ISSN : 0974 - 7435 Volume 8 Issue 7

BioTechnology

An Indian Journal

FULL PAPER

BTAIJ, 8(7), 2013 [963-969]

An AHP method based design for manufacture for parts manufacturability evaluation

Qingming Fan[1]*, Hongjun Liu[2]

[1]School of Mechatronic Engineering, Xi'an Technological University, Xi'an 710032, (CHINA)

[2]National Key Laboratory of Science and Technology on UAV, NWPU, Xi'an 710072, (CHINA)

E-mail : fanqm2005@sina.com

ABSTRACT

In the light of growing global competition, organizations around the world today are constantly under pressure to produce high-quality products at an economical price. Design for manufacturability (DFM) requires product designers to simultaneously consider the manufacturing issues of a product along with the geometrical and design aspects. The integration of design and manufacturing activities into one common engineering effort has been recognized as a key strategy for survival and growth. DFM requires product designers to simultaneously consider the manufacturing issues of a product along with the geometrical and design aspects. In this paper, part manufacturability was analyzed in detail. An analytic hierarchy process (AHP) method is introduced to assign weighting factors to features to reflect their functional importance. Results from the case studies show that the system is capable of generating sound manufacturability indices that could help product designers in making designs easier to manufacture.

KEYWORDS

Design for manufacturability;
Fuzzy sets;
Analytic hierarchy process.

INTRODUCTION

Background

In the 1960s, manufacturing workshop courses disappeared in design students' curricula in the United States[1]. As a result, manufacturability analysis of the design has been neglected over the years. Substantial consideration has been given to the design of products for performance (functionality, quality, aesthetics and ergonomics, etc.)[2]. However, since the designers ignore the manufacturability of the design, sometime it is not possible to manufacture the part or the design justifies high manufacturing cost and long delivery time.

With increased global competition the pressure to get quality products to market in time and at competitive cost is ever increasing. To achieve these objectives, design and manufacturing must work together. In the past decade the area of DFM has been recognized as a worthwhile engineering approach and has come under intense investigation. A large number of methods and tools have been developed for manufacturability evaluation in various domains. DFM today spans a vast spectrum, from simple handwritten scorecards and check sheets to sophisticated knowledge-based design advisory systems.

FULL PAPER

What is design for manufacture?

- There exist more definitions for DFM in the literature:
- DFM means to make product designs that are manufacturability[3].
- DFM is the philosophy and practice of designing a product for optimal fit to a particular manufacturing system[4].
- DFM is the approach to design of mechanical parts, components, and systems that addresses the manufacturability issues during the early stages of conceptual and embodiment design with tradeoffs performed between designs and manufacturing objectives[5].
- DFM is the application of methods and tools to support the choice of best materials and manufacturing processes[6].
- DFM means doing right things before doing things right[7].

Design for manufacturability is the process of proactively designing products to (1) optimize all the manufacturing functions: fabrication, assembly, test, procurement, shipping, delivery, service, and repair, and (2) assure the best cost, quality, reliability, regulatory compliance, safety, time-to-market, and customer satisfaction.[8].

All of above definitions did not make a clear distinction between DFM metric (measure of the manufacturability and the design goodness), DFM method (for search/ optimization, generation/modification, evaluation and decision), and DFM tool (embodiment of method).

In this dissertation, DFM is defined as:

DFM is the practice of designing products with manufacturing in mind. Its goal is to reduce costs required to manufacture a product and improve the ease with which that product can be made. Performing DFM analysis needs to choose DFM metric and methods, specify DFM tasks and the sequence to perform them, and choose or develop DFM tools.

Problem statement

This research lies in the general area of DFM. The objectives of this work are summarized as follows:

1) Evaluate DFM measures and develop the theoretical foundation for evaluating design benefit, manufacturability and perform tradeoffs between design and manufacturing.
2) Develop a domain independent DFM framework which streamlines the DFM analysis across all domains and provide the transparency of the method and metric to the designer. It involves specifying generic DFM tasks and the sequence to perform them.
3) Develop a prototype system to demonstrate the capabilities, flexibility and customizability of the proposed framework.
4) Identify different types of manufacturing knowledge and develop the ways to represent and apply them. Build an information model as the backbone to integrate existing tools into the framework. Develop schemes to check the consistency of the manufacturing knowledge.

