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A WWW-Based Information Management System for Rapid and Integrated Mould Product Development

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As efficient management of product information that covers the whole life cycle is critical to the enhancement of corporate competitiveness. This paper explores the design and development of a World Wide Web (WWW) based product development information management system for a cross-nation manufacturing corporation that is headed by a holding company in Christchurch, New Zealand. Since product data are often managed in a distributed computing environment, common object request broker architecture (CORBA) is employed to ensure the interoperability among distributed information objects. A STEP-based information framework is proposed to preserve the openness of the system. This WWW-based information management system is discussed in this paper, which includes two major components:

1. WWW-based product design and development distributed object-oriented databases and knowledge bases.

2. A WWW-based integrated system platform. Several submodels are introduced, which include an object-oriented database structure, a WWW-based information management system, a WWW database tool, an information access tool, the incremental process-planning method, a cost-optimisation model and an integrated software platform for the integration of CAD, CAPP, CAM, and a WWW-based information management system.

Keywords: Manufacturing information sysem; Object-oriented database (OODB); Product development management; WWW

1. Introduction

The widespread use of the Internet and World Wide Web (WWW) has had a significant effect on the method of inter and intra communication of a manufacturing company. Those efficient inter and intra net communication tools have helped manufacturing companies to reduce production cost, shorten the lead time to market, implement globalisation and concurrent engineering, and make them rethink all of these issues which are at the heart of competitive manufacturing. In order to enhance competitive ability, manufacturing companies must undergo great changes, especially those with globally distributed "partners". It has been widely recognised that having the capability of rapid product development is a key issue in enhancing corporate competitiveness. This may require the support of information systems, especially for companies whose business partners are distributed across the globe. A manufacturing corporation, which is managed by a holding company in Christchurch, New Zealand, is such an international manufacturing group. It has subbranches in Australia and Malaysia. For this company, the integration of various information systems through WWW is a holistic approach to manage complexity in its product design, development, manufacture, and distribution, so that it can respond quickly to customers' requirements.

At present, this company is facing increasing demand by customers for product variety, low cost, and short delivery time. However, there are some hurdles that prevent the company from meeting these customer requirements. First, at different stages of its tool/mould design and making process, discussions are required so that a tool/mould can be developed to conform with the various manufacturing constraints. These discussions are normally among engineers in the company's branches located in different countries through documented letters or e-mail. They are time-consuming and inconvenient to manage. Secondly, many important tool/mould-making process data are not recorded and these data are lost after projects have been finished for a while. The information loss in tool/mould-making, and the delays, errors and long procedures to arrive at product definitions are also caused by lack of supporting information. Sometimes, the same product has to be redesigned because of missing records.

Hence, a product information management system, which is able to record various data through the whole product development cycle and simultaneously to provide an integrated platform for information sharing among different partners or departments, is very important for the company in order to

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shorten its product development cycle and reduce production cost. A WWW-based information management system for rapid and integrated product development has consequently been developed. It consists of several distributed databases with object-oriented structure to store all the tool/mould-making and product development information. Through the intra/internets, all the information is published on the Web. This provides an easy way of accessing all the necessary information throughout the whole life cycle of the product development process. However, information accessibility does not mean that all the information can be used to support the design and manufacturing processes directly. Sometimes people will be confused when they face so much information and do not know what is useful to them. Therefore, to integrate the available information is a key step for the different partners in the development cycle of a product to share the information effectively [1]. In order to solve this problem, a great effort has been made to develop an integrated information sharing platform in a computer network environment. Some prototypes have been developed, e.g. [1–5]. However, these prototypes have some limitations to their applications, especially in a WWW environment. The first is the requirement for a formal WWW-based distributed database structure with suitable product data models for a manufacturing company, i.e. a decision must be made about what information should be shared and how to represent and record the information for product development and for the relevant tool/mould-making processes. In practice, the company production manager usually makes decisions about what information is required, when it is required and how it will be used, depending on the context of the current problem [4]. The data structure of the product information management system may also vary with the structure and culture of the company. Considering these questions in advance, and collecting all the critical pieces of information for the decision-making, and finally integrating the information and decisions into a product model, is usually difficult [5].

