Application of object-oriented framework on manufacturing domain

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Abstract

Purpose – The purpose of this paper is to address the capture and documentation of essential design for manufacture (DFM) pieces of information to make design decisions. Essential manufacturing information is that which can affect the fulfilment of functional requirements and product constraints. The hierarchical structure of the main components for the open architecture-process planning model (PPM), manufacturing activity model (MAM) and manufacturing resource model (MRM) are discussed. The aim of the approach is to define manufacturing knowledge structures and develop a knowledge-based application for DFM.

Design/methodology/approach – This work addresses the capture and documentation of essential DFM pieces of information to make design decisions. Essential manufacturing information is that which can affect the fulfilment of functional requirements and product constraints. The hierarchical structure of the main components for the open architecture-PPM, MAM and MRM are discussed. The aim of the approach is to define manufacturing knowledge structures and develop a knowledge-based application for DFM.

Findings – This paper gives details of the application framework development by integrating object-oriented technology and component-based development. This will help to achieve large-scale software reuse for manufacturing application development projects. This paper also gives an overview of a computer system for automated concurrent engineering, and more particularly, to a method for the concurrent design of parts, tools and processes.

Originality/value – The workability of this approach was tested in a machine-tool manufacturing firm and the same has been presented as a case.

Keywords Design for manufacture, Object oriented technology, Concurrent engineering, Manufacturing systems, Knowledge base, Information management

Paper type Research paper

1. Introduction

Developing successful new products requires the ability to predict, early in the product development process, the life cycle impact of design decisions. Downstream life cycle issues include considerations of how the product will be made, shipped, installed, used, serviced and retired or recycled (Jeffrey et al., 2004). Ignoring downstream issues (or producing poor estimates) leads to poor product designs that may cause unforeseen problems and excessive costs.
Concurrent engineering (CE) aims to integrate product design and manufacturing cycles in a systematic way to facilitate the swift, cost-effective progression of new product from raw concept to end customer.

In an effort to help designers better assess the downstream life cycle impacts of their design choices, manufacturing companies and researchers have developed many design decision support tools referred to as design for X methodologies (Sungshik and David, 2008).

Therefore, the goal of this research is to analyze and identify the fundamental elements or objects that are necessary for modeling manufacturing and process planning framework used in collaborative design and manufacturing. The resulting analysis is to develop a manufacturing information-based design tool integrated with an intelligence design system using in collaborative design and manufacturing to support machine-tool designers’ activities achieve cost-effective design.

2. Literature review
To achieve software interoperability, information models are necessary and critical to specify common terms and programming interfaces. In design, a product model is being developed in ISO 10303 (informally known as the standard for exchange of product data (STEP)) (ISO 10303-I:1994, 1994). The support for the seamless integration of preliminary design and preliminary process planning, is established by an open, neutral manufacturing process object model using object-oriented technology (OOT) established (Lamghabbar et al., 2004). This model supports the knowledge representation of manufacturing activities, resources, cost and time. The ISO 16100 Part 2 (Industrial automation systems and integration – manufacturing software capability profiling – information model for interoperability) working draft has been developed based on this model.

Information modeling of conceptual design integrated with process planning in the context of design for manufacture (DFM) is outlined by Feng and Song (2000). An object-oriented model for concurrent optimization of the design and manufacturing stages of product development given by Lamghabbar et al. (2004). Design for manufacturing concepts and its new directions, which have to be considered during design, are discussed by Jeffrey et al. (2004). Li and Qiu (2006) give a review on technologies and methodologies for collaborative product development systems.

Comprehensive review is carried out by Yang et al. (2008) on the recent development of product modeling technology. Four types of product modeling methodologies are discussed in detail. Two object-oriented product modeling methods: STEP- and UML-based product modeling are compared. Ali and Abhay (2006) and Ling et al. (2007) give a knowledge system model to support manufacturing knowledge during preliminary design. Manufacturing knowledge verification in design support systems is outlined by Cochrane et al. (2008) and Oluwatuminu et al. (2004). Xu et al. (2007) outline a decision support system using CE for product design.

Shukor and Axinte (2009) make analysis on manufacturability analysis systems developed to allow the evaluation of various manufacturability aspects during the design stage and consequently to reduce the costs and time to market of the designed products. Nategh (2009) proposes a model for CE planning on the basis of forward and backward effects (FBE) of manufacturing processes.
It is important to model and estimate the costs to guide designers to make some decisions to lower product costs. Charles et al. (2005) give model in three-dimensional CE using goal programming approach for cost management.