THE MANUFACTURING INFORMATION MODEL FOR DESIGN FOR MANUFACTURING

The manufacturing information model

In general, three types of models may be needed to support manufacturing evaluation: product models, process models, and cost models. A product model needs to model geometry, manufacturing features, and some non-geometry information such as tolerance and surface finish at different abstraction level of manufacturability analysis. A process data model describes a process activity, its sub-activities, and the associated data. A manufacturing process model encodes the capabilities of a manufacturing process including shape producing capabilities, dimensions, tolerance and surface quality capabilities, geometric and technological constraints and manufacturing cost. Traditionally, there are two methods for process shape producing capability modeling: process-based methods and part-based methods. In a process-based method, machine tools, fixture devices, cutting tools and kinematics motions as well as operation precedence in manufacturing processes are utilized to capture the capability of the process. In a part-based method, feature types, attributes and numbers in a machining process are adopted to define its capability. The capability of a manufacturing process can be also expressed in the form of constraints. Constraints can be classified into three levels: universal level constraints, shop level constraints, and machine level constraints. Manufacturing resources are defined as the equipment which enables industry to turn raw materials into marketable products[9]. Different representations of manufacturing resources have been employed by a variety of software tools, which perform various tasks. Resource model should include: tooling/materials, resource descriptions, equipment/labor, materials knowledge, and so forth[10]. Several manufacturing resource models were developed in MO system[11], and NIST rapid response manufacturing (RRM) project[12]. Jurrens et al.[9] proposed the requirements specification for the manufacturing resource information modeling. An information model for the manufacturing resource is available[6]. The model is in EXPRESS and developed for the NIST Rapid Response Manufacturing Intramural Project. Cost models can be classified as activity-based cost models, scaling cost models and statistical cost models[13, 14]. Activity-based cost model decomposes the cost into elementary cost items and then respective costs of these items are estimated. It gives relatively precise results but detailed product and manufacturing process information is needed. The task of gathering all the required date is time consuming. Scaling cost model estimates the cost by interpolation or extrapolation of historical data for closely related product. It assumes there is a simple relationship between the considered parameter and the final cost. Statistical cost model is constructed based on statistical relationships and operates as a black box. Cost estimation formula plays an important role in the cost models. The formula relates the cost as a dependent variable to one or more independent cost drivers.

Industry and academia long for a standardized data format that is platform and application independent. The recent effort on AP240[15] reflects the trend that the product model, manufacturing process and resource model will become standardized in the near future.

Manufacturing information model express

A semantic network is a labeled directed graph representing objects/entities, their properties and their relationships. The structure of a semantic net is shown graphically in the terms of nodes and the arcs connecting them. Nodes are often referred to as objects/entities and the arcs as links or relationship between two nodes. Figure 1 shows an example of application of semantic network to model the objects/entities and their relationships in DFM analysis.

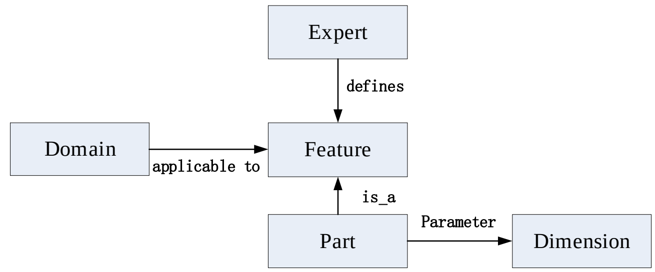


Figure 1 : A semantic network example

The three items of objects/entities, attribute, and value occur so frequently in modeling DFM information that it is possible to build a simplified semantic net using just them. An entity-attribute-value (EAV) or triplet could be used to characterize the part model, material library and manufacturing resource. The EAV triple representation is convenient for listing knowledge in the form of a table and thus translating the table into computer. Some example of an EAV triple table is shown in TABLE 1.