The critical issues in managing and sharing information for a cross-nation corporation are:

1. How to build the databases/knowledge bases with WWW publishing and real-time information accessing mechanisms in a user-friendly operating environment.
2. How to develop a system, which can capture related data and knowledge in real-time and share this data and knowledge to support the product development processes.
3. How to develop a platform to integrate the information management system with the software packages that are employed at different stages of the product development process.

Boynton [4] suggested that the important issue for developing a design information system to support company-wide design is not the product modelling aspect, but the information dissemination aspect.

This paper will discuss the problems mentioned above by presenting a WWW-based integrated product development information management system. This system can support product design and manufacturing processes directly in a WWW environment.

2. The System Framework

The overall structure of the WWW-based information management system is shown in Figure 1.

The system was mainly built in two parts, namely, a WWW-based information management system and an integrated platform. The first part includes distributed relational databases, STEP databases and knowledge bases, WWW database tool (WDT), and user interfaces for the different departments of the company, to manage the product information. The second part includes a collaborative communication tool, an information access tool, an incremental process planning (IPP) user interface and a cost optimisation model. This platform is developed by using current WWW development tools (i.e. visual Interdev, JavaScript). The application tools are developed as agents that run in a distributed environment.

The distributed relational databases and knowledge bases record all the data and knowledge gathered from the previous product developments in the company. The user interfaces were developed and can be viewed through Internet Explorer, which can be used by the different departments to change and manage the databases and knowledge bases on the intra- or internet. The integrated platform was developed to integrate CAD, CAM, computer simulation packages, and the WWW-based information management system in order to support so-called "smart drawing" and "smart manufacturing". An incremental process planning user interface together with the cost optimisation model were developed to select or plan suitable manufacturing processes for design features from a cost optimisation point of view. The multi-object optimisation algorithm for cost has been discussed in [6]. The information access tool was designed as a search tool to access all related databases and knowledge bases according to the requirements of the integrated platform. Some of the major models or tools mentioned above will be discussed further in the paper.

3. WWW-Based Information Management System

The current design and manufacturing practice in a manufacturing company often involves complicated communication, interaction, and data exchange between individuals inside or outside the company, e.g. engineers, suppliers, and customers. For

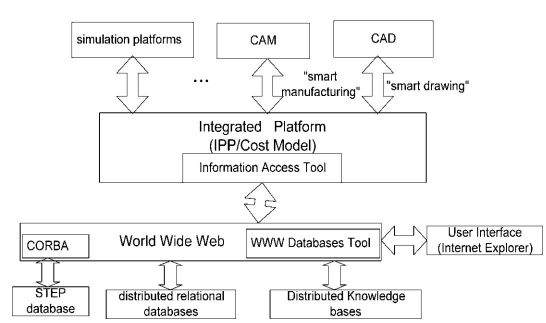

Fig. 1. Framework of the WWW-based integrated product development information management system.

example, to design a part, a design engineer may need to access information on process planning to determine the production requirements or the product data management system to find a similar part and the revision levels. The challenge is how to create the related information and knowledge so that it can be shared in real-time. The development of intra/internet communication technology has provided a feasible solution to company-wide knowledge sharing and real-time communication. Hence, a WWW-based distributed database and knowledge-base management system is a fundamental part of the information integration in a manufacturing company.

3.1 Product Data Model

When data is added to a database, it becomes a model of that part to which the data refers. As there is an increased need for up-to-date information, an automated database management system (DBMS) was developed based on groups of formalised data modelling rules called product data models. Nowadays, a product data model is usually object oriented. The EXPRESS data modelling language in STEP has provided a useful tool to represent various product data. STEP is an international standard architecture for modelling a product. Hence, STEP and the object oriented modelling method were used in this project [7]. Candadai [8] reported another application of STEP to build a product data model. However, STEP is a developing data modelling architecture and it still has some limitations for product data modelling, such as instance data or type data [1]. It does not include a mechanism for using classification and inheritance for modelling products in a particular company [9]. Because of the limitations of STEP, the data model discussed in this paper was built by both the STEP modelling method and the traditional relational data modelling technique. For data that STEP cannot describe, we created a related object using the object-oriented method and connected it to its STEP object by using relationships. One of the advantages of using an object-oriented database (OODB) is that all the data in the object can be extracted by object identity or found by key. The newly created objects can also be stored. The structure of the OODBS and the STEP database will be discussed in the next section. All data in an object can be read easily and recorded using object oriented programming languages (OOPLs) such as EXPRESS, C++ or JAVA.

