

Intelligent Functional Model for Costs Minimization in Hybrid Manufacturing Systems

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Abstract. The paper deals with the intelligent functional model for optimizing the product design and its manufacturing process in hybrid manufacturing systems consisting of people, machines and computers. The knowledge-based framework of an intelligent functional model has been developed. It furnishes the possibility for a product designer and manufacturer to find an optimal production plan in the early stage of the product design. The mathematical model formalization is provided. A consecutive optimization scheme has been applied for selecting an optimal alternative of a product design and its production plan. The proposed model is being implemented both in industry and university education process.

Key words: hybrid manufacturing system, optimization, integration, intelligent, model, knowledge base.

1. Introduction

The 21st century manufacturing has been described from many perspectives in terms of integrated manufacturing, cellular manufacturing, size and structure of industrial organization, etc. Sun and Frick (1999) investigated the transformation of a Computer Integrated Manufacturing (CIM) paradigm to that of Computer and Human Integrated Manufacturing (CHIM). Sampler (1999) proposed to redefine an industry structure in the information age discovering new possibilities by means of Internet and splitting large companies into the smaller ones. Nadler and Tushman (1999) emphasized the perspective of the organi-

zation design creating “differentiation” and “integration”, or the capacity to link different units within the same organization seeking in the organizations the future to institutionalize the changes. Humphreys *et al.* (1999) focused on the development of the cell structure within the company in order to identify the potential problems that could arise among various participants who operated in a cellular environment. All these investigations on the creation and integration of the information flows in manufacturing systems are interrelated.

The 21st century as the age of information has emanated with great abilities of the information flows and information technology in manufacturing systems. The idea of employing information technology to integrate various functions of an enterprise emerged in industry and in university research laboratories a long time ago, e.g., the concept of the CIM by many authors was defined (Harrington, 1973; Mitchell, 1991; Alsene, 1999; Urban *et al.*, 1999) as the integration of various computer systems. Computer systems as Computer-Aided Design (CAD), Computer-Aided Process Planning (CAPP), Enterprise Resources Planning (ERP), etc, have originated in traditional areas of manufacture automation. The problem exists when the above-mentioned systems are to be linked with an interoperating entity as during past 10–30 years various conceptions of automation in manufacturing systems sprung up. Some researchers groups (Lau, 1998; Pennathur *et al.*, 1999; Chung and Lau, 2000) pointed out that manufacturing environment had stopped achieving full automation in both the manufacture of products and management of information flows more than two decades ago. By the late 1980s, it was generally accepted that in future the demand for manufactured products would be met by a small workforce operating in a highly modern organization employing productive and advanced technologies (McCune, 1993; Sampler, 1999). The reality is that fully automated processes based on hard automation except a few limited cases are not viable due to technical and economic reasons. Total automation does not lend itself to situations where it is frequently to be changed because of user needs, costs or engineering improvement (Pennathur *et al.*, 1999).

The emphasis on improved industrial productivity at reduced cost has appeared to be limited by the influence on the design, development, and implementation of manufacturing systems. It means no total automation, but increase in the efficiency and effectiveness of a manufacturing enterprise through the integration and exploitation of available modern information and production technology, and human skills. This integration has to be guided by the changes in managing the way of thinking and the organizational structure. In most cases these requirements can satisfy Hybrid Manufacturing System (HMS) that consists of humans, machines and computers, described in Section 2.

This paper reports how an intelligent function model in the HMS can facilitate and accelerate the enterprise business process in a new competitive age. In this context, the developed intelligent functional model covers a wide range of activities and interactions among humans, machines and computers for the efficient design and manufacture of a new product. To implement the above-mentioned model in a hybrid manufacturing system is to institutionalize fast changes in business environment. This research is focused on the delivery time of new products to the market as a critical issue for a manufacturing system in the competitive world.

The main objective of this research is to develop a framework of an intelligent functional model on the basis of a knowledge-based (KB) system that helps both the designer to adopt the principles of Design for Manufacturability (DFM) and the manufacturer to find for a product the optimal production plan. In this paper, a knowledge-based functional representation scheme, which uses rule-based representation, is also offered as a designer’s tool for new product development in its conception stage.

The rest of this paper is organized as follows. Section 2 describes the peculiarities of HMS, Section 3 presents the computer integration of information flows in HMS. Section 4 categorizes the intelligent functional model of product and process design using the DFX approach. Section 5 presents the case study; Section 6 illustrates the implementation and further research. Final section deals with discussion and conclusions.