TABLE 1 : Entity-attribute-value triplet example of parameters

Entity	Attribute	Value
Parameter	Diameter	8
Parameter	length	10

The first row in TABLE 1 represents that diameter is a parameter and has a value of 8. EAV triples are especially useful for representing facts, and the patterns to match the facts in the antecedent of a rule. Another example is given in TABLE 2.

TABLE 2 : Entity-attribute-value triplet example of a hole

Entity	Attribute	Value
feature	name	Hole
feature	ID	1
feature	Parameter-name	diameter
feature	Parameter-value	6

However, to make the design of EAV triple table more concise and unambiguous when modeling the part model, material information, operation information, resource information and so on, Entity-Relationship-Diagram (ERD) has been chosen as the information mod-

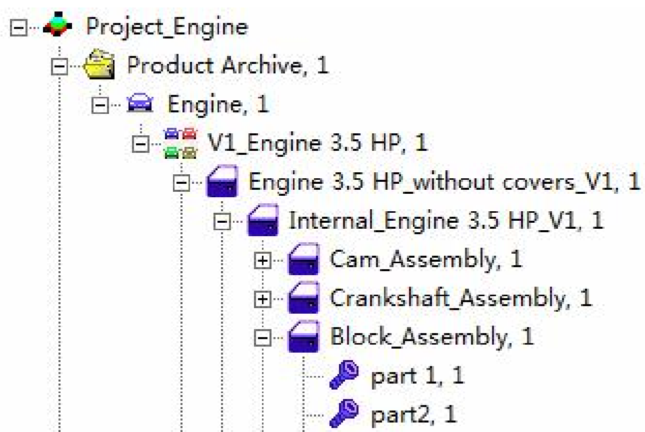
FULL PAPER

eling method in this work. Information modeling methods include Entity-Relationship method (ER), Function Modeling method and object-oriented method (OO). Function Modeling approach focuses on decomposing system functionality and the information flow between different objects; O-O approach defines the object as the basic element which contains both data and functions, thus it is easy to model complex objects and provides good extensibility. ER approach emphasizes on identifying the entities, their attributes and the relationships among the entities. As discussed above, each type of manufacturing information has entities, attributes and relations, thus ER is appropriate to model the manufacturing information.

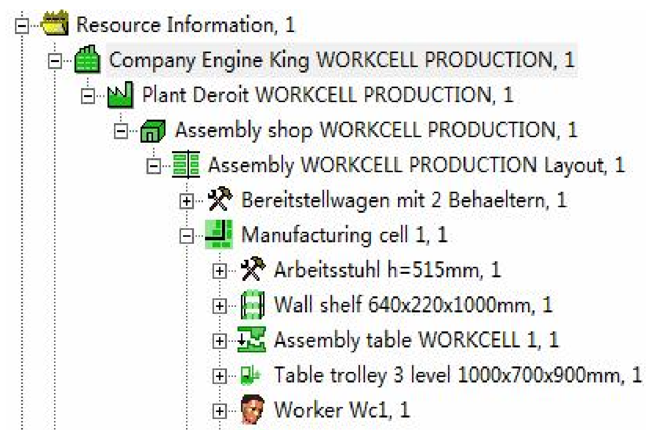
Another desired characteristic is to model the hierarchy and inheritance of the manufacturing information, as Figure 2 shows.

Such a representation can be achieved by adding parent item to the current item, which is used as a pointer to high-level entity. Figure 3 shows the scheme to model the part attribute template. Every feature is a weak entity of both entity user and entity manufacturing process.

