decision-making process is made necessary by the inability of decision makers to promptly address all the questions posed by potential customers at the enquiry stage and also to diagnose efficiently many of the malfunctions that arise at machine, cell, and entire system levels during manufacturing. More recently, Oduoza and Xiong [7] recognised that decision support systems required to process customer order enquiries would need to be equipped with sufficient information/knowledge of the manufacturing process to enable prompt and accurate response at the customer enquiry stage. The authors developed a decision support system framework to help SMEs achieve this objective.

2.1 Knowledge classifications within product development

In order to provide the appropriate knowledge to support product development, it is necessary to capture the appropriate knowledge, but what is knowledge? Many research projects have been carried out on this subject in relation to product development, however, there are several interpretations; knowledge is contextual and relational, people create knowledge as they interact in a social context and this knowledge in turn influences their behaviour, perception and cognition [8]. Knowledge has been defined by Davenport et al. [9] as information combined with experience, context, interpretation and reflection. Knowledge in terms of its creation and application has been defined by Liebowitz and Megbolugbe [10] as the key components for decision making and include data, information and knowledge, and individual organisational processes.

Data is raw or discerned elements and when these elements are patterned in a certain way, data is transformed into information. As rules or heuristics are applied to information, knowledge is then created as actionable information for producing some value-added benefit.

Engineers engaging in new product development bring to their work the formal and articulated expertise of their disciplines that have been socially constructed through time by particular professional or academic communities [11]. This knowledge initially frames their attention when they approach a problem; however, by making sense of a particular problem and of the information they encounter, and by taking action and revising their interpretations, they develop, analyse and create new knowledge. The knowledge that is created and shared amongst organisational members can be categorised into two typical forms of knowledge—tacit and explicit [1]. Mohrman et al. [11] explains that an organisation striving to derive competitive advantage from knowledge management needs to understand which elements of the organisation's processes affects its ability to acquire, create and apply knowledge. Knowledge helps to achieve improved business performance through product and process, and in this sense knowledge can be classified not only from the knowledge type (tacit and explicit) but also from the knowledge domain (product related and process related) [12]. Using this definition, knowledge has four classifications:

- *Tacit-product related*; know-how (human brain)
- *Tacit-process related*; human capability (human brain and culture),
- *Explicit-product related*; knowledge base (knowledge repository),
- *Explicit-process related*; workflow (workflow system).

One of the main challenges facing NPD organisations is how to acquire the required knowledge and manage sources of uncertainty in order to reduce the risk of failure of either the project or the resultant product [13]. Acquiring the necessary knowledge to address problems, uncertainties, and potential causes of failure, assumptions and the relationship between them is difficult, maintaining that knowledge for use in further projects is even more difficult because of the volume of knowledge created during each new product development project, and these include:

- *Project knowledge* related to the product, its production and use.
- *Technical knowledge* concerns the product, its parts, materials and associated technologies.
- *Procedural knowledge* concerns producing and using the product and acting in a project.
- *Organisational knowledge* concerning communication and collaboration.

Knowledge management literature is increasingly viewing IT as only one element of knowledge management: useful for storage of explicit knowledge, but less helpful for sharing tacit knowledge and stimulating the use and creation of knowledge. How to manage this knowledge has become an important issue in the research community and several authors have explored its nature, concepts, frameworks, architectures, methodologies, tools, functions, and as a result there are several frameworks that have been defined to manage knowledge. Knowledge in product development environment is considered to consist of four activities.

1. Identification; the identification of knowledge required to develop new products, including product specifications, process, tooling and material capabilities
2. Capture; how the knowledge is captured stored and retrieved.
3. Formalise and present; how knowledge can be formalised and presented to ensure its use in existing and future projects.
4. Utilisation; how the knowledge identified, captured and formalised can be integrated into products and decisions, and applied in other projects.

Figure 2 demonstrates information/knowledge management framework for a product life cycle showing all the sources and phases at which information about the product can be derived. Each of the phases has data and knowledge that describe the characteristics of that stage in the product life cycle. Such information are useful to both the design and manufacture engineers and also to the customer who would need a full understanding of product attributes to enable optimal design, manufacture and guaranteed product performance. At the order enquiry stage, a potential