2. Hybrid Manufacturing System (HMS)

Manufacturing system refers very broadly to all the activities required to create products, processes and production management including the relationships among customers, sup-

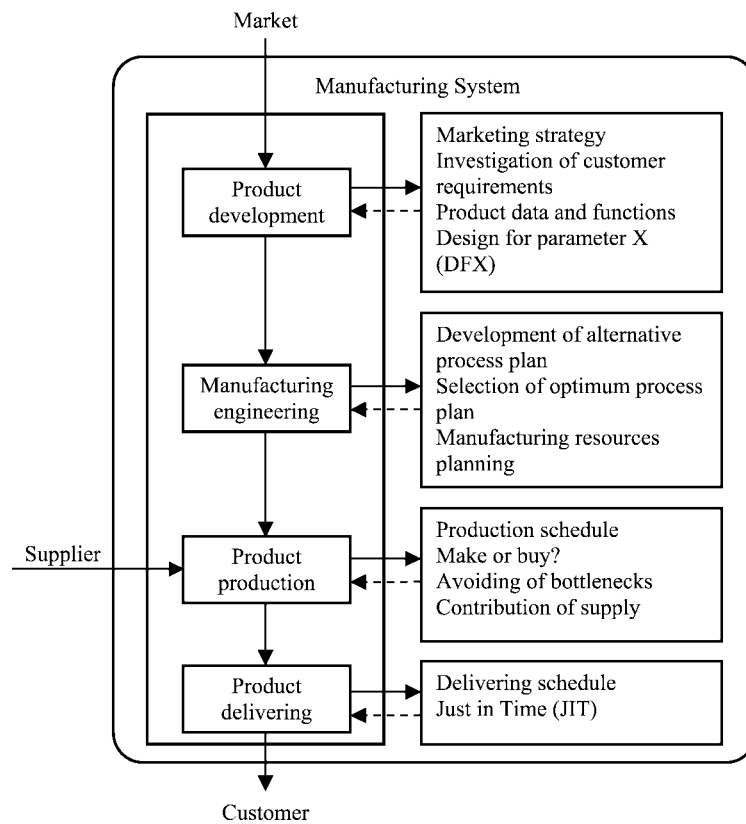


Fig. 1. Performance of a manufacturing system.

pliers, developers and producers (Fig. 1). In this paper a manufacturing system embraces various meanings such as: factory, enterprise, and company, the latter including the organization with a few functions. There are two basic types of manufacturing systems in new production environment: 1) the entire product development and its production cycle, and 2) the mass or batch production cycle of separate components or parts. According to the Hill (1999), these two types of companies flag up a growing problem for many industrialized nations: the hollowing of the manufacturing section. A hollow company leaves for itself the functions of marketing, new product development and delivery. Sometimes it is also possible to take the functions of products assembling and their testing. In such cases, there are strong relations with suppliers producing all parts and components, and supplying them for assembles. Suppliers become the companies of the second type in the above-mentioned classification scheme.

The manufacturing goals of the 21st century can be briefly defined: more products made in less time with zero defects and increased customization. There are different methods to achieve these aims. Researchers and industrialists from various countries (McCune, 1993; Bargelis, 1999; Nadler and Tushman, 1999) described these ways systematizing the peculiarities (Table 1) of the factory of the future (FOF). Table 1 shows some common groups of the peculiarities of the FOF, which reduce uncertainty by modeling the desired enterprise and predicting its performance in the nearest future. The first focus of peculiarity groups is that manufacturers are turning to smaller factories for management reasons, as the 21st century factory owners will purposely cut the employee rolls short because small factories are better manageable. The second focus emphasizes the flexibility of a manufacturing system moving out from full automation. Total automation may be theoretically possible, but it may not always be desirable. According to Pennathur *et al.* (1999), the thinking of the 1980s management that human influence in the activity of a manufacturing system can be completely eliminated needs to be examined by asking and answering questions such as ‘*can automation be implemented to an extent that there*

Table 1
Peculiarities of the Factories of the Future (FOF)

Peculiarities	Remarks
(1) FOF will have to be global and local	Influence of globalization
(2) Will be small	Not all, but majority
(3) Will produce more products in less space	Hollowing effect
(4) Need to stay close to customers	But not by shifting factory's location
(5) Will be “focused” on the product with high performance, integrity and flexibility	Modularity perspective
(6) Will be more flexible and fast	Capable of manufacturing at high speed
(7) Will have to develop a competency in the design	Concurrent engineering
(8) Will be customer driven	No products for stock
(9) Will produce highly customized products	In small lots
(10) Will become less dependent on the independent actions of disaggregated individuals	In order to succeed the aims

is very limited or no role for humans to play in modern manufacturing? The third focus points out the customer's current and future needs and wishes, and possibility to achieve them in the cheapest and fastest way.

Assuming these peculiarities of the FOF we support the proposal of Pennathur *et al.* (1999), whose hybrid manufacturing systems may dominate in future. These systems involve humans, machines, and computers in an effective partnership in various areas of their activity related to the material and information flows. The material flows regulate the processes on the shop floor of a manufacturing system, and are characterized by a number of automated equipment, such as robots, computer numerical control (CNC) machines, flexible machine stations (FMS), special machines or transfer lines. The information flow helps to create and to manage the products, processes and relationships among suppliers-producers-customers inside and outside of a manufacturing system. The information technology integrates the information flows of the manufacturing system. The possibility to integrate the above-mentioned functions in the HMS is emphasized in Section 3.

3. Computer Integration of Information Flows in HMS

The idea of computer integration in an enterprise having existed for a long time, the information flow of a separate domain is not well mastered. This idea was first formulated by Harrington (1973) but until now industrialists have much trouble implementing this approach into industry because CIM is not the sum or totality of separate components, it is linking them into an inter-operating system that will satisfy the enterprise's business objectives. The integrating system is a computer system that is utilized jointly by the members of different functional units (Alsene, 1999).

