COST FORECASTING MODEL OF PRODUCT AND PROCESS DEVELOPMENT AT THE BUSINESS CONCEPTION STAGE

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Abstract: This paper deals with cost forecasting model of product and process development at the business conception stage in order-handled manufacturing system. Mechanical products as solid design and sheet metal design have been considered in this research.

Key words: Product, process, cost, development, forecasting.

1. INTRODUCTION

The manufacturing environment during past several years very much has changed; it became modern competitive weapon for mastering of new production methods and appearance of novel products. It turns to Global manufacturing (GM) environment which may be characterized by two main parameters: high level of competition and economy of labour [1]. The need of new products and processes design with minimum cost is increased. New manufacturing strategy, therefore, that expands agility and flexibility, high productivity, reduced design cycle and product delivery time to customer has appeared. It demands effective new design methods, techniques and tools applying laser, information and other high technologies. Cost forecasting of product and process development at the business conception stage becomes very urgent in GM [2]. Cost forecasting model may be able to foreseen different possibilities in discriminating GM environment finding best developers of novel products and producers in order-handling manufacturing system. It has to use the logistics information flows among different business partners located apart in large distances and estimating every contribution and cost outlay [3].

The main objective of this research is to develop and generalize theoretical methods of product and process modelling, and cost forecasting at the business conception stage for production of big variety product types and low production volumes. Mechanical products as solid design and sheet metal design have been considered in this research.

2. COST FORECASTING MODEL

Integration of scientific principles and good practice for optimal new product and process development at the early business implementation stage become decisive. A role for winning orders and achieving high competitiveness in GM environment belongs to computers and modelling of the product and process concurrent design [4]. The customer target cost of a product often close to materials cost is tendering. Order-winners, therefore, have to develop an optimal product and process with minimum cost and appropriate tooling, facilities, material suppliers, and logistics functions. Make or buy strategy [5] in today’s discriminating manufacturing area demands a strong functions repartition among customers, products developers and producers, which are apart in large distances.

2.1 Methodology and Model Structure

The methodology applied in this paper is modelling of the information-based system definition. This definition is based on the
investigations done at the mechanical products and processes development area during 12-15 years. The investigations on different solid and sheet metal design products and processes, manufacturing operations and costs also product delivery time have been motivated on the interactions among these elements. The causal models have been used in the form of mathematical equations [6] for the achievement of the paper research objectives, because various factors are influencing the cost forecasting of product and process development at the business conception stage. The structure of a proposed model for single run, small batch and medium batch order-handled manufacturing system is presented in Fig. 1. The model is based on a man-machine computing approach and it concurrently considers the early stage of new product and process development. First step is observation of market needs and proposals; there are two possibilities – to get order for production of customer product or try to develop own one. Creation of a new product with high investments and risky is related and often majority companies the first possibility are choosing. Next steps are product and process development applying the experience and traditions of customers, producers and competitors. Products’ classification approach aiming decrease the uncertainty is used. It helps employing knowledge and good practice for products and processes that are set up in separate class levels. The forecasting of manufacturing cost for each alternative is arranged and checked with market requirements. If alternative does not satisfy market requirements then product or process must be re-designed. Best product alternative to the business is implemented.

2.2 Development of a New Product Conception

The optimal variant of a product virtual prototype (VP) according to the customer requirements as a first step of its conception is developed. Product functionality, parameters and production costs as main criterions have been used. Product analogous often have been taken. If no analogous, then design axioms and Design for Excellent (DFX) methodology [7] have been used. Necessary information for product design at the conception stage in Fig. 2 is systematized. Next step is creation of product Physical Prototype (PP) applying Rapid Prototyping (RP) techniques for solid products and traditional technologies for sheet metal design products. Product PP is useful seeking aims as follows:

- Design visualization
- Finding design mistakes
- Marketing studies
• Consideration and improvement of product functionality and parameters
• Communication tool for simultaneous engineering.

Different RP methods for new product development are available. Web-based portal of RP customers and developers [8] are created for this aim. It supports cooperation among customers, suppliers and product developers finding best RP alternative, which on costs estimation and delivery reliability are based. Sometimes to avoid PP when product is very simple or production volume is small is possible. In this case all necessary products’ data in VP may be presented.