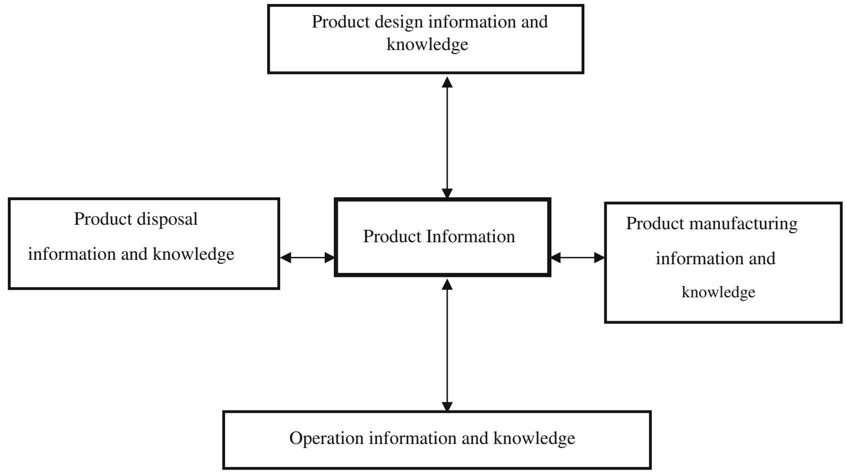

Fig. 2 Information and knowledge framework derived based on product life cycle

customer would be made aware of all relevant information including data on product functionality, durability, efficiency, energy requirement, etc., while the sales representative will negotiate on product specification and requirements, mode of operation, value added, cost price, delivery due date, maintenance requirements, etc. The sales department working in collaboration with the design/production department will also establish that they can deliver what has been promised to the customer within the due date. This will involve material requirement planning, supplier management, production scheduling and planning, outsourcing requirement, quality assurance etc. An order is confirmed only when there is an agreement/contract established between customer and the enterprise.

3 Methodology for framework development

Framework development for this study has been made possible by the application of the following various research methods.

(a) Literature review in order to understand the state of the art defining best practices in knowledge management, knowledge modelling and how they support lean thinking within the product development process.

(b) Case study to identify a set of evolving issues underpinning traditional product development achieved through interviews, case company documents and reference manuals from British and International standards sources.

(c) Process modelling using Integrated Definition for Function Modeling (IDEFO) is a technique which highlights interactions encountered within product development and also systematically and sequentially links activities in a logical sequence. The hierarchical nature of IDEFO facilitates the ability to construct (AS-IS) models that have a top-down representation and interpretation, but which are based on a bottom-up analysis approach. It begins with assembling basic information about the process and finally groups activities that are closely related or functionally similar out of which the hierarchy then emerges. Beginning with the top-most activity, the TO-BE functional structure can be described through a logical decomposition.

Due to space constraints, this paper has only described overall process level interactions within the product development process (Fig. 5) and the decomposition of the product and tool design (Fig. 6) using IDEFO methodology. IDEFO is a widely used technique for design and analysis of systems. Its use in improving the productivity and communication in computer-integrated manufacturing systems and as a tool for business process reengineering is widely documented [14, 15]. IDEFO methodology shows a systematic decomposition from parent to child with increasing level of detail. Dhokia et al. [16] applied IDEFO methodology to define the process control for cryogenic CNC machining of soft elastomers. Knowledge framework is proposed which identifies, captures, formalises and represents knowledge useful in product development. The identified knowledge will be implemented in a knowledge-based product development software tool developed using Delphi and database servers.

3.1 Case study

The company studied is a medium-sized enterprise based in the West Midlands of the UK with a long-established history of operation in the cold roll-forming industry. Cold roll forming fabricates forming flat metal strips into a variety of profile shapes by using forming rolls. The number of forming roll stations depends on the complexity of the profile to be produced, but generally most profiles produced use between five and 42 forming stations; cold roll-formed profiles differ from conventional hot rolled-profiles in a number of ways and include the following:

- Relatively thin material can be formed ranging in thickness from 0.5 to 9.0 mm;
- The wall thickness is standard throughout the length of the profile;
- The manner of fabrication and flexibility of shape formation.
- Assembly is possible using a Meccano type system—any number of holes can be pierced into the material prior to forming.
- Cold roll forming can be utilised for a variety of materials including steel, copper, brass, aluminium and titanium

Figure 3 shows a typical forming pass and a cross-section showing how the material behaves during forming. The strip passes between the top roll and the bottom roll, which are shaped to give the correct form required for that particular part of the forming process. It shows each element of the material, the edge of the strip, the radius and the bottom centre line all travelling through the forming rolls on a different plane to the *Z*-axis to which they originally started, as a result of various degrees of deformation. The edge of strip between points 1 and 2 begins to stretch in the *Z*-plane (longitudinal forming direction), as well as bending in the *YZ* plane in the positive *Y*-direction. The radius element undergoes a gradual bending in the *XY* plane thus forming the required radius, as the radius is formed plastic deformation of the material increases from point 1 to a maximum at point 3 where the material passes through the forming rolls. The baseline element undergoes to a somewhat increased degree the same deformation as the element in the radius.