Computer systems as Computer-Aided Design (CAD), Computer-Aided Process Planning (CAPP), Computer-Aided Engineering (CAE), Enterprise Resources Planning (ERP), etc. are widely used in industry. It is a seldom case when in industry we have a well run integrated computer system which is utilized jointly by the members of different functional units creating CAD/CAM (computer-aided design and manufacturing system). Unfortunately, there are a lot of difficulties in the total integration of activities of different areas in manufacturing systems (Fig. 2). There are four main areas of the activities: product design, manufacture, delivery and exploitation. Each area has its database on different formats and approaches. On the other hand, users sometimes need the same data, which are created by different software and different suppliers. Various users of a manufacturing system have to share information with each other. Such procedures, in most cases, become a difficult task. Many papers on this research field have been published. CIM has been regarded as a competitive weapon to improve manufacturing and business performance. In the past 10 to 20 years CIM has been widely implemented at a different level of integration. However, failure with CIM has also been widely reported (Sun and Frick, 1999). Urban *et al.* (1999) proposed a database approach to the sharing of data between an engineering design and analysis tools. Their proposal goes beyond

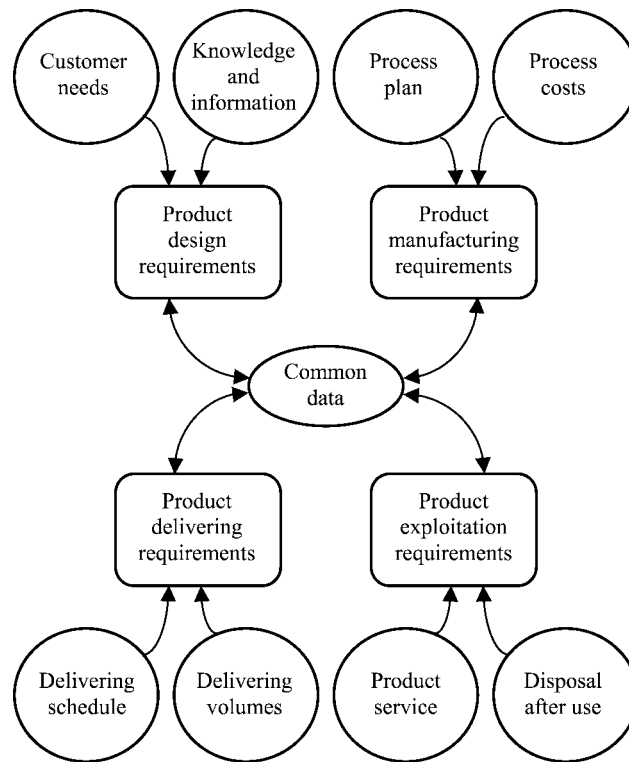


Fig. 2. The structure of a total integration of the information flows in a manufacturing system.

the functionality of current product data management tools, which deal with the product data at a semantic level. Their research focuses on the product design requirements area (Fig. 2). The work done by Zhang *et al.* (2001) is related to the same area. They have developed the Engineering Functional Design Expert (EFDEX) system to perform an intelligent functional design of engineering systems. It is assigned to upgrade the traditional CAD technology providing computer-aided tools to link design functions. EFDEX system uses the Artificial Intelligence (AI) problem solving methods, in particular, and the intelligent functional design, emphasizing the search for product variants with better product performance parameters. There are no comments in last two papers how to share the information with manufacturers and other manufacturing system participants.

Toh *et al.* (1999) developed a holonic approach for modeling enterprise functionality; this research is related to the product manufacturing requirements (Fig. 2). The researchers have solved the problem of integration of the information flows by applying the holon as the functional entity representing a unique combination of resource and employee in the enterprise. Three types of holons and their interaction to the modeling of enterprise functionality are given in their work. This methodology focuses on humans as the most flexible and adaptive resource. Harding and Popplewell (2001) tackled a similar problem, presenting how information models, databases and support tools can

be used to reduce uncertainty when modeling the desired enterprise. The factory design system has two main components: (1) an information model, called the Factory Data Model (FDM), and (2) design and evaluation tools, called Factory Design Process (FDP). The factory design procedure is provided with an information-centered, multi-view design system to facilitate and accelerate the design or the re-design of a manufacturing enterprise. This research provides valuable support to the enterprise design procedure, however, it is not ideal to support the manufacturing system in operational and planning activities. Chung and Lau (2000) has developed a Hybrid Manufacturing Information System (HMIS) which manages the information flows from a combination of relational, free format and rule knowledge data models. The research is assigned to the data exchange among various systems with the data from a common database that consists of a rule knowledge database, a relational database and a free format database. This development has been implemented in a high-technology company for data exchange. Sun and Frick (1999) investigated a shift from CIM to Computer and Human Integrated Manufacturing (CHIM). The philosophy here is the best mix and match between technological and human factors. In this paradigm, the improvement of the performance depends on both human resources and technologies. This approach satisfies the generation and integration of the HMIS information flow. However, linking the appropriate skill of humans that would be able to control complex machines and computers programs, the specialized software and hardware have to be prepared for retraining of engineers.

