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Enhancing of injection mould quotation accuracy

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Abstract. Quotation in the field of injection mould manufacturing is a highly complicated task. The simple cause of this is that one must estimate the mould design and manufacturing time and cost, with unknown tool construction and complexity. The aim of the authors is to summarize existing quotation methods and to introduce an experimental cost estimation system, which permits calculation of realistic manufacturing cost and time in advance, based on the local design and manufacturing environment.

Key words: injection technology, mould quotation, cost estimation.

1. INTRODUCTION

The minimal or competitive production price can be determined only after estimating the self-cost of mould design and manufacture. In the early phase of the project there is no way to create a detailed mould design and manufacturing plan in order to gain accurate cost and time estimations. In the case of underestimation, the cost of a quotation increases further more the deficit. On the other hand, if the price is too high, we may loose not only an order but an important costumer. If we win a project with too low price, the design and manufacturing process will be non-profitable. Thus we need an accurate estimation of the time and cost data with as little effort as possible.

Cost estimations are made in various ways by different companies. In [1] several upper-level and middle-level management decisions are made concerning problems starting from plant location to supply chain management.

In mould making industry, four basic quotation methods are used to estimate time and cost of tool design and manufacturing [2].

The first method is known as *intuitive estimation* since it is based on the personal experience. The application of this method needs a lot of experience and deep knowledge on the design and manufacturing environment. A junior expert can estimate the real data with a huge error that can exceed ±50%.

The second method is called *analogue estimation*, which uses time and cost data of previous mould productions. This method is more reliable than the intuitive one, if a large database is available. Even with using a computer program for evaluations with this method, the cost expert must have a deep knowledge about previous mould constructions and manufacturing processes. The previously produced documents about mould design and manufacturing must be well maintained. This method cannot be applied in case of relatively new mould types for which past experience is missing. The accuracy of the analogue estimation method can usually achieve ±35% [[2]].

The third method is called *parametric estimation*; it utilizes some selected product design parameters, which are essential in cost and production time estimation. Mostly the overall mass of the product or global dimensions are used, but also some more complicated and sophisticated graphical and calculation methods are used (without essential benefit to the estimation accuracy). This method is applicable only for rough calculation [[2,3]].

The fourth method is *analytic estimation*, in which case the object is divided into components and this method determines cost and time data for the simplified components. Using this method, the engineer must have a deep knowledge in mould design and technology in order to identify the essential features and division borders. The method is very time-consuming, but an expert user with special skills and experience can achieve the level of estimation accuracy ±5%, while a beginner can achieve only ±15% [[2]].

The quality of the estimation depends on the experience and background of the user of the described methods.

Table 1 shows the advantages and disadvantages of the cost estimation methods. Based on these considerations we can determine the features of an ideal quotation system: it must be easy to use, must require short processing time, should yield accurate results with consideration of current and actual design and manufacturing environment and the results must not depend on the user's experience.

In [[4]] a parametric cost estimation system for die casting is described; the cost is in direct proportion to material cost. In [[5]] the parametric method is used for the estimation of the mould cost. The relation between cost and product

Table 1. Advantages and disadvantages of known cost estimation methods

Method	Advantages	Disadvantages
Intuitive	Fast, easy-to-use	Experience-based, inaccurate, non-consistent
Analogue	Environment oriented	Time-consuming, huge database
Parametric	Fast, simple	Inaccurate, heuristic
Analytic	Accurate	Time-consuming, experience-based, sophisticated

complexity is investigated in [6] using the parametric method. In [7] a modification of the analogue method is used; an artificial neural network is used for similarity estimation. Chin and Wong developed a rule based expert system, which can divide the mould making project to sub-processes [8].

2. THE ECOTEST/MOULD COST ESTIMATION SYSTEM

Following [3], a method, based on an artificial neural network, is proposed for time and cost estimation in plastic injection moulds design and manufacturing process. The proposed expert system creates relationships between the essential features of the product and the estimated time and cost data. This system reuses the post-processed cost data of complex moulds and determines the hidden relationships between the characteristic features of the part and overall cost (Fig. 1). The artificial neural network is a tool for computational tasks, which has biological analogy. An artificial neural network is a hierarchical net of simple elements which are called nodes (Fig. 2) [9].