3.2 Interaction of activities within the product development process

In order to give a clear description of the knowledge management framework, Fig. 4 describes activities within product development which have been subdivided into five process steps linked to the knowledge management cycle and clearly showing the identify, capture, formalise and present and utilise stages.

1. Identify: Product development stage describing the process map in order to identify AS-IS state.
2. Capture: Process mapping stage utilises process maps to identify and capture product development knowledge requirements
3. Formalise: Formalise knowledge in order to utilise in future product development projects.
4. Present: Manufacturing knowledge base and product data archive which create knowledge base to store and retrieve product development knowledge.
5. Knowledge-based product development framework: Knowledge-based product development system which identifies, captures, formalises and presents knowledge to be utilised for existing and future product development projects

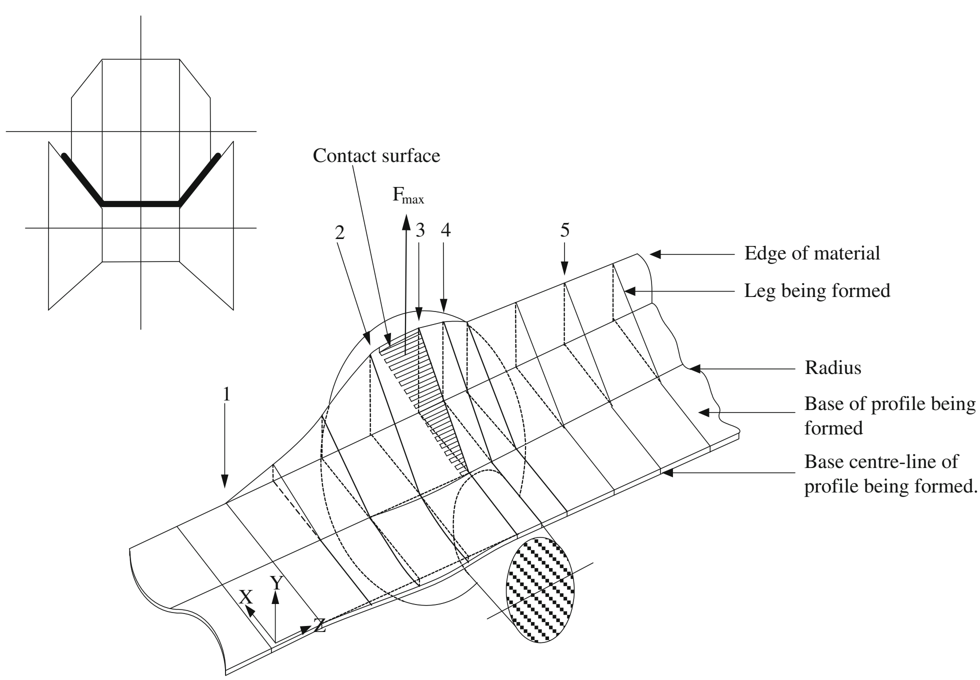

Fig. 3 Typical forming pass and cross section showing material behaviour during metal forming [18]

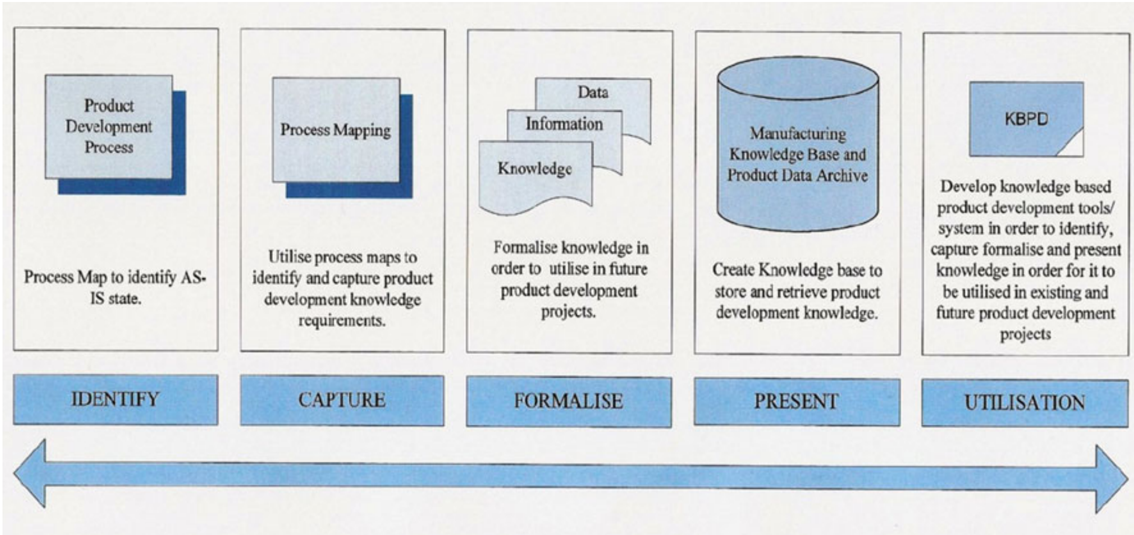

Fig. 4 Interactions of activities within the product development process

3.3 Process mapping and modelling in product development

Process mapping in product development identifies all the steps and decisions within a process expressed diagrammatically. It describes the following;