Our focus is the creation and integration of the data and information flows among the new product design and its manufacturing engineering. Moreover, we seek for an easy share of the integrated data among all participants of the manufacturing system (Fig. 2). A new product design and manufacturing engineering are the main stages of a product life cycle taking nearly up to 80% of its costs. Therefore, so many efforts are needed to solve this constantly and fast changing area of the manufacturing system. In Section 4 the conception of an integrated product and the process design are investigated by creating the intelligent functional model for costs minimization applying the knowledge base and DFX (Design for X) approach.

4. Intelligent Functional Model of Product and Process Design Using DFX Approach

DFX approach is based on Concurrent Engineering (CE) methodology. This methodology (Prasad, 1996) endeavors to carry out in parallel or almost in parallel the activities, which have typically been carried out sequentially. There are not many computer-based examples of CE for a product and process design (Chen *et al.*, 2002). This is not a truly simultaneous activity. CE can be achieved interacting and sharing the information among designers and manufacturers varying the value of engineering approach in which a multi-disciplinary team works to reduce the product costs once it has been designed. The appropriate software and hardware, which can help to achieve the concurrent engineering of a product and process design, are needed. This research is devoted to the achievement

of this objective. The urgency of this problem is indicated by recent publications (Kusiak, 2002; Derely and Fillz, 2002).

Taking into account our early research (Bargelis 1996; Bargelis 1998) we have developed a framework of an intelligent functional model for integrated design of the product and process using DFX approach (Fig. 3). It is assigned to the early design stage of a new product. The decisions made at the early design stage of a product mostly influence the product costs. Producers cannot change anything in a designed product. Thus, the product design should be optimized at a design stage not only in terms of the parameters of its performance and functions, but in terms of its effortless low-cost manufacture and also its assembly. The acronym DFX is deployed into DFMA (design for manufacturability and assemblability), DFC (design for cost), DFPC (design for process capability), etc, which are related to lean manufacturing.

According to this framework the model for developing the optimal process of the product is created on the software level with KB. The model uses the methods of mathematical logic, the theory of sets and the theory of chances. The first version of software has been programmed using dBase and Visual Basic 6.0 objective programming language and Structural Query Language (SQL) query in one direction, and retrieving a set of answers in the other one. The model generates the available process alternatives of the product. On the other hand, some alternatives of the product are available using KB of DFM rules and also the facts. For generating the alternatives of both the product and the process the knowledge base (KB) of DFM has been developed for separate classes of the products P , their parts R and design features D . The classification system of the products and their design features have been created, where each P and D are appointed to the separate class level. Then the product P is expressed as a set of original parts R

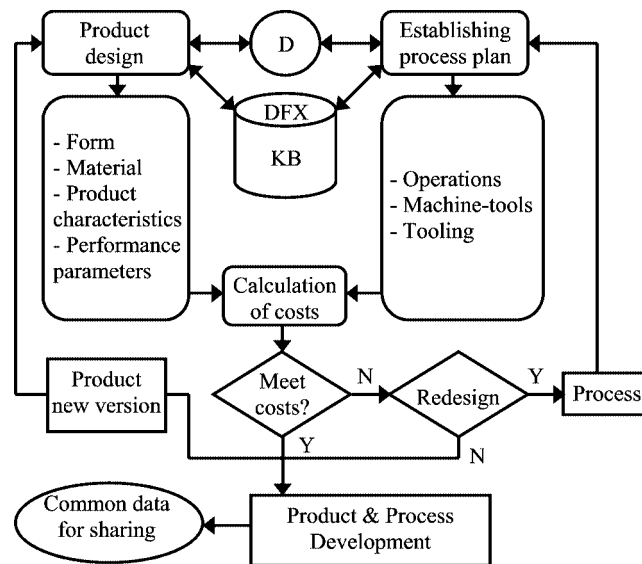


Fig. 3. Framework of the product and process integrated design using DFX approach.

and standard components S

$$P = \left(\bigcup_{i=1}^h R_i \right) \cup \left(\bigcup_{j=1}^m S_j \right). \quad (1)$$

Searching for the optimal product with respect to its manufacturability and assimilability we have to seek the following conditions

$$\begin{aligned} 0 < R &\leq n, & n &\rightarrow \min, \\ 0 < S &\leq m, & m &\rightarrow \max. \end{aligned}$$

Each part R and S of the product P is expressed as a set of design features D

$$R = \bigcup_{l=1}^r D_l = \{D_1, D_2, \dots, D_l\}. \quad (2)$$

The complexity of each D_l is denoted by a set of parameters Q_p , $p = (1, \dots, v)$, e.g., geometrical form, dimensions, tolerances, quality of the surface, etc. The designer can vary the product combining different numbers of R and S , and different qualitative and quantitative parameters of D . The product design procedure has to be closely related to the development of its processes and manufacturing resources. The main objective of process development is to create an optimal process plan (O) applying the rules and facts of DFMA. The optimum criterion $C(O_k)$ for every alternative of the process is used aiming at the set $\{C(O_n)\}$. The correct set lay-outing the elements of a set O_n is formulated as

$$\{C(O_k)\}: C(O_1) > C(O_2) > \dots > C(O_n). \quad (3)$$

It could be said that the task of the developed model is selection of a set of possible processes and manufacturing resources for each component or part

$$\forall O_k \exists (O(D_l) \times I(D_l)) \times \{H_1, H_2, \dots, H_o\}, \quad (4)$$

where $O(D_l)$ are processes of the design feature D_l ; $I(D_l)$ is a set of manufacturing resources of design feature D_l ; $\{H_1, H_2, \dots, H_o\}$ is a set of manufacturing rules for the design feature D_l .