A perceptron-based neural network is used, where the nodes summarize the weighted inputs and transform them into a non-linear function. If three layers of nodes are created, where the first contains the input data, the third represents output data and the relationship is determined by the learning process itself.

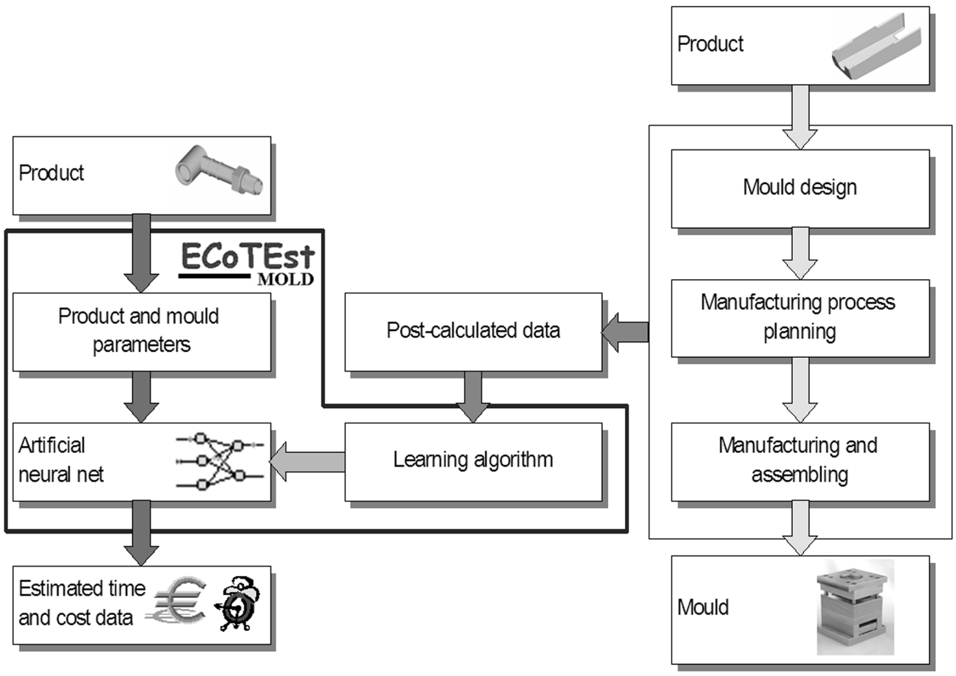


Fig. 1. Concept of the ECoTEst MOLD.

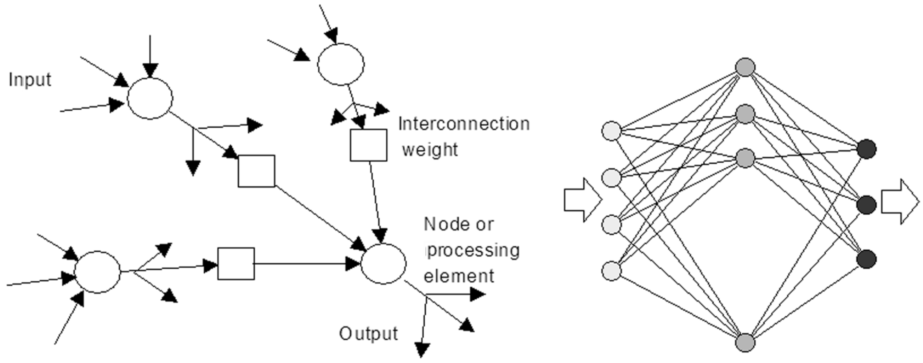


Fig. 2. Perceptron-based artificial neural network.

The learning process needs a case base, which consists of post-calculated time and cost data of moulds. The usage of this data has several advantages. On one hand, these moulds were designed and manufactured by the given (i.e. user) company, so they contain the in-house effects and particularities of the design and manufacturing process. This fact ensures that the actual design and manufacturing environment is considered. Production of a mould needs different time and cost in different mould shops, because the skills of the employees, quality and number of machine tools are different.