1. Flow of materials and information
2. Displays all the tasks contained within a process
3. Transformation of inputs into outputs
4. Decision-making process
5. Interrelationships and interdependence between process steps

Process mapping was used to identify activities, knowledge and information associated with the process in the current form in order to understand, identify and improve knowledge requirements for the process. Process mapping of the product development process showed that all activities can be summarised into three distinct categories:

- ○ Manufacturing knowledge; knowledge that affects the manufacturing capabilities of the process, product and process concerns and the resolution of those concerns.
- ○ Product data which includes the product module, manufacturing module, tooling module and product and manufacturing history.
- ○ A product (or service).

Kasvi et al. [17] went one stage further to subdivide these categories into five potential outputs:

- ○ A product (or service) delivered to an internal or external customer.
- ○ Project knowledge related to the product, its production and use.
- ○ Technical knowledge concerning the product, its parts and technologies.
- ○ Procedural knowledge associated with producing and using the product.
- ○ Organisational knowledge relevant for communication and collaboration.

These types of knowledge can be both process- and product-specific; however, for the purpose of this research, they have been identified as knowledge related to the product development process.

3.4 Process modelling using integration definition for function modelling

Process modelling will help the product development process in cold roll-forming since:

○ Designers do not fully understand the principles of the cold roll-forming process
○ Available knowledge is not always captured or represented in a format that is accessible by all concerned
○ Appropriate knowledge is not always available at the various stages of the new product development process
○ Key performance indicators do not measure process parameters such as cost, schedule, adherence and right first time.
○ Poor communication results in delays and capacity management

The process model enabled the identification of system controls, resources, tasks and process inputs and outputs for all activities and was carried out for each department. The product development process at Metsec PLC is divided into four phases: product information received from the customer relating to the product to be developed, the enquiry/ engineering change request phase, new product introduction phase, problems/concerns and resolutions phase with each phase defined as a knowledge group and the knowledge required by each phase was mapped using a hierarchical system.

The standard product development process as described in this study is made up seven activities; sales, production planning and purchasing, product and tool design, roll and tool manufacture, quality assurance, material supply and production. The process level of the model described in Fig. 5 gives a complete overview of all activities involved within the product development process, the model also illustrates information flows which are exchanged between the various activities, and also a representation of the information and knowledge that has an impact on decisions taken during the process activities. For instance, the output "production planning information for quotation" could affect the decision to quote or decline to quote for new product.

Overall, the sales activity/department based on customer enquiry/confirmed production order will trigger production planning and purchasing which in turn sends a message for product and tool design and prototype samples. This activity in turn would trigger the requirements for roll and tool manufacture within quality assurance guided and controlled by legislation, manufacturing constraints and organisational policy and final production of samples.

Product and tool design process shown in Fig. 6 have been chosen as a typical product development activity to demonstrate the sequence of activities and overall requirements associated with final prototype manufacture. It is the process of designing a product and associated tooling that meets the required customer specifications and describes most of the decisions taken about the product and process.