An optimal variant of the process is selected from the set of possible production operations $A(D_l)$ and manufacturing resources $I(D_l)$. The optimal process planning is related to the optimal utilization of available manufacturing methods and resources. Pure mathematical optimization is not meant in this case. A consecutive method of reducing the manufacturing costs of the process for separate components has been used (Fig. 4). There are three stages of developing the optimal process: 1) optimal utilization of material, 2) optimal selection of operations and their sequence, 3) optimal selection of manufacturing resources.

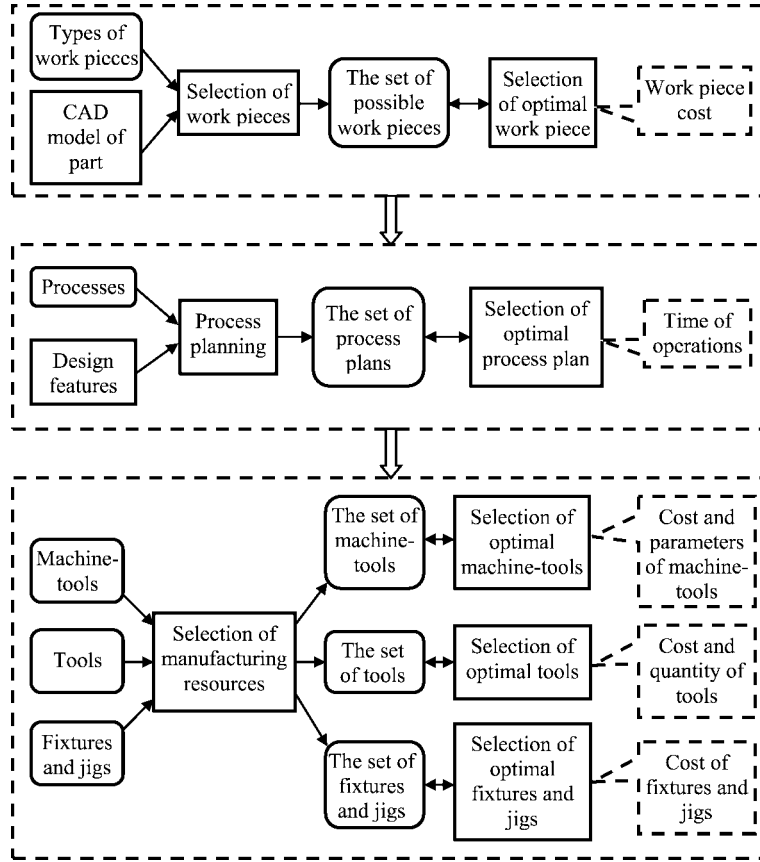


Fig. 4. Consecutive scheme of the process optimization.

For optimal utilization of material we have created a general aim function that has been used for optimizing the consumption of various materials

$$k = \frac{\sum_{i=1}^n (M)_n \cdot p}{\sum_{j=1}^m N_j} \rightarrow 1.0, \quad (5)$$

where k is the coefficient of material consumption; M is the mass of work piece, kg; p is the number of work pieces; N is the mass of raw materials used for production of M , kg.

When mass M_R of part R is equal to M , i.e., $M_R = M$ is an ideal case; it is seldom available for parts with low qualitative and quantitative parameters and a simple geometrical form or in high-run production.

The first stage of process optimization is related with other two stages selecting the process operations and the manufacturing resources (Fig. 4). The optimal selection of operations $A(D_l)$ of the process O_k from available alternatives is related to the total

process manufacturing time T

$$T = \sum_{i=1}^s (T_0)_i \rightarrow \min, \quad (6)$$

where T_0 is the manufacturing time of operations, hr.

$$T_0 = T_c + T_m, \quad (7)$$

where T_c is the conditionally constant time of operation, hr, which depends on qualitative and quantitative parameters of P, R, D and operations $A(D_l)$. KB has been developed for selection of T_c in terms of decision rules with the database scheme that is portioned into two relational schemes; T_m is the machining time of an operation, hr.

$$T_m = \left[\sum_{q=1}^{p1} (T(D_{c1}))_q \cdot e_1 + \sum_{q=1}^{p2} (T(D_{c2}))_q \cdot e_2 + \sum_{q=1}^{p3} (T(D_{f1}))_q \cdot e_3 + \sum_{q=1}^{p4} (T(D_{f2}))_q \cdot e_4 \right] \cdot k_m \cdot k_v, \quad (8)$$

where $T(D_{c1})$ and $T(D_{c2})$ are the machining time of cylindrical exposed and unexposed design features, hr, respectively; $T(D_{f1})$ and $T(D_{f2})$ are the machining time of flat exposed and unexposed design features, hr, respectively; e_1, \dots, e_4 are the density of each type of the design features in a part or component; k_m is the coefficient evaluating the material being machined; k_v is the coefficient evaluating the process capability.