3.2 Product Information Management System

3.2.1 OODBMS Structure

Figure 2 shows the framework of the distributed object-oriented information management system for plastic mould design and manufacturing, which was developed for a manufacturing company in New Zealand. It represents a generic structure of an object oriented database management system (OODBMS) in the system. As shown in Fig. 2, this information system includes product information, tool information, manufacturing information, and supplier information. These structures of the information systems are built according to the requirements and the structures of the company, i.e. the product design

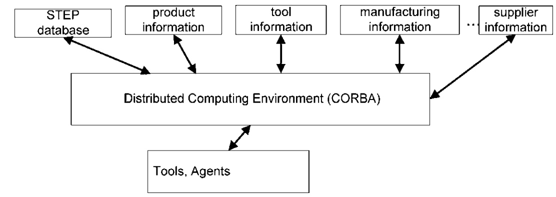

Fig. 2. Distributed information structure for a plastic mould design and manufacturing.

database contains all the design specifications, geometric information and other information (i.e. manufacturability, cost). These information systems were built on an object oriented database structure and managed by using CORBA under a distributed computing environment. Detailed information about how to use CORBA to integrate structured databases in multi-operation systems and multi-language environments are addressed well in [10–12]. Hence, the distributed information management system eliminates the need to follow the predefined access paths to reach the target data, and makes the data access more flexible, even under different operation systems. The structure of the information system facilitates uninterrupted queries and is well suited to the manufacturing environment. All the databases in the system were developed in an ORACLE software package. ORACLE supports large databases with multi-user accesses, which is suitable for a distributed multi-user system. All the data in ORACLE databases can be accessed via ODBC and JDBC interfaces by using object oriented programming languages (OOPLs) such as Visual C++, Borland Delphi or JAVA. This flexibly programmable interfacing ability makes sure that the databases can be accessed more easily and can be further developed.

The object hierarchy of an object-oriented database that we developed for a mould/tool design and manufacturing company in Christchurch is shown in Fig. 3, which contains the detailed contents of the data class that was created, based on the structure of the information in different departments. To support various types of data in the industry, different types of object were developed. The structure of these objects and the relationships between the objects are very important for both the database management system and the system integration. For instance, it is usual that certain product design knowledge in a knowledge base must be associated with a product number or other identity number, so that it can be correctly and effectively retrieved during production. Figure 3 also shows several custom interface objects, such as product interface, tool interface, and manufacture interface. These interface objects were developed for the different departments in a company by using Internet Explorer to access the databases according to predefined privileges.

3.2.2 STEP Database Structure

Product data are an important factor that must be considered when deciding dynamic changes of the product development processes. Under the WWW environment, as different CAD/CAM systems are employed by companies, the data sharing or exchange between different systems is very important for achieving rapid product development. Databases

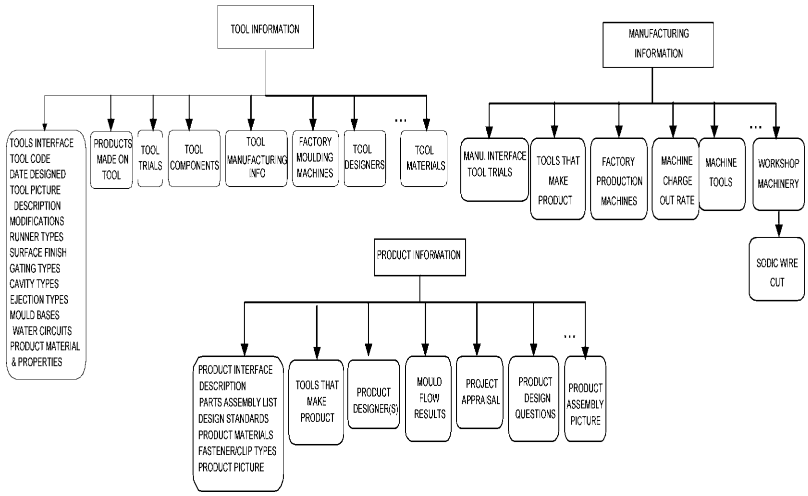

Fig. 3. The structure of an OODBMS for mould product development.