Manufacturing information modeling efforts have been focused on manufacturing resource capability modeling, process plan modeling and manufacturing cost modeling. Several manufacturing models have been developed, but they are not in the standardization stage.

The above-mentioned models have not been fully integrated with each other or with another information model. Some specific issues to be addressed are as follows:

- most published process plan models form detailed process planning, not the preliminary process planning in the early product assessment stage, and need to be extended to the manufacturing information hierarchical structure;
- most manufacturing resource models incorporate many functional and geometric characteristics of resources, but not the needed behavioral characteristics and capability during processing; and
- the type of methods used for manufacturing cost and time estimation should be integrated into the manufacturing process model.

### 3. Case study with machine-tool company

An analysis of orders executed over a period of three years was carried out in a machine-tool manufacturing company, producing a wide range of machines tools. Results of the analysis showed that out of a total of 60 projects executed per year, 40 projects had serious problems.

Analysis of the problems revealed that there were difficulties in addressing the important issues associated with operating the manufacturing plant that leads to these serious problems in project execution. For a range of issues associated with operating the manufacturing plant, the results for the top ten are shown in Figure 1. X-axis represents importance and difficulty on a 1-5 scale (scale 5 represents maximum and scale 1 represents minimum, in importance and difficulty).

To address these important issues associated with operating the manufacturing plant, computer-based information systems were deployed in the company. The information systems introduced was required to have certain important features to address the issues associated with operating the manufacturing plant. There were difficulties in addressing the issues associated with operating the manufacturing plant.

Features of importance and difficulties in traditional information systems introduced were analysed. These are shown in Figure 2, showing only the top ten in terms of importance. X-axis represents importance and difficulty on a 1-6 scale (scale 6 represents maximum and scale 1 represents minimum in, importance and difficulty).

It was seen that the conventional design process followed in the company was taking too much time. Time overrun was the primary culprit, cost overrun and quality problems accompanied. Since manufacturing time could not be reduced much without major capital investment, it was decided to try and reduced time for design.

Hence it is decided to make a study to modify or replace the existing information system with the OOT which will ensure CE and design for manufacturing concepts.
4. Traditional versus concurrent design

Competition in the marketplace forces machine-tool manufacturing firms to continuously generate new (and more attractive) product designs while maintaining high quality, low costs and short lead times (Charles et al., 2005). Traditionally, decisions on these issues were taken in a serial pattern. First, a product design was selected from a set of feasible designs, driven primarily by marketing objectives and engineering constraints. The chosen design was then transferred to the production planning function that developed an appropriate manufacturing plan. Such plans were guided primarily by operational objectives (e.g. cost minimization, capacity utilization, load balancing, etc.). Finally, the product design and the production plan decisions became
constraints for the logistics function that determined the supply sources. This serial pattern is known to generate solutions that suffer from two major deficiencies (Gunasekaran, 1998). First, it is slow because parallel processing opportunities are often missed. Second, it leads to sub-optimal solutions, because each stage can make, at best, sequential locally optimal choices. CE is a paradigm aimed at eliminating such flaws. CE dictates that product and process decisions are made in parallel as much as possible and that production considerations be incorporated into the early stages of product design. The CE concept leads to a fundamental tradeoff. On one hand, it reduces the need for re-design and re-work (thus reducing development time) and increases the chances for smoother production (thus helping to minimize cost and improve quality). Figure 3 shows process in sequential and concurrent development in a machine-tool manufacturing company (Ho and Lin, 2009).

4.1 The early effects of design
By the time a machine has been designed, only about 8 percent of the total product budget has been spent (Charles and Ramon, 1993). But by that point, the design has determined 80 percent of the lifetime cost of the product (Figure 4). The design
determines the manufacturability, and that determines a significant part of the introduction and production cost, the 80 percent of the product. Once this cost is locked in, it is very hard for manufacturing to remove it. Cost reduction programs should start with product design, because it has the most influence over the design’s overall cost.