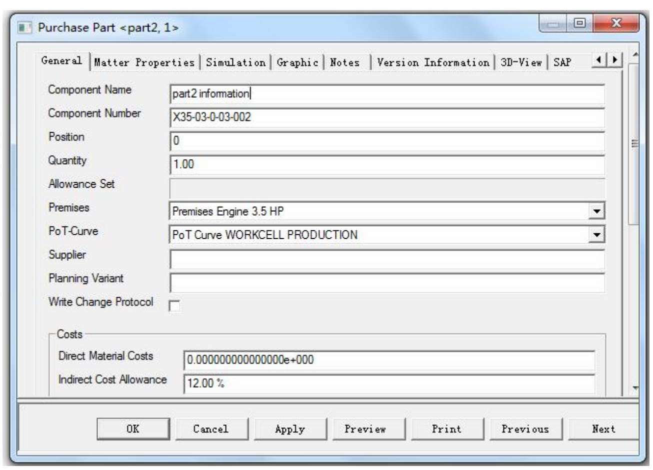
By specifying the parent item of each feature, the feature hierarchy can be established flexibly according to different manufacturing processes and different experts. Figure 4 show some parameter examples related to certain features. These parameters can be added, modified, and deleted dynamically through standard da-



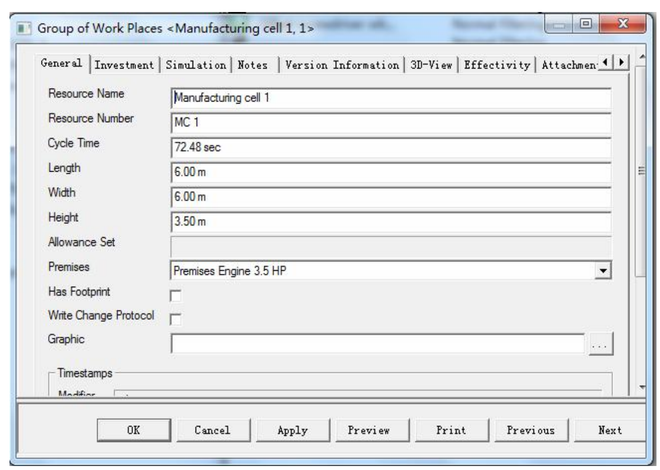
(a) Part structure hierarchy



(c) Resource structure hierarchy



(b) Part information



(d) Resource Information

Figure 2: Hierarchal nature of manufacturing information

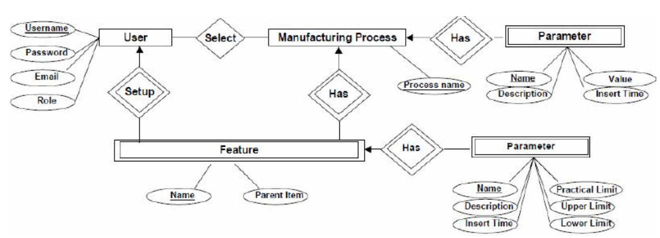


Figure 3 : Meta model of part template

Feature	Parameter	Practical Limit?	Upper Limit	Lower Limit	Description	Insert Date
Part	Batch Size	--	--	--	The batch size of...	20040121110833
Part	Tolerance	V	0.13	0.05	tolerance	20040121110852
Part	Surface Finish	V	3.2	0.8	Surface finish	20040121110925
Part	Thickness	V	5	0.1	There is a range f...	20040420115511

Figure 4 : Part Features and parameters

tabase operation.

In a similar way, the material, operation, resource, cost/time structures can be modeled.

MACHINABILITY EVALUATION

Machinability evaluation is hierarchical, includes qualitative evaluation and quantitative evaluation in general. The former only make an estimate of yes or no, namely estimate whether the designed features and parts could be manufactured smoothly under the presently environment. The latter make an optimized select, namely if there are diversified equipments could meet with the machining demands of current features, then select the most economical one (tool, cutter etc.). For qualitative evaluation, constraint-based rule could be used on single feature and general feature of the part respectively to validate machinability. For quantitative evaluation, owing to select equipment is a complicated optimize process which influenced by diversified factors, multi-factors evaluation should be used to establish an optimized equipment select model, in which the weight value of factor indicate the relative weightiness, use experts' knowledge to verify the result in finally.