When the product P consists either of cylindrical exposed for machining design features D_{c1} or flat unexposed for machining design features D_{f2} then the minimum and maximum values of T_m can be clarified

$$T_m(\min) = \sum_{q=1}^{r1} (T(D_{c1}))_q \cdot k_m \cdot k_v, \quad (9)$$

and

$$T_m(\max) = \sum_{q=1}^{r2} (T(D_{f2}))_q \cdot k_m \cdot k_v. \quad (10)$$

The last optimization stage is related with the optimal selection of machine tools. It means the optimal value of any machine tool utilization coefficient η is to be achieved applying the following aim function

$$\eta = \frac{\sum_{j=1}^t (T_0 \cdot g)_j}{\sum_{i=1}^u F_i} \rightarrow 1.0, \quad (11)$$

where g is the production volume of parts that are produced by the same machine tool type; F_i is the hours available for the same machine tool type, hr.

The selection of machine tools could be expressed as follows

$$S(A_l) = \{s \in S_k | \text{satisfy } J_s\}, \quad S_k \subset S, \quad (12)$$

where J_s are the search conditions for machine tools according to a set of operations A_l .

It is possible to generate some alternatives in each optimization stage (Fig. 4). The process alternative is a combination of the results of separate stages. The last stage of manufacturing process generation of the part R is the evaluation of available alternatives. The result of this evaluation is an optimal manufacturing process

$$\forall R_i \exists O_j^* = (\{A_{ij}^*\}, \{S_{ijk}^*\}), \quad A_{ij}^* \in \{A_{ij}\}, \quad S_{ijk}^* \in \{S_{ijk}\}, \quad (13)$$

where $\{A_{ij}^*\}$ is the optimal set of operations; $\{S_{ijk}^*\}$ is the optimal set of machine tools.

The KB for intelligent functional model has been developed. It consists of three types of knowledge: 1) product knowledge, 2) process knowledge, and 3) process planning rules. Each type of knowledge is expressed as factual, heuristic, declarative, inferred and meta-knowledge.

Product knowledge covers available materials (M), standard components (S), products (P) classes and analogues, guidelines, rules and facts, etc, for designing the best alternative of the 3D CAD model of a new product. This knowledge for the development of 3D CAD model of a product is employed.

Process knowledge embraces available work pieces, processes, operations, machine tools, fixtures and jigs, cutting and gauge tools, and miscellanies for process development, which are used in KB. Process knowledge holds all the necessary information of a manufacturing system including the statistical data of the processes capability using the cheapest production alternative. This knowledge is related to each manufacturing system and is to be filled into developed KB.

Process planning rules are logical expressions that may be used for process planning of a product. The process planning rules are classified into separate groups according to the developed model task (Fig. 5).

The object – oriented method is applied for preparing the knowledge in each separate group, i.e., the knowledge of the design feature (D) of the part (R) is presented in Fig. 6. The analogue structure of the knowledge for other elements of KB has been developed. In addition, the semantic network has also been created for each operation (A) based on the connections between D and A by the means of the *available_process_using* operator. This operator proposed a set of available operations (A) for each D . When the process is selected the appropriate machine tool is attached by means of the other type of the *available_apply_machine tool* operator.

The structure of KB contains a collection of rules and the associated database. The database contains the essential information related to the peculiarities in each group of KB structure. The set of promises *IF* and the set of conclusions *THEN* have been used for selection of a suitable decision by appropriate rules. Approximately 120 process-planning

rules have been created for the intelligent functional model in a hybrid manufacturing system. A typical example of the process-planning rule in the work piece selection group of KB (Fig. 5) is as follows:

IF part is a stepped-shaft,
AND difference of diameters of the steps is less than 15 mm,
THEN work piece is a rolled bar.

The developed intelligent functional model has been tested both in laboratory and industry. The model has generated a number of alternatives of the process plan for various components. The verification and validation tests for the developed model have been conducted in the laboratory. Some companies of Lithuania took a part conducting the acceptance tests of that model. According to the results of the above-mentioned tests a vital number of model corrections has been made. Section 5 illustrates how the developed model works and some available results from its activity are presented.