4.2 Concurrency planning on the basis of FBE
In a sequential manufacturing system, the results of each process are transferred to the department responsible for the next process (Ling et al., 2007). The processes occurring at later stages of manufacture do not receive due attention, systematically. Concurrency as a remedy for this drawback can be planned in different ways; on the basis of the FEs, BEs, or combined FBE of the processes. In the first approach, the dependence of each process on its preceding processes is only taken into consideration for scheduling the activities. In other words, it is implicitly assumed that each process influences only the following ones. This kind of relation is called “FE” in this paper. Scheduling and implementing of the processes within a FE-based manufacturing system entails “forward chaining” or “forward processing”. However, in practice each process can also be dependent on its following processes as well. In other words, each process can influence its succeeding ones. For instance, process planning being traditionally carried out after design, usually influences back design results. In many cases, considerations specific to process planning necessitates that designs be altered. Production capabilities also have a similar effect on design and process planning. “BE” denotes this kind of relation in this paper. Analysis of BE needs “backward chaining” or “backward processing”. Neglecting BE is the major source of re-work frequently occurring in FE-based and sequential manufacturing systems. The early start of the processes possessing high BE is an effective means of voiding re-work and enhancing the degree of concurrency of the activities.
In a truly parallel work, both FBE should be taken into consideration in order to schedule the activities, set up the multidisciplinary teams with appropriate constituents and determine the focal points. In other words, thorough concurrency planning necessitates both forward and backward chaining. The early involvement of the processes with high degrees of FBE is of special importance in order to obtain the best results through a CE-based manufacturing system (Yassine et al., 2008; Xu et al., 2007).

5. CE in a machine-tool manufacturing company

Figure 5 shows the aforementioned methodology, in a machine-tool manufacturing company producing a wide range of machines with processes and their interconnections. CE was developed for a project in this company to develop two new products. Production includes a wide range of machines like conventional turning, milling, drilling and grinding machines, CNC machines and machining centres. The project involved almost every activity typical to this industry, from research to customer requirement planning (Barreiro et al., 2003).

6. Object-oriented databases

An object-oriented database (OODB) is a system offering database management facilities in an object-oriented programming (OOP) environment. Data are stored as objects and can be interpreted only using the methods specified by its class. An object class is a set of objects that share a common structure and a common behavior. The relationship between similar objects is preserved (inheritance) as are references between objects. Queries can be faster because joins are often not needed (as in a relational database).

![Figure 5. Typical CE network in a machine-tool manufacturing company](image-url)
This is because an object can be retrieved directly without a search, by following its object ID. An object database management system provides a storage place for objects in a multi-user client/server environment. An OODB is fundamentally created around an object-oriented data model. An object is something that has both data and the actions that reads or manipulates the data. An object has a well-defined role in application domain. An object-oriented model is becoming more and increasingly popular because it can totally represent complicated connections as well as represent data and data processing in a consistent way (Graham, 2001; Bagui, 2003).

6.1 Need for OODB management systems
Process integration was the driving force that inspired the development of OODB systems. A primary characteristic of object-oriented applications is the ability to efficiently manage very complex information efficiently. With applications becoming more complex and users becoming more demanding, this type of database is becoming more necessary. One of the areas which is impacting, for the need of efficient and flexible OODB systems, is in the area of design support systems, i.e. computer-aided design (CAD), computer-aided software engineering (CASE) and office information systems. These applications require databases that can handle very complex data, that can develop smoothly, and can provide the high-performance dictated by interactive systems. With these possibilities in mind, it is not surprising that the CAD, CASE, computer-aided manufacturing areas are specifically being targeted by OODB vendors. Factory and office automation are other areas where OODB technology is also very valuable. OODB systems can provide solutions for intricate problems and put them within the reach of users. OODB provides a unifying paradigm for the development of database from data model.

The difference between the traditional approach and the object-oriented approach is shown in Figure 6. The object-oriented models were achieved in accordance to the requirements of integration in a complex information system and to the functions of traditional databases’ administration systems. The main concept used is the object. It is described by a complex network which constitute the object’s attributes and methods (similar to group technology) (Figure 7).

<table>
<thead>
<tr>
<th>Conceiving Level</th>
<th>Traditional approach</th>
<th>Object-Oriented approach</th>
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<td></td>
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<td>B</td>
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<tr>
<th>Logical Level</th>
<th>Data</th>
<th>Processing</th>
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<tr>
<td>Implementation Level</td>
<td>Program files</td>
<td>Data files</td>
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Figure 6.
Difference between the traditional approach and the object-oriented approach
The CAPP module’s database contains:
- graphical data related to the parts, which have the shape and dimensions as basic types of the object-oriented models;
- alphanumeric data, which contain technological information; and
- methods base, which comprises optimization and calculation algorithms.