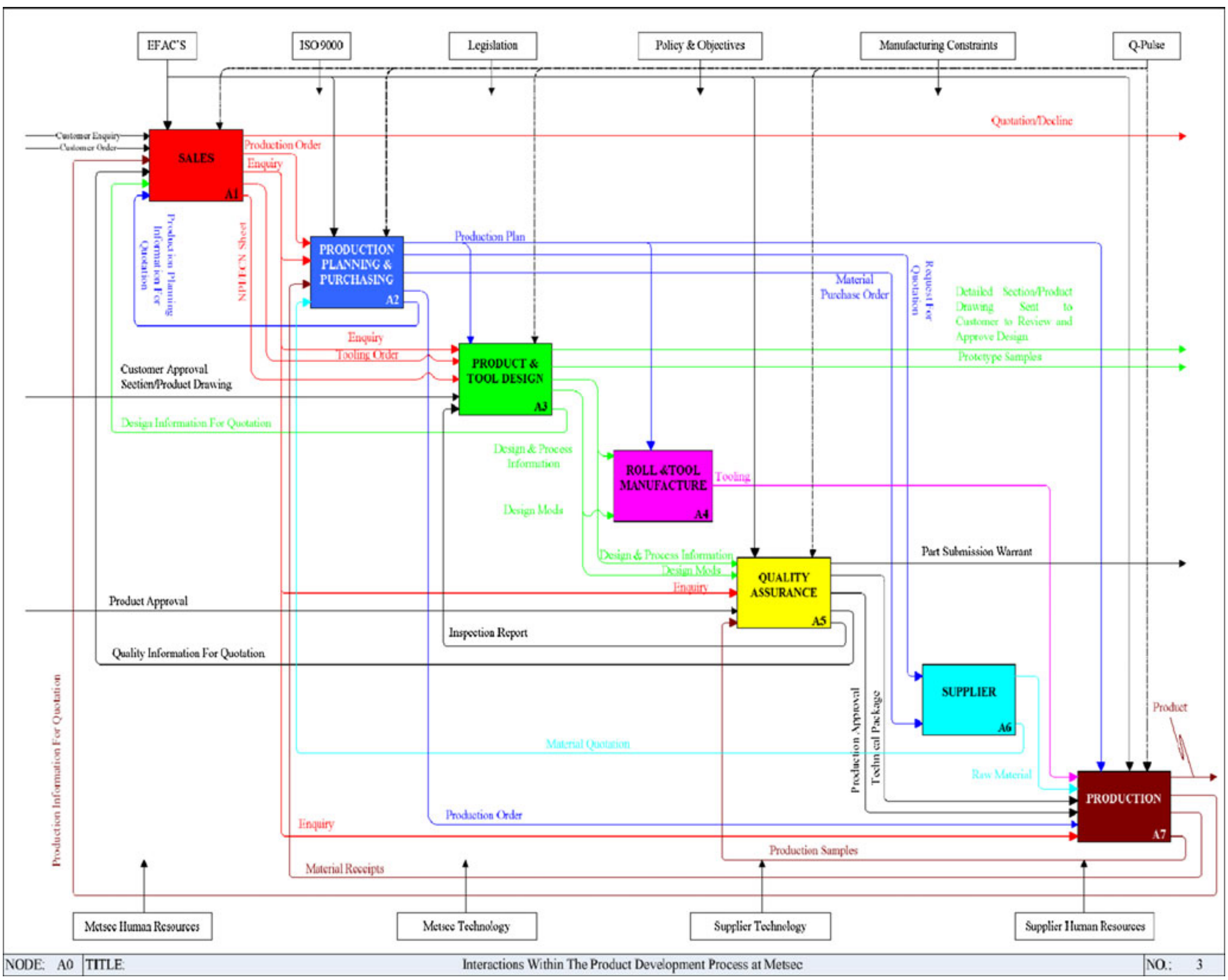

Fig. 5 Process level interactions within the product development process

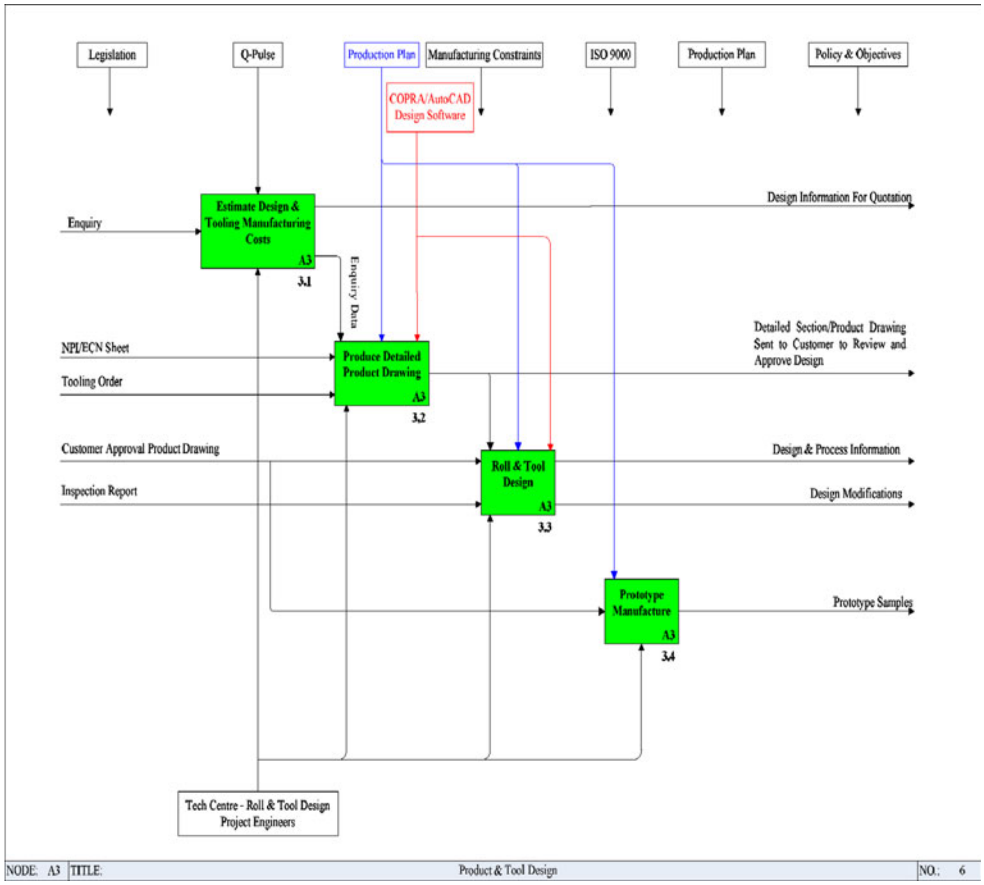

Fig. 6 Product and tool design process during cold roll forming

Figure 6 shows the product and tool design process in cold roll forming divided into four activities:

- Produce an estimate of design and tooling manufacturing costs (activity 3.1).
- Produce detailed product design (activity 3.2).
- Produce roll and tool design (activity 3.3)
- Prototype manufacture (activity 3.4)

This process commences as soon as an enquiry is received, and the project engineers review the relevant specifications taking into account; size, shape, material specification, structural properties required, tolerances, specific customer requirements and other features to determine how the product can be manufactured, and tooling, equipment and machinery required. This stage of the product development process is implemented in line with and controlled by legislation, production plan, manufacturing constraints and organisational policy/objectives.

4 Knowledge-based framework to support product development in cold roll-forming environment

Framework to support product development in a manufacturing environment is broken down into the following components; manufacturing knowledge base, system structure, product data module, product module, manufacturing module, tooling module, product manufacturing history, manufacturing knowledge base, manufacturing process capability and material attributes.