The post-calculated data has other advantages as well. These moulds have already been produced, therefore the cost and time data are absolutely exact and there is no need to use theoretical formulas. The post-calculated data contains also the cost of correction of the manufacturing failures, which can be interpreted as a disadvantage. The manufacturing failures are stochastic, their importance and cost cannot be forecasted, and so the correction of measured data is needed in order to eliminate random effects. But considering manufacturing processes of several moulds, the average cost of repairing is relatively constant. This value characterizes the technical and human state of the mould shop and this is an important indicator.

One of the most important problems is the content of the learning case base. In the installation phase of the project, the system must be adjusted by the systematic learning process.

It is not practical to exclude non-typical moulds or moulds that had too many manufacturing problems, because they can cause distortion of the results. We must create a most heterogeneous case base, because the extrapolation skill of the net is rather weak.

The learning process needs about 80–100 implemented cases for installation; thus it can perform properly on an annual production of a middle size mould shop. After installing EcoTEst, in the beginning (maximum for a year) it is recommended to use the system as an alternative or background solution parallel with one of the above-listed methods, to control and compare the results and to complete the case base with new post-calculated data. When the system contains about 200 cases, it is able to learn efficiently.

It is suggested to supplement the case base with new post-calculated project results and to execute new learning process once or twice a year. Such a maintenance ensures the continuous evolution of the accuracy and the capacity of the system.

3. INPUT/OUTPUT PARAMETERS

One of the most important steps of the system development process is the definition of the input and output parameter set. The output parameter set can be defined rather simply, because it is determined by the time and cost data required. The needed data is as follows:

- Total cost of the project
- Material cost
- Design time and cost of the mould
- Time and cost of process planning and NC programming
- Time and cost of manufacturing grouped by machines (milling, turning, grinding, EDM, drilling etc.)
- Time and cost of fitting and assembly

The selection of input parameters is a more difficult problem. The reason for that is that the selected parameters must satisfy several conflicting conditions. One can only use such parameters, which can be determined from the representation of the design like 2D drawing, physical model, 3D CAD model in any format, etc. Every essential property of the products must be selected, which has essential effect on the mould structure, size and complexity. The concept of the mould must be developed during quotation, and some characteristic properties must be taken into account to obtain accurate results. One of the most important viewpoints in the parameter selection is the clear structure and avoiding a too large number of parameters. Based on these rules, the input parameters are as follows.

Global/overall dimensions of the product

One of the most significant parameters is the maximal dimension of the part. The part's height, being parallel to the mould open-close direction, influences the height of the mould. The dimensions normal to the mould height influence the closing force required and the injection machine.

Mass of the product

The mass of the product determines the material cost of the elastic or plastic part and influences the mould machine selection.

Number of cavities

With higher number of cavities a higher productivity of the mould can be obtained; however, the cost of mould making is also larger. The operation of a multi-cavity mould requires a moulding machine, which is able to ensure the needed force.

Complexity of the product

The complexity of a part is a sophisticated term, not easy to define. In the ECoTEst system this parameter is defined in a scale from 1 to 10, where 1 means the simplest and 10 the most complicate mould structure. These categories can mean different mould structures in each mould shop, so during installation the case studies must be included to support users. One should not use the minimum and maximum values of the scale in the beginning, because in the future cost estimation for more simple or more complicated moulds may be needed.

Estimated overall size of the mould

Based on parameters, mentioned above, the overall size of the mould (Fig. 3) is estimated; it is appropriate to use standard plate dimensions of the material in order to reduce material cost.

Complexity of the mould structure

Complexity of the mould structure is scaled from 1 to 10 similarly to the product. The mould structure is simple if it consists only of core and cavity plates and the dividing surface is flat, while a multi-cavity mould with sliders, lifters, two-step ejections and threaded insert means very high complexity.