6.2 *Object query language*
Object-oriented and object-relational databases often use a query language called object query language (OQL) to manipulate and retrieve data. OQL is similar to SQL in that it uses many of the same rules, grammar and vocabulary (Kifer *et al.*, 2005). OQL has been recognized as an object database management group standard for querying OODBs. Similar to SQL, OQL, uses a select-from-where structure to formulate extensive queries.

7. *Manufacturing process model*
The developed manufacturing process object captures and represents the information necessary to provide reliable information supporting the concurrent product realisation. The model consists of a group of related class. The class is an information entity, which has one or more attributes; zero or more methods; constraints and relationships. Attributes define what the classes attribute consists of identification name, data and definition. Methods define the functions class performs. Constraints limit the behavior of class. Relationships relate the class with others in the model. A relationship includes inheritance, composition, aggregation and recursion. Based on the requirements, the object modeling method using OODBs’ administration system (OODBAS),
as well as the OOP has been chosen because it has the features of the encapsulation, inheritance, composition, recursion and cardinality of relationships (Oluwatuminu et al., 2004).

7.1 Information exchange between preliminary design and preliminary process planning

Figure 8 shows the communication between preliminary design and preliminary process planning based on the integrated design object model and manufacturing process object model. Design information, such as form, structure, materials and other product properties, needs to be shared by process planning based on the design object model. Likewise, manufacturing information on preliminary process planning, such as primary manufacturing processes, process sequences, process parameters, setup specification and cost/time needs to be made available for product design based on the manufacturing process model, to guide product designers to optimize design specifications. Therefore, an integrated information model that supports the two-way communication between preliminary design and preliminary process planning is important and necessary. The design information includes the requirements, function, behavior and form/structure of artifacts (Feng and Song, 2000). Modeling of processes, resource cost is described in the following sections.

7.2 Conceiving of the process planning model

Process plan modeling is to describe the process plan strategy of a manufacturing process. A process plan model includes a hierarchically structured process plan: generic plan, macro plan, detailed plan and micro plan. In conceiving the process planning model (PPM), the possibility of using different methods was taken into account, two of them being basic:

1. the method through variants; and
2. the generative method.

The method through variants (variant process planning) is conceptually based on the idea that similar parts are being manufactured in similar ways. Therefore,
one of the main components of the PPM is that of part coding, which uses the principle of group technology. In a consistent database, the variant which is closest to the needed part must be identified. Creating and modifying the typified process is the job of the engineer.

The first activity carried out is that of coding, classifying and grouping the parts on families, which represents the preparation state, followed by the production state, which refers to the usage of the PPM during actual production. The database which was created during the preparation state undergoes a process of continuous completing with new part types which will be machined. Their regrouping will be made based on the group technology, by modifying and adapting the configuration of the new part type as needed. The main role is that of the database and that of the knowledge base, which must be updated and improved constantly. In Figure 9, the scheme of the work structure in a PPM through variants is presented (Cochrane et al., 2008).

The principle based on the automatic realisation of the machining process’ sequences, without the operator’s decisional intervention is found in the generative method (generative process planning), shown in Figure 10.

To realise a generative PPM, it is necessary to have a knowledge base which includes three main components:

1. the parts’ description;
2. the knowledge base and the database; and
3. the decisional logics with the calculation algorithms.

Because of the necessity to process and transmit a large amount of information and in order to realise the integration in the CIM system, for the conceiving of the PP module it was necessary to use besides of the variant and generative methods the OODBAS, as well as the OOP (Kifer et al., 2005).

7.3 The realisation of the PPM

The processing of graphical information from CAD files is made together with that of the technological information, thus realising as a first step an association between geometrical shapes and machining procedures. Thus, the machining variants which

![Figure 9. The scheme of the work structure](image)
are technically possible, according to the database with the technological equipment, are being established. After the surfaces-machining procedures association stage, there follows the establishing of the final machining procedure of a surface based on the tolerance and roughness conditions.

Based on the economic analysis, the optimal machining process is automatically being determined and afterwards the technological documentation for the manufacturing is issued (machining parameters are being calculated, the necessary devices and cutting tools are being designed, the necessary time is set, etc.). The information stream inside the PPM module is shown in Figure 11, and the stages are those beginning with taking over the (graphical and technical) information from the CAD module’s database and ending with the optimization of the technological process according to the previously set criteria.