- Manufacturing knowledge-base system definition

  Throughout the product development process, project engineers have to make decisions which can affect the overall performance of the final product. Each decision is motivated by some level of justification and quite often, this is based on certain assumptions. Unfortunately, such decisions are sometimes not well documented, forgotten, based on illogical assumptions or misinterpreted. The manufacturing knowledge-base applicable in product development aims to capture decisions taken and their context in order to support effective decision making in future product development activities.
- Overall system structure

  In order to give a clear description of the system, it is necessary to subdivide it into its constituent parts as shown in Fig. 7; the system contains two main elements (databases): product data archive and a manufacture knowledge-base with each component linking to the

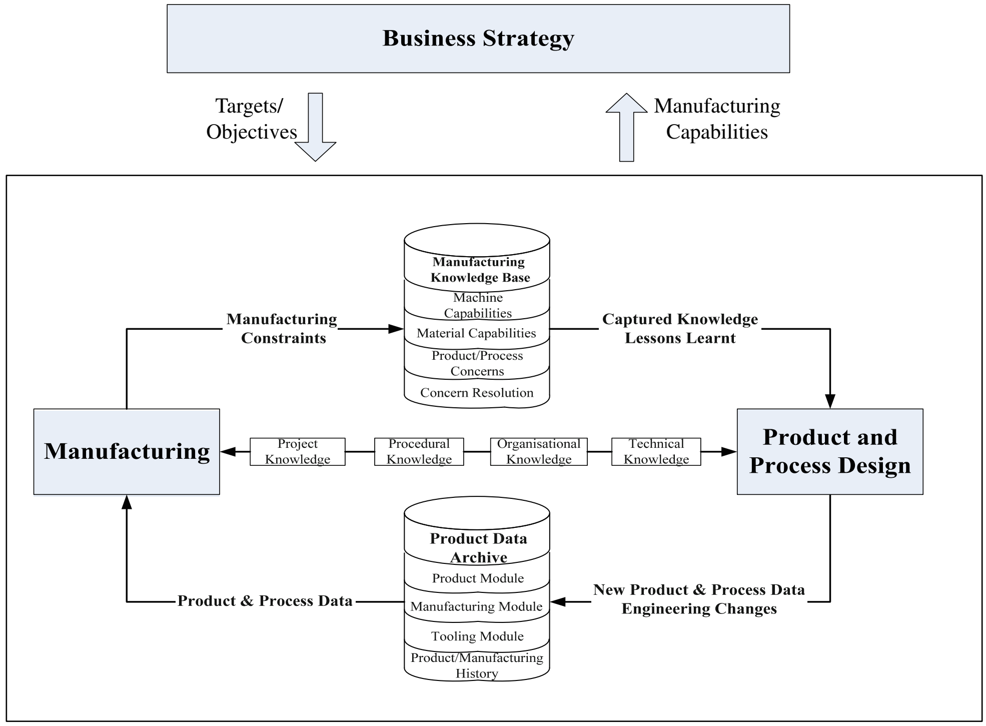

Fig. 7 Knowledge-based framework to support product development

manufacture and product/process design activities. The system is designed in such a way that end-users and project engineers can access the two databases from their work stations.