Manufacturing constraint-based machinability evaluation

Manufacturing constraint is manufacturing environment's constrain on part attributes, such as part structure, dimension, precision…etc., parts which satisfied the demand of manufacturing constraint could be manufactured conveniently and economically under the presently manufacturing environment. Part is composed of features by a proper way, and each feature have a corresponding manufacturing method and equipment, thus manufacturing environment's constrain on part convert into constrain on single feature and total feature of part. Constrain could adopt an expression of rule and deduction, which save constrain by rule in constrain base, in the meantime add more constrains in constrain base to perfect the system with the development of manufacturing experience and technology. The establishment of manufacturing constrain rule is to establish the relation between machining equipment and feature by machining method, then confirm the corresponding feature attribute value according to the machining capability of each equipment.

According to the relation of feature-machining equipment, put various features into series corresponding constrain rule one by one, If the feature could not satisfy any constrain rule then means that it's attribute value have exceeded the range of manufacturing constrain; whereas, if couples of constrain rule are satisfied then means the feature is machinable, but now the machining method or equipment is not unique, the equipment which could satisfy the constrain will form a equipment candidate set (factor set), optimization should be carried on by following two-level fuzzy synthetically evaluation.

The analytic hierarchy process (AHP) methodologies

The Analytic Hierarchy Process (AHP) was originally developed by Saaty in the 1970's and since that time has been applied to many areas. AHP decomposes a complex multi criteria problem into a system of hierarchies and converts individual preferences into ratio-scale weights. AHP has the ability to incorporate intangible and subjective elements as well as quantitative elements in the decision problem. According to Forman, AHP has three primary functions: structuring complexity, measurement, and synthesis. Structuring complexity means breaking a decision problem into a hierarchy structure that starts from the main goal to the criteria, and sub criteria down to alternatives. Saaty suggests using a simple nine point numerical scale. Then judgmental preferences of the design alternatives are pariwise compared for each criterion and so does the judgmental importance of the decision criteria. Finally, the relative priorities are aggregated to arrive at a priority ranking of the design alternatives. The AHP method is built upon several axioms including Reciprocal axiom, Homogeneity axiom, Synthesis axiom and Expectation axiom. While other axioms seem consonant with real world practice, the Synthesis axiom (The priorities of the elements in a hierarchy do not depend on lower level elements) fails in many applications. Saaty realized this problem and proposed two basic ways to apply the AHP in those situations where the synthesis axiom does not apply. Another criticism about AHP is that the number of comparison is huge. Moreover, adding or subtracting one alternative need to repeat all the comparisons which is very time consuming and may cause rank reversal. The nine-point scale is also suspected by some researchers and they argue that it may be more appropriate to ask the decision maker set up his own data scale.

Machinability quantitative evaluation based on fuzzy synthetically evaluation

Here take the optimization of slow-feed grinder as an example.

Firstly, suppose that the number of candidate grinders is m, the candidate set is $T = \{t_1, t_2, \ldots\ldots, t_m\}$, suppose the factors which influence the select of slow-feed grinder could be divided into two levels according to attribute in the same time. Quality, efficiency and cost which is the optimized object of grinder selection should be the first level influence factors; the second level influence factors should be the dimension of waited machining feature, demanded roughness concentration and material characteristic.