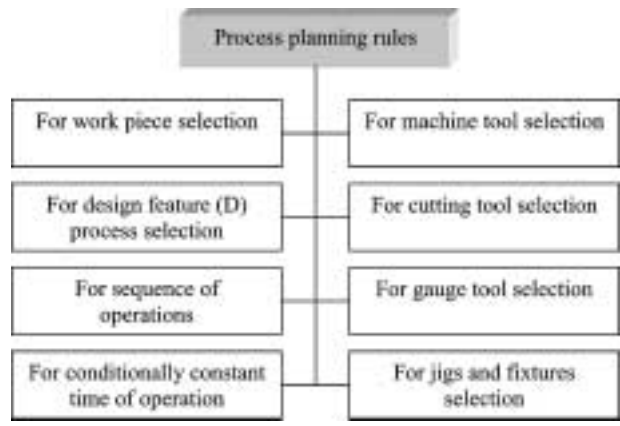


Fig. 5. Classification of the process planning rules.

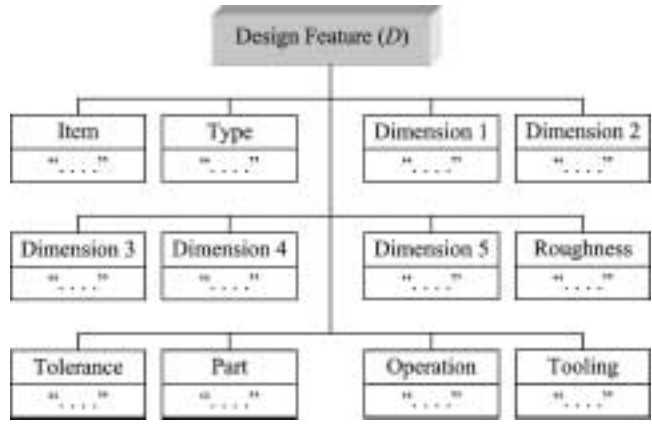


Fig. 6. Knowledge of the design features (D) of a part (R).

5. Case Study

There is shown a sequence of model work aiming at the optimal alternative of the process plan in the conception design stage of a component. A typical mechanical component – a stepped shaft with various design features and their qualitative – quantitative parameters has been taken. Firstly, a 3D CAD model of a chosen component has been created using the standard CAD software. The principal data of the model are presented in Table 2.

The second step of a model operation is the data extraction from the 3D CAD model. The extraction of the data is performed at the interactive regime. The extracted data are as follows:

- Component_type = 'shaft'
- Component_material = 'steel 45'
- Component_length = '200'
- Component_max.diameter = '40'

According to the extracted data of the component the next step for the model operation is selection of the available alternatives of a work piece. The model suggests two types of work pieces for the component:

The first type:

- Work piece profile = 'rolled bar'
- Work piece material = 'steel 45'
- Length = '205'
- Diameter = '45'

The second type:

- Work piece profile = 'stamping'
- Work piece material = 'steel 45'
- Length = '205'
- Diameter = 'stepped 35/45'

The intelligent functional model proposes two alternatives of the process plan for each type of a work piece using *IF/THEN* operators and the remaining groups of the process planning rules (Fig. 5). It combines the 3D CAD data of the component and the data of the work piece. Four alternatives of the developed process plan of the component are presented in Table 3. Fig. 7 illustrates the manufacturing costs determined by the model for each alternative process plan.

Table 2
Principal data of 3D CAD model

Material	Length, mm	Maximum diameter, mm	Number of design features	Minimum tolerance, mm	Minimum roughness, μm
Medium-carbon steel 45	200	40	13	0.15	0.63

Table 3
 Alternatives of the process plan for a selected component

Work piece alternatives	Process plan alternatives	
1. Rolled bar	Alternative 1	Alternative 2
	05 Cylindrical turning 1	05 Milling – centering
	10 Cylindrical turning 2	10 Cylindrical turning
	15 Drilling	15 Drilling
	20 Milling	20 Milling
	25 Grinding	25 Grinding
2. Stamping	Alternative 3	Alternative 4
	05 Form turning	05 Longitudinal turning
	10 Drilling	10 Drilling
	15 Milling	15 Milling
	20 Grinding	20 Grinding

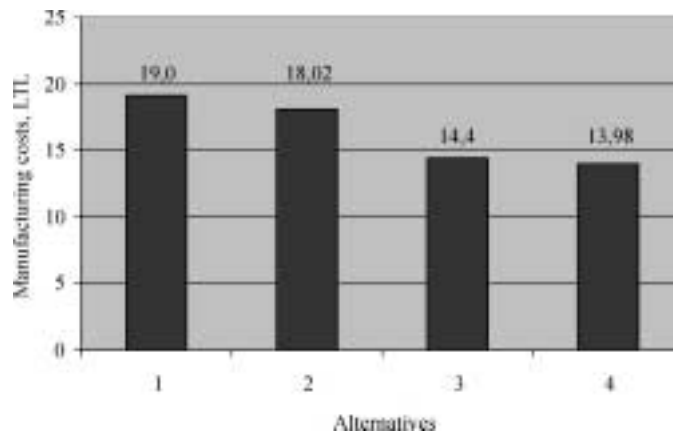


Fig. 7. Manufacturing costs of the process plan alternatives determined by model.

Seeking for the lean production the manufacturing cost should be deployed into its components. This procedure can indicate the possibility to decrease the component cost by introducing appropriate engineering to the product and process design. Distribution of manufacturing cost into its components is carried out by means of the model and presented in Fig. 8.