- Product data module

  The product data archive is a database providing information and knowledge required to support manufacturing activities. The archive contains the product, manufacture, and tooling modules and the product manufacturing history.

- Product module

  The product module details the product specifications and covers such elements as a product drawing, quality requirements, packing specifications, delivery requirements and material specifications with standards for revision and redesign.

- Manufacturing module

  Decision making during the product development process is often quite difficult as not all persons directly involved in the process have access to all the necessary information and knowledge related to the manufacturing process. To overcome this issue, all the necessary information relating to the manufacturing process such as process capabilities, capacity, machine sizes, machine speeds, standard operating procedures are assembled to create a manufacturing module. This module is positioned in the product data archive in the form of charts, spreadsheets and specifications. The manufacturing module, therefore, is the knowledge required to develop the manufacturing methods and processes for a new product.

- Tooling module

  The tooling module consists of a variety of tools including forming roll design, cut off tool designs, piercing tool designs, tool setting sheets, programmes for the production lines, and all the information necessary to produce tooling and set tooling on the machines.

- Product manufacturing history

  Product manufacturing history provides details of each product from the enquiry, through new product introduction and manufacture and details all engineering changes relating to the product.

- Manufacturing knowledge base

  The manufacturing knowledge base is a database with the information and knowledge required to support the product and process design activities. The database contains machine capabilities, material capabilities, product/process concerns and problem resolution. These elements are explained in more detail in the following subsections

- Machine capabilities:

  The manufacturing capabilities element of the manufacturing knowledge base is utilised to select suitable manufacturing equipment and production lines for the manufacture of a specific product. The selection of suitable manufacturing equipment is carried out in conjunction with the product module information.

- Material attributes:

  The material attributes element of the manufacturing knowledge base is probably the most important aspect to be considered when developing new product, selection of the wrong material could result in tooling being over or under engineered. Material properties in particular the yield strength can affect process design.

4.1 Application of knowledge-based product development system in cold roll-forming environment

This section describes how the knowledge management framework can support cold roll-forming process in a manufacturing environment. In the case company, Metsec, all documents relating to cold roll-forming process are stored according to document number derived from part number and document type. For instance number 13942 IS shows that number 13942 refers to the product while "IS" refers to the document type—inspection sheet. Figure 8 is a screen shot of document types stored within the product data archive. The information about cold roll forming is available on four status levels; active–current document revision, obsolete documents (stored to create product/ manufacturing history model), inactive (made inactive due product replacement), and draft (document being amended due to engineering change).

Figure 9 shows a screen shot of document list screen. Here, the document is searched by document type, part number, document number, revision level, document owner, customer, product market sector or type of product.

All the above information from the product data archive are fed into the manufacturing knowledge base where the information provided will facilitate the manufacturing process as well as resolve any concerns. Lessons learnt are then used to support decision making during the product development process and for continuous improvement.

5 Conclusions

This study has developed a knowledge-based management system that adapts knowledge management concepts into product development where the major objectives were to provide decision support to help engineers through the utilisation of captured knowledge, minimise costs, achieve quality assurance and shorten time to market. Product development activities must be formalised and structured in such a way that any engineering decisions taken are based on proven knowledge and experience. Failure to apply proven knowledge and experience could result in product and process redesign, which would be seen as non-value adding and waste of valuable resource. As such, there is a need for a knowledge-based framework to support product development, which includes a knowledge-based system developed from an organisation's knowledge and past experience captured in a database. This process involves the identification, capture, formalisation and presentation of knowledge and its utilisation to support effective decision making within a product development environment.

The conclusions, drawn from this study, are:

1. Literature review, highlighted that very little research has been carried out on how information and knowl-

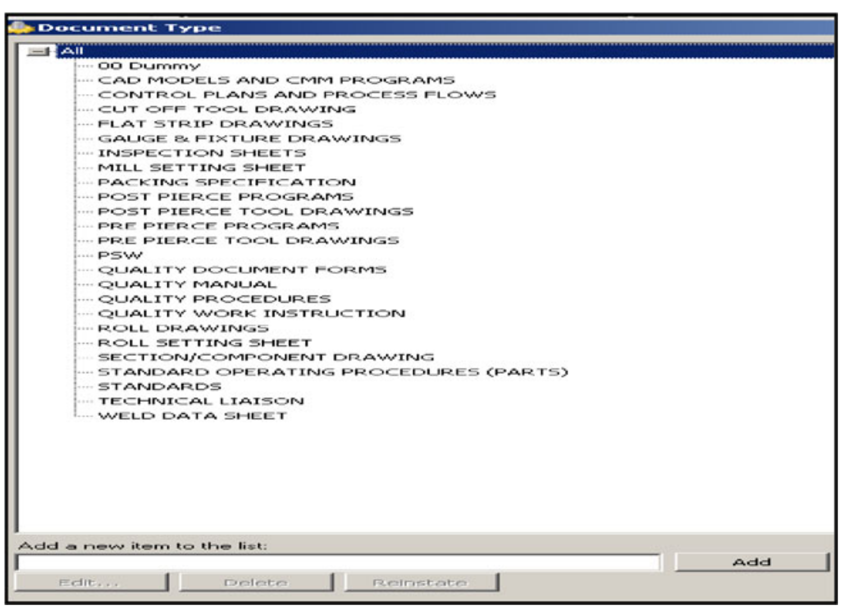

Fig. 8 Screen shot of document types stored within the product data archive

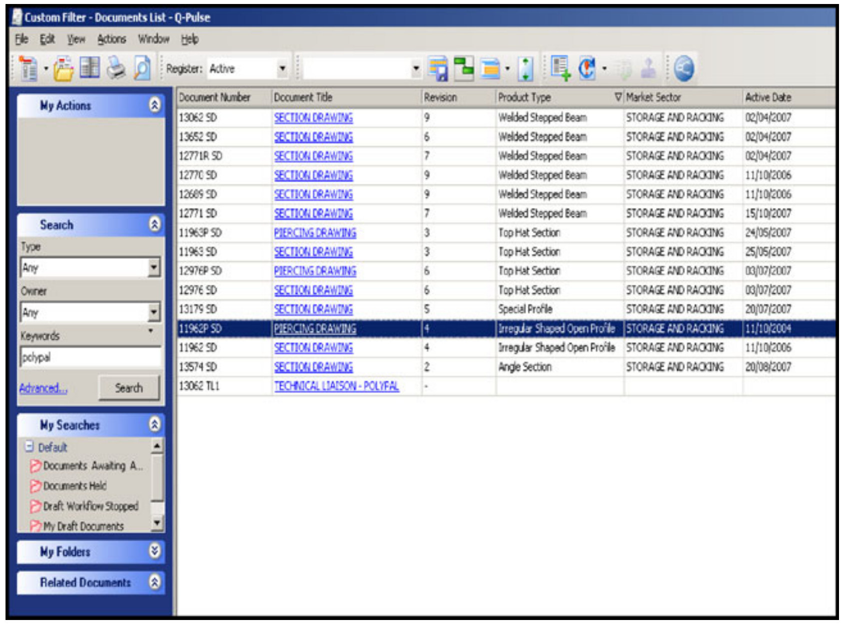

Fig. 9 Screen shot of document list screen

edge can be utilised to support the product development process, and showed that the lack of exploitation of knowledge has a major impact on overall product development performance. Knowledge and experiences gained from existing projects are often poorly documented and scarcely transferred to future projects. The study has defined a knowledge-based product development framework to support product development and outlined the necessary steps required to implement the framework. The process modelling using IDEF0 proved to be an understandable and easy-to-use modelling technique to identify the information and knowledge required during the product development process. The process model highlighted the need to formalise the product development process and the importance of capturing and defining only value-adding activities. The process modelling also identified that decisions taken during the product development process need to be supported by proven engineering knowledge and experience, which needs to be identified, captured, formalised and presented in a way that will allow its utilisation in future product development programmes.

2. In the case study, four key phases of the product development process at Metsec PLC were defined such as obtaining product information, enquiry/engineering change request, new product introduction/engineering change note and problem/concerns resolution. Furthermore, the knowledge required by each phase was identified and mapped. The findings showed that the knowledge identified is of critical importance and influences decision making with regard to manufacturing design, selection of production equipment, selection of process parameters, tool design, fabrication and assembly. However, the knowledge required to support these activities is distributed throughout the organisation and must be captured, formalised and presented for future use in order to support effective decision making.

Overall, the knowledge-based product development system gave an overview of product data archive and manufacturing knowledge-base system developed to support the framework. The advantages of the framework are:

(a) Improved communication and collaboration between the various departments and functions associated with the product development process.
(b) Standardised knowledge required within the product development process in a format that can be interpreted and used by all.
(c) Improved sharing and provision of data and knowledge within the organisation.
(d) Activities within product development are carried out according to limitations of the process, resources and material.
(e) Reduction in product and process problems/concerns by eliminating most feedbacks and iterations caused by not sharing knowledge and information.
(f) Improved delivery performance (right first time) of product, tooling and manufacturing processes.

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