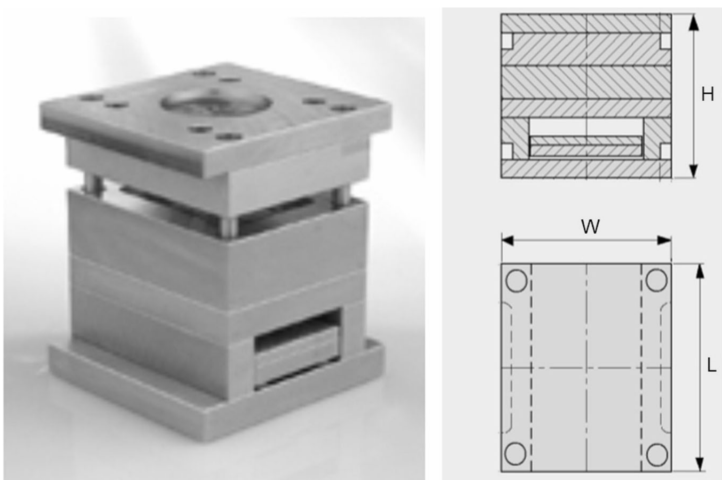


Fig. 3. Overall schema of a mould.

Type of the runner system

An injection mould has a standard runner surface or a hot runner system (Fig. 4). A standard runner surface is more simple and cheaper to manufacture, but the time of an injection cycle is longer and provides significantly more material wastes. Although applying a hot runner system leads to shorter cycle time and nearly zero material waste, it is considerably more costly.

Complexity of sliders and lifters

These parameters characterize the geometric complexity of sliders and lifters in a scale from 1 to 10.

Quantity of sliders and lifters

Sliders and lifters form undercut surfaces, which cannot be formed only by a core and cavity (Fig. 5). Application of more sliders means higher mould complexity, more components, and so the cost of the design, process planning and manufacturing will be higher (this parameter is also scaled from 1 to 10).

Quantity of deep ribs and cavities

Deep ribs and cavities increase the cost of a mould as they can not be machined by milling but on EDMs. The additional cost appears both in the planning and manufacturing phase (the parameter is scaled from 1 to 10).

Quantity of EDMed surfaces

One has to determine surfaces, which cannot be manufactured on a milling machine, but only on an EDM, because of their shape (weak walls) or material (also scaled from 1 to 10).

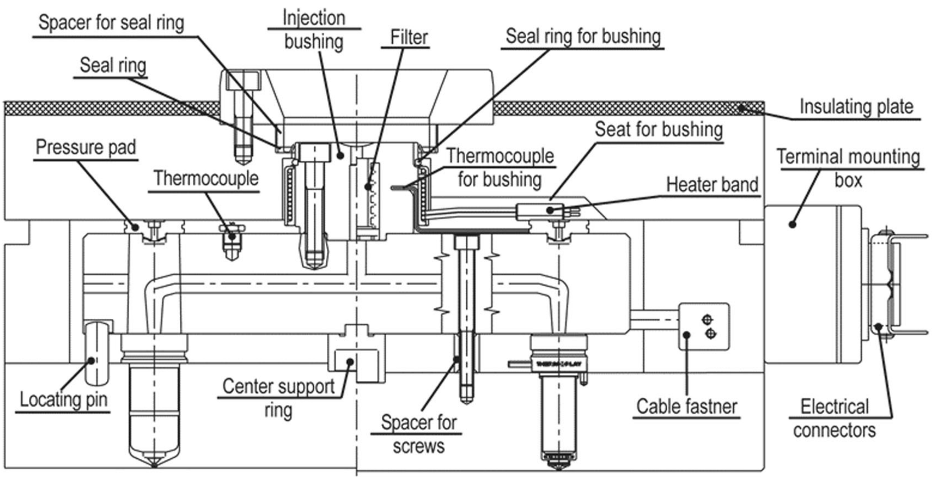


Fig. 4. The hot runner system.