6. Implementation and Further Research

The developed model or its separate parts are implemented in industry of Lithuania. The implementation results in some companies have shown that the model is able to gener-

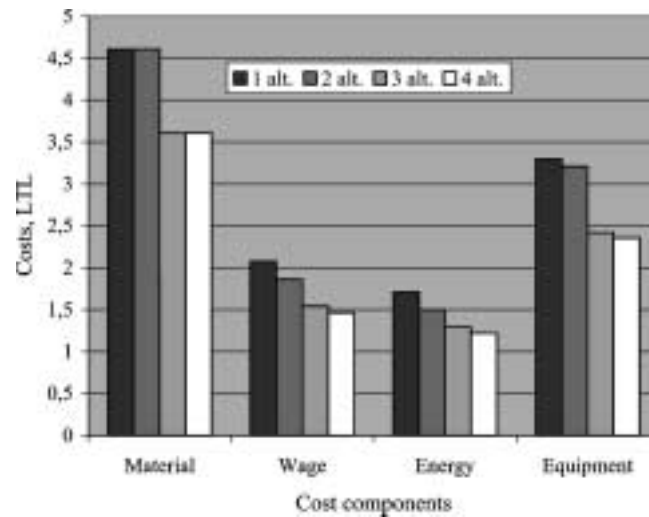


Fig. 8. Deployment of a manufacturing costs for each alternative of the process plan.

ate several alternatives for a work piece and a process plan for each part both in virtual and real environment. It is applicable for the optimal process planning. Application of the model makes it possible to determine whether it is feasible to produce the part with appropriate resources and reduce the time (to 40–60%) of alternative process plan evaluation. Comparing the results of manufacturing costs calculation, obtained using the created model and traditional methods, the noticeable inadequacy does not exceed 8–12%. On the other hand, the implementation of the model requires changing the former order of organization activity preparing and sharing the information for the product and process design. Sometimes it causes dissatisfaction of the employees in an organization. The appropriate re-training program of engineers is necessary seeking their more effective work in the integrated manner. This model is also applied to the educational process of the Faculty of Mechanical Engineering and the Faculty of Technologies in Panevėžys Institute of Kaunas University of Technology.

We are planning to investigate and to upgrade the structure of HMS seeking more effective interfaces among various computer systems employed for generation of necessary information. It depends on the size of the organization and its functions. On the other hand, an Internet technology evolved rapidly over the last decade, and web sites have become the most popular and visible components. Our further research, therefore, is devoted to the new product design collaboration applying the web-based system when developers, suppliers, manufacturers and buyers are located apart at large distances and in different countries. The research object is development of an appropriate portal, which could help in better communication when searching the cheapest developers and producers of products in various companies and countries.

7. Discussion and Conclusions

The research in this paper presents an intelligent functional model for the costs minimization in the hybrid manufacturing system for the integrated product and process design. The new product and process design is the essential task of the manufacturing organization that defines other areas of the company activities. The framework of an intelligent functional model based on the integration of the information flow of separate domains applying the knowledge base and combination of DFX method for the product and process design has been developed. It has been stated that the optimization process is time consuming and a consecutive scheme has been used for the process optimization of products and components.

The method that has been described in this paper accomplishes the objective of this research. However, this is not the only method currently available. It has its advantages and disadvantages. The advantages are several: the originated interfaces and DFX approach has been simultaneously used for the product and process design taking into account the qualitative and quantitative parameters of their design feature (D). The mathematical formalization, particularly functional expressions, heavily aligns the developed alternatives of the process plan during their optimization procedure. The principal shortcoming of the developed model is poor intelligence of its product design part in comparison to reviewed works (Zhang *et al.*, 2001); unfortunately, the latter research does not include the process design part of a product.

Briefly we can conclude as follows:

1. The intelligent functional model by using the object-oriented approach, which describes the properties of different objects and relations among them, has been created.
2. The developed knowledge base of the model encompasses the information about products, processes, manufacturing resources and production rules. It is applicable to the optimal process planning.
3. Process planning optimization is based on the algorithm of consecutive reduction of manufacturing resources and appropriate objective functions make it possible to reduce the time and costs for the product and process design.
4. The created model helps to disclose the regularity of changes of the manufacturing costs by changing the structure of the product and process; the combination of operations and allowances diminish the costs of materials and other resources.

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Intelektualus funkcinis modelis išlaidoms mažinti hibridinėse gamybos sistemose

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Straipsnyje aprašytas intelektualus funkcinis modelis, skirtas gaminio konstrukcijai ir jo gamybos procesui optimizuoti hibridinėse gamybos sistemose, sudarytose iš žmonių, mašinų ir kompiuterių. Pasiūlyta intelektualaus modelio schema, grindžiama žinių baze, kuri padeda ir gaminio konstruktoriui, ir gamintojui rasti optimalų gaminio gamybos planą. Pateiktas modelio matematinis formalizavimas. Sukurtas intelektualus funkcinis modelis naudoja nuoseklią optimizavimo schemą ir gaminio, ir jo gamybos plano optimaliai alternatyvai parinkti. Pasiūlytas modelis diegiamas ir pramonėje, ir universitetinėse studijose.