based on STEP can support product data exchange among heterogeneous CAD/CAM systems. Proprietary file formats are not suitable for data exchange among different systems. STEP is promising, in that it is emerging as a new standard for the exchange of product data throughout the whole life cycle of products in distributed network environments. Xie et al. [6] and Tuet et al. [13] presented a STEP-based information modelling framework to cover the whole life cycle of mould part design and manufacturing processes. This information modelling framework which is called a step-structure information modelling framework contains four top-down information layers, which are the knowledge layer, parts layer, feature layer, and parametric layer. The parametric layer contains the geometric data of the shape feature of the mould parts and tool features. The feature layer contains all the feature information, which includes not only the feature information (i.e. attributes) but also the relationships with other feature-level information objects and objects defined by users. The part layer contains all the part information that includes feature information and relationships among different part-level information objects. The knowledge layer contains not only the part information, but also “knowledge related” information objects and a reference engine. The knowledge in the knowledge layer is extracted from the part layer and the feature layer. This framework has been used for information modelling of sheet metal parts and can be extended easily for other product development processes. A knowledge base based on the information framework above, is built for rapid mould/tool product development. Figure 4 shows a product information form that is based on the STEP-based information framework structure. Product designers and manufacturers can use this form to review and modify related information through Internet Explorer after it is published on the World Wide Web.

3.3 WWW Database Tool

Although the database technology has been evolving for a long time, an effective way to access the databases through the intra/internets so that the data in the databases can be shared on a global scale is still missing [9]. Hence, it is necessary to develop a WWW database tool (WDT) that can publish and manage all the relational data or knowledge bases over the Web. The WDT developed by our group can be used to publish and manage the databases in a distributed WWW environment automatically.

As shown in Fig. 5, the WDT was developed by using several computer languages, which include those programming languages on the Web page, such as JavaScript, Hypertext Markup language (HTML), Web authoring language, and Common Gateway Interface (CGI). CGI provides a standard protocol for communication between the client browser and the Web server. It was used to develop the dynamic data linkers between the Web server and the database management system for the different departments, to access the databases through the intra/internets. HTML is used to design the Web pages. Visual C++ was used as a programming platform for developing the WDT. Based on this platform, the programming entities, such as CGI linkers and HTML web pages, were coded and linked together. The WDT context classes were also developed using C++ and the WDT proxy.

4. WWW-Based Integrated System Platform

Figure 6 shows the integrated platform, which is an intermediate layer between the WWW information management systems and the different software packages that are integrated into the platform as agents. This integrated platform is responsible for production optimisation and real-time information retrieval between the WWW-based information management system and the agents.

This platform consists of several major components, i.e. a collaborative communication tool (CCT), an incremental process planning (IPP) user interface, a production cost optimisation model and an information access tool (IAT). By using this platform, all the software packages, IPP user interface, cost model and databases as shown in Fig. 6 can be accessed directly through the intra/internets.