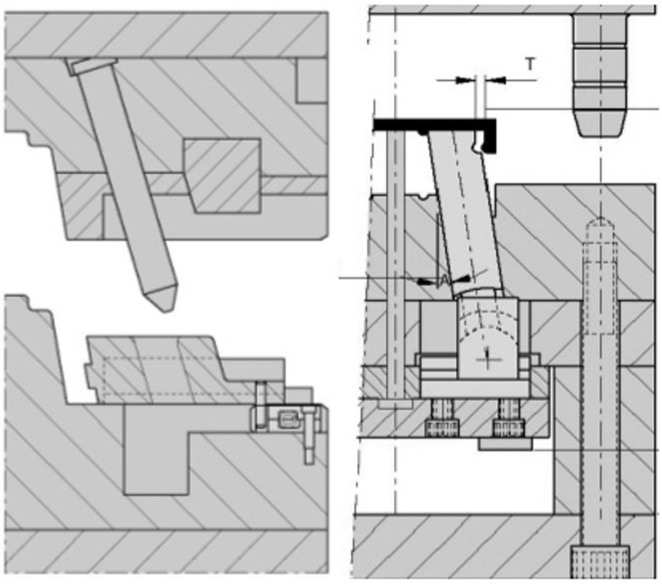


Fig. 5. A slider and a lifter.

There are several reasons why the application of the EDM technology increases the manufacturing cost. First of all, EDM technology requires electrodes, which demands additional tool design and process planning and manufacturing. Secondly, the EDM process has low productivity. Thirdly, if the product's surface requirements do not allow EDMed surface quality, the surface finishing demands additional manual manufacturing.

Quality of the product's surface

The product surface must meet design requirements, functionality and manufacturability. The surface structure and quality depend on the mould's manufacturing process. If necessary, this structure can be eliminated by manual manufacturing or super-finishing.

In certain cases the costumer requires special surface structure like leather design. This structure can generally be manufactured by EDM. The surface can be machined also by electrochemical machining, which needs many manual pre-processes (e.g. the milling paths or the EDMed hard surface layer must be removed).

Heat treatment requirements

Certain product parts need heat treatment that leads to additional cost and production time as well as to additional transportation, if the heat treatment cannot be managed in the mould shop.

In the cost estimation system there are three types of parameters to be distinguished. The first type are exact numerical values such as overall dimensions of the part. The second type of parameters can be generated from the mould's requirement list, for example from the heat treatment requirements or type of the runner system. The parameters of the third type have subjective values, like complexity of the mould structure. The effect of subjectivity can be reduced by a user's manual, where the selected values can be illustrated by examples.

Interpretation and specification of input parameters require perfection in the mould design. The conceptual mould design is also required in advance, as the overall size of the mould, the number of lifters and sliders can not be defined without that.

4. AN INDUSTRIAL EXAMPLE

Figure 6 shows one of the test parts, a handle frame. The overall dimensions of the part are $265 \times 110 \times 45$ mm, the material of the part is ABS/PC, and because of there are no undercuts, the mould has a simple structure (open/close, no sliders and lifters). The required number of the cavities is 1, and the customer required a simple runner system. There are no undercuts, but there is a lot of ribs, which increase the complexity of the part. The visible surfaces need a fine EDMed structure. Table 2 shows the case file of this mould.

Based on industrial practice we processed about 100 cases. During the data processing we collected various cases, several products have more than one mould with different runner systems and different numbers of cavities; thus the effect of these parameters is well represented. This case base is suitable for developing and for the ANN-based learning process. Of course it can be used in the study of the case-based reasoning approach of mould quotation.

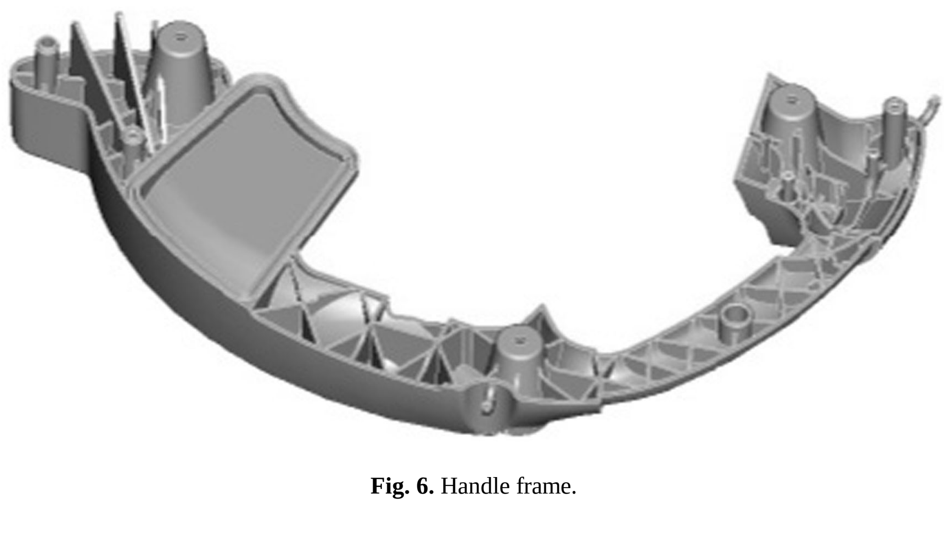
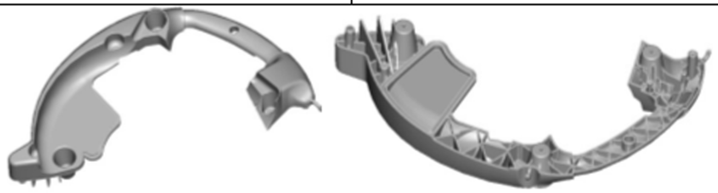