The classifier of mechanical and electronical products that are produced in Lithuania is presented in Table 1. Jointly the conditional values of investments $m$ for infrastructure, licenses, RP facilities and so on, Euro/h, and coefficient $r$ of product design complexity applying consideration statistical data have been modelled.

Available products $G$ according to the developed classifier into a terminative number $K$ of different class levels are classified:

$$G = \{G_1, G_2, ..., G_n, G_s\}; \quad (1)$$

A lot $G_1$ belonging to the class $K_1$ could be expressed:

$$G_1 = \{K1 : K1 \in A1\} \quad (2)$$

where $A1$ is parameters’ entire of products class $K1$.

Any product $G_n$ consists of a lot $R$ original parts and a lot of $S$ standard components. Aiming to the optimal product and process design it is necessary to search a best combination of parameters $R$ and $S$ as follows:

$$\begin{align*}
0 < R \leq n, \quad n \to \min, \\
0 < S \leq m, \quad m \to \max
\end{align*} \quad (3)$$

where $n$ is number of original parts; $m$ is number of standard components.

Every original part $R$ and standard component $S$ consists of design features $D$ with various qualitative and quantitative parameters. Entire of design features $D$ is also classified into two classes – rotational and prismatic geometrical form. Thus product original part $R$ as a lot of $D$ can be written:

$$R = \bigcup_{i=1}^{n} D_i = \{D_1, D_2, ..., D_l\} \quad (5)$$

The complexity of design feature $D_i$ is expressed by the lot of parameters as geometrical form, dimensions, tolerances and surface roughness, and so on. Therefore, each design feature $D$ could be described by the parameters set as follows:

$$D_j(f_j, a_j, b_j, c_j, d_j), \quad D_j \in KEK \subset E \quad (6)$$

where $f_j$ is geometrical form; $a_j$ are dimensions; $b_j$ are qualitative and quantitative parameters; $c_j$ is surface roughness; $d_j$ are tolerances; $KEK$ is classifier of design features; $E$ is set of design features.

Product conception development costs by applied investments $N$ can be defined:

$$N = (m + s)/r \cdot p \quad (7)$$
where \( m \) is investment of infrastructure, Euro/h (Table 1); \( s \) is engineer labour cost, (6.2 - 9.3 Euro/h in Lithuania); \( r \) is a coefficient of a product complexity (Table 1); \( p \) is a probability of the requested target value and the actual designed value.

Fig. 3 presents the real investment curve for complex products cost definition at the conception stage and analogously Fig. 4 presents the same data for simple products. The distribution of products into two groups is conditional and it is not mean that development of simple products is easier then complex. The definition of customer requirements and market needs also creation an optimal process with minimal manufacturing cost is very consuming and hard job. It is very difficult to plan a straight period and resources for this aim.

![Complex products](image1)

![Simple products](image2)

**2.3 Prediction of Process Engineering and Production Costs**

The process prediction model by the dependence of production volume \( (V) \), initial material sort \( (M_i) \) of a part, material profile \( (P) \), variety of design features \( (D) \), and their qualitative and quantitative parameters \( (Q) \) have been developed. In this way, any material sort and its initial profile type demand appropriate technological operations, e.g. if a part is made of thin sheet metal (thickness from 0.7 to 6 mm), then the operations will be as follows: preparatory, guillotining, cutting, punching, stamping, bending, welding, cleaning, painting, galvanizing and so on. Manufacturing process can be made from different sequence of technological operations. When the thickness of the sheet is increased, some of mentioned operations are omitted, and instead additional operations (milling, heat treatment, grinding and so on) are introduced and all of them may be in one complete set or may have various combinations. Therefore, any sort of material \( M_i \), and other above mentioned parameters correspond to the function \( f \) of a definite set of technological operations \( O \):

\[
O = f(V, M_i, P, D, Q) \quad (8)
\]

The number of product parts, their size as well as the parameters mentioned in equation (8) predetermines the combination of technological operations not only for metal sheets, but for any type and profile of material (bars, moulds, and
forges) as well. There are some chances matching number of product parts and their complexity for minimal costs. When the production process plan of a part with its technological operations and appropriate machinery is forecasted, then it is possible to forecast manufacturing cost. Manufacturing costs are divided into three fundamental categories \[9\]: fixed cost, variable cost and material cost. Thus, total costs \( S \) of a manufacturing process is calculated:

\[
S = S_1 + S_2 + S_3 \quad (9)
\]

where \( S_1 \) is material cost; \( S_2 \) is fixed cost; \( S_3 \) is variable cost.