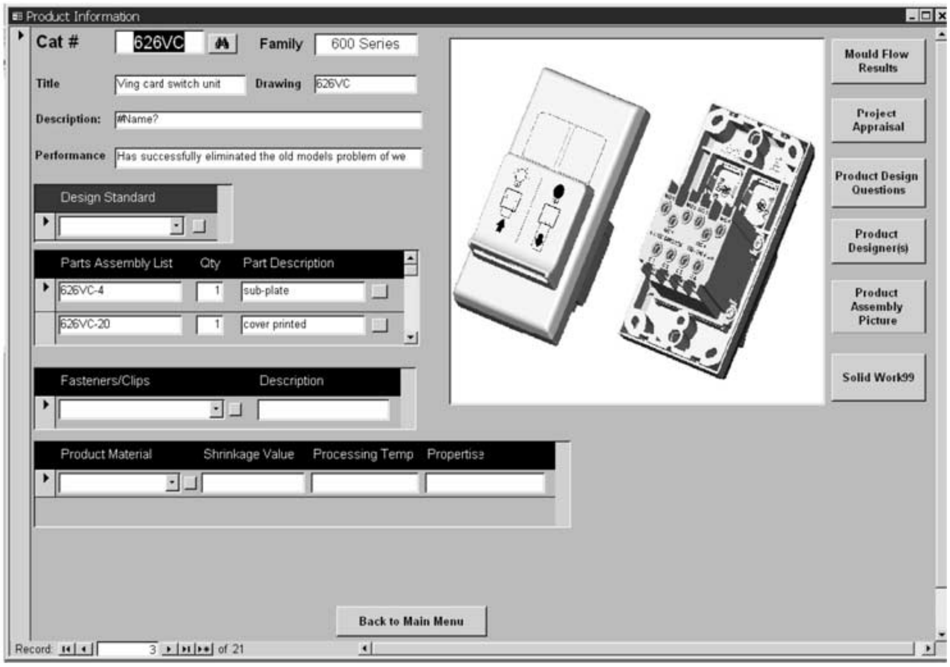

Fig. 4. A knowledge-based example for mould/tool product design/manufacturing.

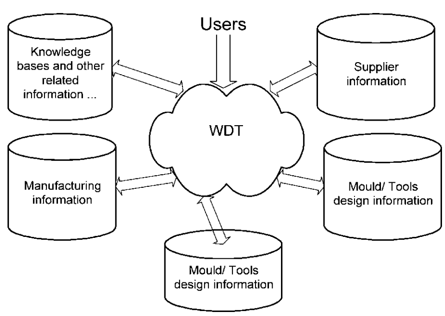

Fig. 5. The WWW database tool (WDT) developed by using multi-computer languages.

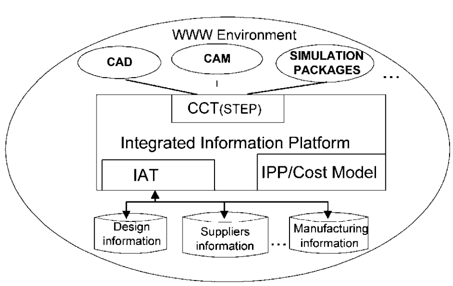

Fig. 6. The structure of the WWW-based integrated information management system.

In this platform, each agent manager is implemented as a CORBA object and exports certain common methods as an external interface. Other functions can be implemented in the same way. For example, the detailed implementation method for a WWW data retrieval tool is shown as follows:

1. First define a CORBA object named Retrieve using CORBA IDL, its IDL description is as follows:

   Interface Retrieve {
   Void retrievedata(in string dataFileName, in string schemaName, in string ProductName, out string productspecification, out string dataFile, out string schemaFile, out string ProductContent)
   }

   Users can use function "retrievedata" to obtain the information required through product name, dataFilename, etc. An interface can be provided for users to input all the information for data search. The code can be written in C++.
2. Define the interface to the native code in the JAVA program, create corresponding.h file using JDK tool java.h. Then, implement the native function using C++ and compile the C++ code into DLL. When the DLL is loaded, the JAVA program can invoke the function.

4.1 IAT and CCT

Many applications enabled by the WWW, such as virtual university, distance learning, electronic commerce, information gathering and filtering, require tools for supporting the effective retrieval of information. The goal of designing IAT is to provide a means for users to search on-line for the data or knowledge according to a particular information enquiry in a product development process, and to communicate in real-time with the information management systems via the intra/internets. It was designed to be able to control, retrieve and search for the data in real-time through the intra/internets. The collaborative communication tool (CCT) was designed for transferring messages, events and data dynamically in a WWW environment among the software packages, IPP user interface and cost model.

There still exist some problems when developing an IAT which can support concurrent multi-user applications, e.g. collaborative database accessing, distributed object technology, information retrieval, distributed services, and resources management. These problems will influence the communication speed between the OODBMS and the integrated platform. The search speed of IAT is very important for the system since a lower search speed will influence the "dynamic characteristics" of the overall system integration. To accelerate the search speed, the query-oriented search method and the user-oriented search method were combined to develop the searching model in this system.