In realising the PPM decision tables have been used because, in this case, the decision processes can be expressed through algorithms, i.e. according to precise rules. A decision table, Figure 12, is divided in two sectors: conditions and actions. In the upper sector, there is a list of conditional parameters – conditions – whose characteristics depend on entities – actions – listed in the lower section. The rules indicate, for an accurate determination, which action is to be considered and under which circumstances. Thus, by creating a large number of rules, for the specific situations of the production (endowment with technological equipment, personnel skill, etc.), there could be established the preliminary conditions for realising the presentation model of the PPM.
Figure 13 shows the composition of the objects for the model realised for the PPM. The classes of an application are organised as a graph, as in Table I. Contrary to a relational model, the object-oriented model allows not only the description of the static aspect of an application, regarding data and structure, but also the description of the dynamic aspect, regarding the object behavior and communication.

The realisation of the OODB for the computer-aided conception of manufacturing processes makes it possible to use the OOP for drawing out the technological documentation. Beginning with the systemic approach of the mechanical machining process, Figure 13, by defining the subsystems which intervene in the manufacturing system the objects can be defined for each program, e.g. for machine tools, Figure 14. Each object being characterized by state, behavior and identity. The information about an object is to be accessed or modified only through the multitude of tasks (methods) which define the object.
Through the tasks of the machine-tool object, it is possible to call the components (Figure 15). Similarly, for the components of the object machining task (MT), Figure 16, the program-specific functions are called.

From the object’s structure, Figure 17, there can be seen the information’s structure, as well as the tasks’ implementation. The advantages of OOP could be achieved mainly because of the discipline, associated with the encapsulation and with the inheritance (characteristics which allow the development of new classes by describing the differences to the already existing ones).

### 8. Manufacturing activity model

Figure 18 shows the class diagram for a manufacturing activity. Such an activity is a generic manufacturing operation performed on a workpiece. The manufacturing activity class has a recursive definition, which generates a hierarchical structure. The levels in the hierarchy can be, for example, workstation, operation, step and feature. The manufacturing activity indicates the level.
The final result of the manufacturing activity is the artifact to be made.

ArtifactToBeMade has the manufacturing processes, which includes a set of manufacturing activities. Manufacturing consists of many subManufacturingActivities that are defined recursively. The intermediate process represented by workpiece, which is a type of artifact class. Additionally, manufacturing activity will have the following attributes: manufacturing part quantity, manufacturing resource, estimated cost/time, branch and joint. Branch and joint are considered together to form the structure of concurrent and parallel activities.

The ManufacturingActivity class has the following subclasses: setup, handling, processing, load unload and idling activity. This model supports integrated manufacturing activity, sequence, alternative activity, parallel activity, concurrent activity, resource, manufacturing time, and cost.
Object MT (Machine-Tool)

- Gauge dimensions
- Usefull work way
- Rotational range
- Feed range
- Cutting tool change
- Technical conditions

Application of object-oriented framework

Figure 14.
Defining object machine tool

Figure 15.
Tasks of the machine-tool object

Figure 16.
Components of the object MT
9. Manufacturing resource model

Figure 19 shows the manufacturing resource classes. A manufacturing resource is a physical machine or labor skill that is used in manufacturing artifacts. The manufacturing resource class has two subclasses: labor skill and manufacturing equipment. Labor skill represents labor rate and skill description. The manufacturing equipment subclass represents a piece of equipment (a physical entity). There are four subclasses: machine, die, mold and tool for machining. If necessary, other equipment classes may be added to the manufacturing equipment class. A piece of equipment has a set of parameters that describe equipment. A machine can be a machining centre, casting machine, forging machine, electrical discharge machine and so on. A machine has a set of parameters, such as dimension scope and tolerance scope. A tool represents a tool used in the machining process, such as a cutter, extender, holder and gauge. Each tool has a set of tool parameters. The tool class has four subclasses: cutting tool, fixture tool, gauging tool and accessory tool.

10. Manufacturing cost and time

Manufacturing cost and time estimations have been built into the object model. The activity-based costing method has been adopted to form the basis for estimating the cost and time described in this paper. A manufacturing process consists of many manufacturing activities. Each manufacturing activity can be one of many processing activities, such as setup, load/unload, handling and processing. Each processing activity involves the cost of using any resources and overhead cost.