When the optimized object is quality use the third factor of second level influence factors to carried on machinability evaluation to candidate grinders. The evaluation matrix is:

$$\mathbf{R_q} = \begin{bmatrix} \mathbf{R_{1q}} \\ \mathbf{R_{2q}} \\ \mathbf{R_{3q}} \end{bmatrix} = \begin{bmatrix} \mathbf{r_{11q}} & \mathbf{r_{12q}} & \cdots & \mathbf{r_{1jq}} & \cdots & \mathbf{r_{1mq}} \\ \mathbf{r_{21q}} & \mathbf{r_{22q}} & \cdots & \mathbf{r_{2jq}} & \cdots & \mathbf{r_{2mq}} \\ \mathbf{r_{31q}} & \mathbf{r_{32q}} & \cdots & \mathbf{r_{3jq}} & \cdots & \mathbf{r_{3mq}} \end{bmatrix} \quad (1)$$

There into r_{1jq} stand for when the optimized object is quality (q), the No. j grinder's influence elements on the first factor of the second level. To poise the influence elements' reversely essentiality, establish the weight distribution of factors, namely influence elements on quality of factors of the second level. Suppose: $W_q = (w_{1q}, \ w_{2q}, \ w_{3q})$, then when the optimized object is quality the evaluation set of candidate grinders is:

$$\mathbf{S_q} = \mathbf{Wq\ Rq} = (\mathbf{w_{1q}}, \mathbf{w_{2q}}, \mathbf{w_{3q}}) \begin{bmatrix} \mathbf{r_{11q}} \ \mathbf{r_{12q}} \cdots \mathbf{r_{1jq}} \cdots \mathbf{r_{1mq}} \\ \mathbf{r_{21q}} \ \mathbf{r_{22q}} \cdots \mathbf{r_{2jq}} \cdots \mathbf{r_{2mq}} \\ \mathbf{r_{31q}} \ \mathbf{r_{32q}} \cdots \mathbf{r_{3jq}} \cdots \mathbf{r_{3mq}} \end{bmatrix}$$

$$= (\mathbf{s_{1q}}, \ \mathbf{s_{2q}}, \ \ldots, \ \mathbf{s_{jq}}, \ \ldots, \ \mathbf{s_{mq}}) \quad (2)$$

Here in:

$$s_{jq} = w_{1q} r_{1jq} + w_{2q} r_{2jq} + w_{3q} r_{3jq} \quad (j = 1, 2, \cdots, m).$$

The model bear, which give attention to all the elements according to weight, bear obviously superiority compared with other synthesized operation model.

According to the same theory, when the optimized object respectively is efficiency and cost, the candidate grinders' evaluation set respectively is:

$$S_e = (s_{1e}, \ s_{2e}, \ \ldots, \ s_{je}, \ \ldots, \ s_{me})$$

$$S_c = (s_{1c}, \ s_{2c}, \ \ldots, \ s_{jc}, \ \ldots, \ s_{mc})$$

Suppose $(u_q, \ u_e, \ u_c)$ is the weight distributions set for the relatively essentiality of poised quality, efficiency and cost, then the m candidates' total evaluation set is

$$\mathbf{S} = (\mathbf{u_q}, \ \mathbf{u_e}, \ \mathbf{u_c}) \begin{bmatrix} \mathbf{s_{1q}} & \mathbf{s_{2q}} & \cdots & \mathbf{s_{jq}} & \cdots & \mathbf{s_{mq}} \\ \mathbf{s_{1e}} & \mathbf{s_{2e}} & \cdots & \mathbf{s_{je}} & \cdots & \mathbf{s_{me}} \\ \mathbf{s_{1c}} & \mathbf{s_{2c}} & \cdots & \mathbf{s_{jc}} & \cdots & \mathbf{s_{mc}} \end{bmatrix}$$

$$= (\mathbf{s_1}, \ \mathbf{s_2}, \ \ldots, \ \mathbf{s_j}, \ \ldots, \ \mathbf{s_m}) \quad (3)$$

if $s_k = \max s_i \quad (i = 1 \sim m)$, then the No. K of the candidates is the selected grinder. There into the weight of could be confirmed by level analysis.

CONCLUSION

At all times manufacturability of part is a hot point in the field of manufacturing and an important researching content of concurrent engineering, but in actual product designing course, confliction between design and manufacture is hackneyed due to short of manufacturability analysis and corresponding applicable tools, causes iterative modification of design and iterative harmoniousness between design and manufacture.