As mentioned earlier in this section, the CCT was a tool to facilitate and manage the real-time communications in a WWW environment between the engineering software packages, the IPP interface and the cost optimisation model. It can capture data, messages, or events dynamically and transfer them to the different engineering software packages, the IPP user interface, and the cost model real-time through an intra/internet. For example, if a designer adds a feature to a product design by using a CAD package (e.g. ProEngineer), the CCT can, through the intra/internet, capture this change and transfer it to other software models for further processing, e.g. the IPP user interface, CAM package or computer simulation package. The feedback can also be sent back to the design platform by the CCT. The CCT was developed by using the ProEngineer application programming toolkit (APT). The API of the ProEngineer toolkit consists of a library of functions, which were written in the C programming language. These functions can be incorporated easily in a program, which is written in C++. Since the CCT was developed on the ProEngineer APT platform, it can run on the ProEngineer operating platform.

4.2 Incremental Process Planning (IPP)

Tu et al. [7] presented an incremental product design and process-planning strategy for developing customised products or one-of-a-kind products. This strategy suggests that the company should plan the manufacturing process for each new or modified feature, which is added to the design of a product. The features, which cannot be manufactured feasibly or economically, should be changed or given up. They also suggested that because of a great variety of one-of-a-kind products and a high demand from the customer for a lower cost and a shorter delivery time, history data and knowledge reuse is necessary for a one-of-a-kind production (OKP) company to develop an OKP product successfully.

The IPP method also plays an important role in a WWW-based product development information management system, since the IPP strategy can help a manufacturing company to avoid production rework, and the history data and knowledge reuse has been shown to be an effective way to cut the product development cost and lead time [7]. The IPP user interface was developed for users to plan the manufacturing processes according to the IPP manufacturing strategy. It interacts and communicates with the data or knowledge bases and other models via intra/internets. The information flows among these models are shown in Fig. 7. In Fig. 7, the IPP user interface

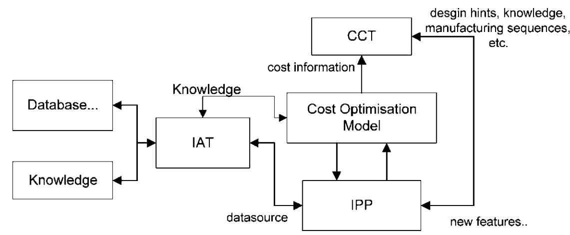

Fig. 7. Information flows among the different models.

can obtain information from the WWW database management system, and send the possible manufacturing process plans to the cost optimisation model. After obtaining the optimisation result from the cost optimisation model, it can save the result in the databases. The IPP user interface can also communicate dynamically with the CAD and CAM packages through the CCT.

4.3 Cost Optimisation Model

The cost optimisation model was developed to reduce the product development cost through optimally or rationally scheduling the production operations on the shop floor. The inputs to this model are possible manufacturing process plans, which were planned by the process planning engineers by using the IPP user interface, and the capacity production resources available, which are normally recorded in a company's MRP system. The outputs from the cost optimisation model are a production schedule and a relevant cost estimate. The cost optimisation model was developed by using a case-based reasoning method, probabilistic dynamic programming, and computer simulation technology. For different products, the cost optimisation function may be different. However, the optimisation algorithm will have something in common, i.e. the cost optimisation model of cutting sheet metal products has been transferred to a common mathematical model of an NP completeness problem [6]. A mathematical model has been built for mould products cost estimation and optimisation. The basic cost of a product can be estimated and optimised when considering several possible manufacturing plans. The model can also send the design engineer a cost estimate quickly by using a case reasoning method to search for a similar solution from the databases via the intra/internet. It can also derive a cost estimate and a production schedule for a designed feature by using a probabilistic dynamic programming technique and computer simulation technology to schedule and manufacture the part or the product virtually [7].

5. System Implementation

Key challenges still exist in the development of WWW-based support systems, e.g. for an intelligent search engine, Web accessibility, collaborative and distributed application environment, scalability of Web servers, intelligent agents, server security, the limitations of the programming languages such as HTML, XML. All these challenges have to be considered while developing a WWW-based information management system for rapid and integrated product development. They will influence the functionality, reliability, and the realisation of the integrated system. In this section, we aim to demonstrate the main functions and the feasibility of the system by briefly describing a prototype system, which was developed for a New Zealand manufacturing company to support their mould product development.