Fig. 6. Handle frame.

Table 2. An industrial example

			No.: 025
Part's name: **Handle frame**	ID.:		**651-1A1-170C**
			
Overall dimensions of product:			265x110x45
Mass of product (g):			253
Material:			ABS/PC
Complexity of the part (1-10):			5
Estimated overall size of mould:			246x396
Number of cavities:			1
Complexity of the mould (1-10):			3
Runner system: 1 – Could runner, 2 – Heated central runner, 3 – Full hot runner system			1
Quantity of deep ribs and cavities (1-10):			6
Quantity of EDM-ed surfaces (1-10):			8
Quantity of sliders and lifters (1-10):			1
Complexity of sliders and lifters (1-10):			1
Quality of product's surface 1 - Milled, 2 - Polished, 3 – Polished glossy, 4 – EDM-ed raw, 5 – EDM-ed medium, 6 – EDM-ed fine, 7 - Photo etched			6
Heat treatment requirements 1 - None, 2 - Hardening, 3 – Hardening and tempering, 4 - Nitriding, 5 – Plasma nitriding			3
Comment, description: open/close, with many ribs			
	Hour	**€**	**€**
Total cost			**17.500**
Material cost			2.356
Total production	**498**		15.144
Design	55		2.192
NC programming	50		1.993
Machining	304		10.255
Nc milling	*130*	*5 819*	
Milling	*20*	*482*	
EDM – die-shinking	*65*	*2 535*	
EDM - wire	*30*	*938*	
Lathe	*7*	*36*	
Drilling	*17*	*100*	
Drinding	*35*	*346*	
Hand work	60		469
Polishing	*30*	*235*	
Fitting	*30*	*235*	
Assembly	30		235

5. CONCLUSIONS

In the case of conventional cost estimation methods, the accuracy and the productivity are somewhat contradictory. The ANN is not a mere means of estimation, but also suitable for resolving conflicts. Based on the local case base, the ANN can create the tailor-made relationship between the product and the manufacturing time and cost required.

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Survevaluvormi hinnapakkumise täpsuse suurendamine

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Survevaluvormi valmistamise hinnapakkumise koostamine on keeruline ülesanne ja selle metoodika väljatöötamine on suureks väljakutseks nii tööriista- kui ka plastdetailide valmistajatele. Tööriistavalmistajatele on probleemiks erinevused tegeliku ja arvutatud aja ning maksumuse vahel, mis on saadud kehtivaid reegleid järgides või hinnatud katseliselt. Hinnata tuleb valuvormi projekteerimise ja valmistamise hinda ning aega, tuginedes plastist toote andmetele, ilma et oleks teada valmistamise tehnoloogia, tööriista struktuur ja keerukus. Artikli eesmärgiks on analüüsida olemasolevaid hinnapakkumise koostamise meetodeid ja tutvustada eksperimentaalse hinnapakkumissüsteemi kontseptsiooni, mis võimaldab arvutada reaalset pressvormi valmistamise aega ning maksumust kiiremini ja täpsemalt, arvestades ettevõttes kehtivat projekteerimise ja valmistamise keskkonda.