An evaluation system of Design For Manufacturing (DFM) according to CE ideas and the evaluation methods for part manufacturability feature-based are put forward which are actual used in the project of "manufacturability evaluation of close-tolerance casting turbine air-cooling blade", greatly improved the design quality and efficiency and obtained a satisfying result.

ACKNOWLEDGEMENTS

The research work is supported by Shaanxi Major Subject Construction Project, President Fund of Xi'an Technological University (XGYXJJ0414), and Shaanxi Provincial Programs for Technology Research and Development Foundation (2012JM2020), namely "Research on Technical Decision Knowledge Base Support System for NC ECM Equipments".

REFERENCES

[1] G.Boothroyd, P.Dewhurst, W.Knight; Product design for manufacture and assembly, 2nd Edition, M.Dekker Inc., New York, **(2002)**.

[2] G.Pahl, W.Beitz; Engineering Design: a systematic approach, Springer, London, New York, **(1996)**.

[3] R.J.Schonberger; World-Class Manufacturing: The Lessons of Simplicity Applied, Free Press, New York, NY, **(1986)**.

[4] S.A.Conradson, L.A.Barford, W.D.Fisher, M.J.Weistein, J.D.Wilker; Manufacturability Tools: An Engineer's Use and Needs, appears in: Electronic Manufacturing Technology Symposium, Design-to-Manufacturing Transfer Cycle. Fifth IEEE/ CHMT International, Lake Buena Vista, FL, 155-8 **(1988)**.

[5] J.Summers, N.Vargas-Hernandez, Z.Zhao, J.Shah, Z.Lacroix; Comparative Study of Representation Structures for Modeling Function and Behavior of Mechanical Devices, Proceeding of ASME Design Engineering Technical Conference, DETC2001/ CIE-21243, Pittsburgh, PA, **(2001)**.

[6] J.Van Vliet, C.Luffervelt, H.Kals, State of the Art Report on Design for Manufacturing", Proceedings of ASME Design Engineering Technical Conference, DETC1999/DFM-8970, Las Vegas, NV, **(1999)**.

[7] K.Aasland; Product programs, variants and modularization, chap. 2 in F.Fabricius, (Ed.); Implementing Design for Manufacturing - DFM in Nordic Industry, **(1997)**; http://www.sintef.no/units/ projects/DFM; SINTEF Materials Technology, Trondheim, Norway.

[8] D.M.Anderson; Design for Manufacturability & Concurrent Engineering; How to Design for Low Cost, Design in High Quality, Design for Lean Manufacture, and Design Quickly for Fast Production, Publisher: C I M Pr, **(2003)**.

[9] K.Jurrens, J.Fowler, M.B.Algeo; Modeling of manufacturing resource information, requirements specification, NISTIR 5707. Gaithersburg, MD: National Institute of Standards and Technology; **(1995)**.

[10] YT.Lee; An overview of information modeling for manufacturing systems integration, NISTIR 6382. Gaithersburg, MD: National Institute of Standards and Technology; **(1999)**.

[11] L.Lapointe, T.Laliberty, R..Bryant; System description document for the manufacturing optimization (MO) systems, CDRL no. 0002AV-5.Washington, DC: Defense Advanced Research Projects Agency, **(1993)**.

[12] http://www.mel.nist.gov/rrm/fy97/ jul97mrmodel.exp.

[13] P.Duverlie, J.M.Castelain Cost/time estimation during design step:parametric method versus case based reasoning method. Int.J.Adv.Manuf.Technol., **15**, 895-906 **(1999)**.

[14] T.Farineau, B.Rabenasolo, J.M.Castelain, Y.Meyer, P.Duverlie; Use of parametric models in an economic evaluation step during the design phase. Int.J.Adv.Manuf.Technol., **17,** 79–86 **(2001)**.

[15] B.Freeman, L.Slovensky; Update on the standard for the exchange of product model Data—STEP ISO 10303–224 & 10303–240. Presented to: the VPERC/VIPER 2003 workshop at Arizona State University; 5–6 June, **(2003)**.