Figure 8 shows the overall structure of the prototype system, which includes several components. This system can be extended and new functions can be added and integrated into the system easily through the agent technology. A CNC machine simulation package called Virtual NC was used to develop the manufacturability test bed, and a shop floor simulation package called ProModel was used to develop the virtual manufacturing shop floor for the cost optimisation model. These software packages can be used as real-time simulation packages for the product manufacturing process. The simulation result will be recorded in the WWW-based information system. This information can be retrieved for decision support for similar product development. A Web client, called Pro/INTRALINK in ProEngineer, makes it possible to access or manipulate the product data through a Web. Specific interfaces have been designed for people in different departments to activate functions that are provided by the integrated platform, i.e. change/search information or see the manufacturing simulation process. C++ is employed to code all the software models described in the paper, such as the IPP user interface, the WDT, and the CCT. These tools can be used to locate related information and can support intelligent searching functions. Using the integrated platform that contains these tools, the WWW-based information management system can be used in different stages of the product development processes, i.e. at an earlier design stage, the designer can search for existing WWW-based database/knowledge bases for similar products through a WWW-based interface that we designed for product designers. This knowledge or information (i.e. cost information, lead time, manufacturing ability) can help the designer to make decisions. The integrated platform supported by the WWW-based information management system can also be used as a concurrent product development platform through information integration and sharing at each stage of the product development processes. Instead of following the traditional sequentially arranged product development process, the system can incorporate considerations such as manufacturability, assemblability, serviceability, and recyclability into the product design or planning stage. Time-consuming reworks can be avoided, and thus the product development time or cost can be cut.

6. Conclusions

It has been recognised that the development of WWW technology provides an efficient and revolutionary tool to help a manufacturing company to change their way of managing and integrating information flows in an enterprise. This paper presented a framework for developing a WWW-based information management system for rapid and integrated product development. A prototype based on this framework has been developed and implemented in a New Zealand manufacturing company to support their mould product development. The structure of the proposed system illustrates two aspects: the basic structure of information sharing, and the integrated environment for task execution (i.e. optimisation). Our initial experiments during the development of this system with its database management system, automatic e-mail transfer system, manufacturing workflow systems, and the cost optimisation model, have been very encouraging. The manufacturing company involved in this project has adopted the system in the mould/tool products development process. Problems existing in the company, mentioned in Section 1, have been solved. The product development cost has been greatly cut and product development lead time has been shortened.

Acknowledgement

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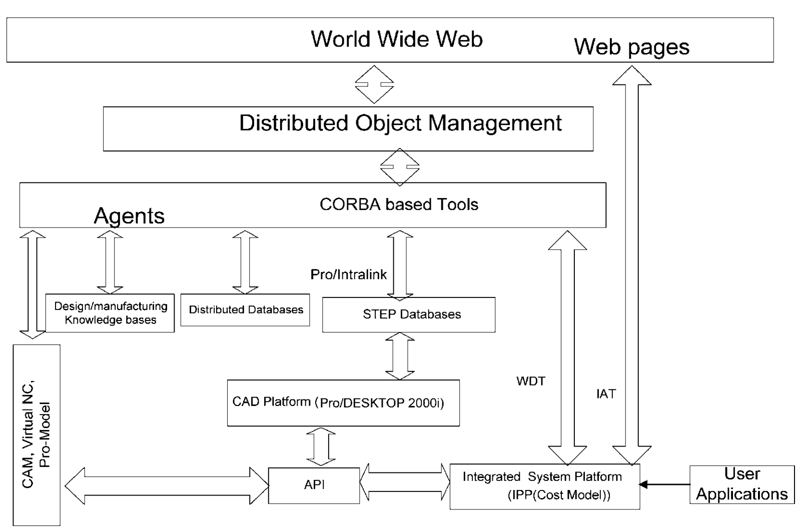

Fig. 8. A WWW-based integrated information management system for mould products design and manufacturing.

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