11. Results and summary of case study

A systematic information modeling technology is used to represent the information relationships and associativities from the system perspective. The object-oriented systems analysis approach is used as the primary tool, to describe the static and dynamic characteristics of information, by using Oracle 9i, Forms6i, Report 6i. The information associations between part design and manufacturing planning are properly described. CE practices such as DFM, QFD and feature-based CAPP were introduced in the new system and practiced for two years. An audit was then undertaken to evaluate the monetary gains from the new system implementation.

A summary of the monetary benefits are shown in Table II:
Application of object-oriented framework

Figure 18. Manufacturing activity class diagram
Figure 19. Manufacturing resource class diagram
Projects suffered delayed delivery/cost overrun/quality = 15/98 × 100 = 15.30%.

Products completed without problems = 83/98 × 100 = 84.70%.

Benefit obtained average per year = $1,280,000.

Average turn over of the company after new system is introduced = $15,625,000.

Benefit obtained as percentage of turnover = 1,280,000/15,625,000 × 100 = 8.19%.

Profit after new system is introduced = $2,750,000.

Profit after new system is introduced as percentage = 2,750,000/15,625,000 × 100 = 17.60%.

Total cost required to implement new system = $2,125,000.

Payback period = $2,225,000/$275,000 = 0.8091 = Approximately ten months.

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<table>
<thead>
<tr>
<th>Sl no.</th>
<th>Benefits and metrics</th>
<th>(1) Cost incurred due to related problems with traditional system average three years ($/year)</th>
<th>(2) Cost incurred due to related problems after implementing object-oriented system average two years ($/year)</th>
<th>Benefits (1) − (2) As cost saved in $/year As %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Development time/cost reduced due to decrease in design/engineering changes good design design optimization knowledgebase related to design/process/material</td>
<td>670,000</td>
<td>1,50,000</td>
<td>520,000 77</td>
</tr>
<tr>
<td>2</td>
<td>Cost reduction due to: material availability, proper material manufacturing costs decrease due to optimum process, correct information reduced number parts due to rationalization</td>
<td>475,000</td>
<td>1,25,000</td>
<td>350,000 73</td>
</tr>
<tr>
<td>3</td>
<td>Improved quality – required accuracy, precision as per customer need, testing as per requirement</td>
<td>350,000</td>
<td>1,20,000</td>
<td>230,000 65</td>
</tr>
<tr>
<td>4</td>
<td>Others benefits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4a</td>
<td>Improved customer service and reducing the scrap</td>
<td></td>
<td></td>
<td>100,000</td>
</tr>
<tr>
<td>4b</td>
<td>Better ability to manage new product development</td>
<td></td>
<td></td>
<td>80,000</td>
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<tr>
<td></td>
<td>Total</td>
<td></td>
<td></td>
<td>12,80,000</td>
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</tbody>
</table>

Table II. Benefits CE implementation

Application of object-oriented framework
After introducing new system, 15 projects were facing problems out of 98 projects executed on an average per year. The company which has made 8.41 percent profit ($1,040,000/year) on an average turnover of $10,000,000 is able to increase the profit margin to 17.60 percent profit ($2,750,000/year) on increased turnover of $15,625,000.

Hence it is decided replace the existing information system with the OOT which will ensure CE and design for manufacturing concepts. This will in turn ensure faster realisation of projects.

12. Conclusion
This paper has described integrated manufacturing application framework to link design stage to the other stages in the manufacturing systems or processes. The integration of the application framework with OOT provides a unique solution for the development of an object-oriented application on the manufacturing domain. We have presented an approach to CE, using OOT, where DFM, QFD have been put into CAPP to achieve design goals with the philosophy of CE where as many activities in the design stage are done parallel to reduce total time for design.

The workability of this approach was tested in a machine-tool manufacturing firm and the same has been presented as a case above. The case study has demonstrated the benefits to be had from such an approach. Furthermore, this model provides software developers with the information foundation for developing new process planning systems such that development time can be significantly reduced.

Future research works can be planned for the creation of a model for evaluation of productivity improvements, in order to quantify time and cost reduction, re-examination of the enhanced model through a workflow perspective, extending the object-oriented approach used here to model the entire production system.

References


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