Material cost \( S_1 \) can be easily defined using the dimensions of work pieces. There is enough software and methods for definition the material consumption applying part’s 3D CAD model \[10, 11\].

Fixed cost \( S_2 \) is related to the investments for machine tool and working space rental. It is to be spent before the parts are produced; therefore, it must be allocated to an individual component. The rate of machine maintenance cost currently obtained from a machine supplier has been used as well. Statistically defined average set up time cost per month is also included in machine cost category.

Variable cost \( S_3 \) is related to the labour cost, which directly depends on total floor-to-floor time in manufacturing shop. A methodology described in references \[9, 12\] for definition labour cost \( S_3 \) has been employed. By applying the above-mentioned cost calculation peculiarities and the acquired statistical data, a broad-brush parametric function is developed for forecasting manufacturing cost \( S \) at the early business engineering stage:

\[
S = \left( S_1 + \sum_{j=1}^{m} (A \cdot S_3 ) \right) F + \frac{J}{E} \quad (10)
\]

where \( S_1 \) is part material cost in Euro; \( A \) is technological operation cost in Euro/h; \( S_3 \) is part manufacturing time in h of an operation; \( F \) is coefficient for organization institutional cost, \( F = 1.05 – 1.20 \) for considered three Lithuanian SMEs; \( J \) is cost for special tooling in Euro; \( E \) is part production volume.

3. RESULTS

The developed methodology by integrated product and process development has been tested. Considering of Global customers, suppliers, producers and consumers’ network showed that Lithuania is a country of producers. It is historically ordered because Lithuania in market has entered too late and at the current moment it feels troubles developing competitive products to market. Local businessmen to do investment for new products development have feared because high risky exists.

The model estimation of investment forecasting accuracy of conditionally simple products development was made. The principal data of products are presented in Table 2. Product \( G1 \) consists of table and 2 chairs and its purpose is to use in summer house. Product \( G2 \) has purpose to use it in office or living room when working with computer. Product \( G3 \) consists of 5 assembling units which can create big variety of products in living rooms and offices. The powder painting and galvanized processes for parts finishing operations have been employed. These products in two different SMEs have been developed and produced.

The investment for product development applying companies’ statistics DB and experience is illustrated in Table 3.

<table>
<thead>
<tr>
<th>Products</th>
<th>Compo-</th>
<th>Raw material</th>
</tr>
</thead>
<tbody>
<tr>
<td>( G )</td>
<td>nents q-ty</td>
<td></td>
</tr>
<tr>
<td>1. Set of furniture</td>
<td>3</td>
<td>Plastics, tubes, sheet metal</td>
</tr>
<tr>
<td>2. Chair</td>
<td>1</td>
<td>Leather, solid metal, tubes</td>
</tr>
<tr>
<td>3. Set of shelf</td>
<td>5</td>
<td>Sheet metal</td>
</tr>
</tbody>
</table>
Table 3. Investment of product design

<table>
<thead>
<tr>
<th>G</th>
<th>Customers requirements in h</th>
<th>Design in h</th>
<th>Test in h</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80</td>
<td>120</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>120</td>
<td>260</td>
<td>90</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>100</td>
<td>60</td>
</tr>
</tbody>
</table>

difficulties appear customer requirements definition for all considered products. Requirements for a product address the needs and objectives of the stakeholders that are expressed by the constraints and performance parameters; therefore, product engineers derive a consistent set of more detailed engineering statements of requirements as the design progresses. In fact, data presented in Table 3 with probability 0.8 – 0.6 has been occurred. The last step of development is forecasting of product manufacturing cost employing expression (10) with accuracy 5 – 12%.

4. CONCLUSION

The created methodology estimates the investment of a new product development with sufficient accuracy. It helps for stakeholders to resolve aiming new business. The presented methodology of investment forecasting, applying the integrated product and process design can be easily adapted into various SMEs. It stimulates activity of searching the new products and manufacturing methods.

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6. REFERENCES


7. ADDITIONAL DATA ABOUT AUTHOR

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