Artificial neural network approach for injection mould cost estimation

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Abstract

The role of the plastic injection technology has increasing role in automotive industry. The mould maker companies face a considerable challenge not only in terms of productivity of design and manufacturing, but also in trying to meet the increased demand in quotation. The article presents the application of an artificial neural network for cost estimation which supports a parallel case-based and heuristic cost estimation system. Altogether fourteen cost types are estimated with a promising result based on thirteen tool description parameters that can be specified simply based on the given CAD model indicating that these are to be specified easily and quickly by an expert preparing the quotation.

Keywords:

injection moulding, cost estimation , artificial neural network

1 INTRODUCTION

The role of the engineering plastics in the automotive industry is increasing in our days. Aluminium and steel parts are replaced by plastic parts, which generate less overall mass, reduce production costs and environment pollution. Due to these trends the mould maker companies face a considerable challenge not only in terms of productivity of design and manufacturing, but also in trying to meet the increased demand in quotation.

For increasing demands companies have to process data in large quantities. The state is well marked by this example: a medium size tool workshop, which can produce about 40-50 moulds per year, makes about 1000-1200 quotations.

The quotation has a strategic role for the mould manufacturer, because it has a serious effect on the company's operation. The main question here is how the manufacturer can balance between profitable production and the customers' budgetary and shipment considerations. Some additional problems are the unknown details of construction and manufacturing process, the confidentiality of the budget and the several business rivals. In addition, a further difficulty in the quotation process arises, how to present accurate data by minimal work, while this expectation is inconsistent. The main property of the known quotation methods [1.] is that the invested work is in direct proportion to the accuracy of data. For the fast process of quotation requests and the short deadlines there is little time for detailed analysis of the problem. Furthermore, in the case of an unsuccessful proposal the invested work is lost, and therefore this work can be defined as "waste". The current industrial practice utilises the personal experiences gained in projects, however vulnerable and doubtful it may prove.

The cost estimation can be explained in different level of product life cycle and in relation to different production technologies. However the circumstances of the product or process, the role and needed accuracy of the cost estimation can be different the methods, which can be applied are very similar.

For example we can speak about the cost estimation related to the part design [2.][3.], the assembly process [4.] or different manufacturing technology, like casting or cutting.

The estimated cost and time values bears large importance in relation to the company's profitability since the minimal or concurrent production price can be determined only after estimating the vendor-cost of mould design and production. However, based on estimated time and with consideration of unutilized manufacturing capacities it can only define a sustainable production's deadline towards the costumers.

In this early phase of the quotation there is no way to create a detailed mould design and manufacturing plan in order to gain accurate cost and time results. In case of underestimation as well as the costumer's stepping back from a purchase order, the cost of a quotation increases the deficit. On the other hand, if less effort is put into the quotation, the price will be too high, and not only an order but a general costumer can be lost. Winning a project with too low price and benefit, the design and manufacturing process will be not profitable.

It is therefore easy to understand that the demand for a quotation is very established which is to provide estimated time and cost data accurately and with as little effort as possible.

Also as in injection mould cost estimation reliable process models are of key importance in computer integrated manufacturing [2.] as model-based solutions can make difficult problems of production control tractable. Increasing complexity is another characteristics which shows up in production processes, systems and in enterprise structures as well [6.]. Models facilitate elaborating new algorithms, supporting decisions, decreasing investment risks and coping with changes and disturbances. However, modelling manufacturing processes may bear difficulties: the diversity of operations, their multidimensional, nonlinear and stochastic nature, partially understood relations, unreliable or incomplete data sets etc.

Learning denotes changes in the system adaptive in the sense that learning techniques enable the system to do the same or similar task more effectively next time. Artificial neural networks (ANNs) are general, multivariable, nonlinear estimators. This artificial intelligence (AI) technique can offer viable solutions, especially for problems where abilities for real-time functioning, uncertainty handling, sensor integration, and learning are essential features, as it will be presented in the next paragraphs. 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 called nodes [10.]. The perceptron-based neural network is used, where the nodes summarize the weighted inputs and transform by a non-linear function. If three layer of nodes are created, where first contains the input data, the third represents output data, the relationship is determined by the learning process itself.

The paper is organised as follows: After introducing the process of mould cost estimation the related input and output parameters are defined followed by the description of the solution's architecture proposed. Comparison results of various cost estimation techniques are detailed appointing the most accurate solution for the injection moulding cost estimation. Summary, acknowledgements and references close the paper.

2 THE PROCESS OF MOULD COST ESTIMATION

The manufacturing cost estimation process of plastic injection moulds is a very complex process, the solution details and the applied methods can be varied. In the industrial practice the companies elaborate unique methods, which consider the technicality of the design and manufacturing environment, the special design and manufacturing practices of the company, the special properties of the moulds, the speciality of suppliers, etc.

However the methods can be varied, the main steps of the applied process are same. The manufacturing cost estimation process is divided into three steps:

1. Pre-processing,
2. Project cost estimation,
3. Detailed manufacturing cost estimation.

The first step of the process is the pre-processing, when the details of the project have to be determined. Accurate cost data can be estimated based on detail and sophisticate base data. The collection of required data is performed by costumer's requirement list and the preliminary mould design.

During the cost estimation it is often needed to divide the manufacturing costs into additional elements, and determine the *detailed manufacturing costs*. It may have several reasons. Based on the result the reality of the estimated cost is evaluated. The load and capacity analysis of the manufacturing system can be performed and the shipment time can be estimated more accurate. The content of the detailed cost data is determined by the structure of the manufacturing system. It contains that cost of performed machining in CNC milling machines, EDMs, drilling machines, etc.

3 INPUT/OUTPUT PARAMETERS

One of the most important steps of the research reported here is the definition of 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 during the typical quotation process. 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 machine (milling, turning, grinding, EDM, drilling etc.)
- Time and cost of fitting and assembly.

The cost elements can be estimated with different methods. Different parameters have effect on concrete values and rates of each cost elements. The design cost is determined by the character of the plastic part and the complexity of the mould. The cost of process planning is driven by the number and complexity of shaping elements (core, cavity, slides, lifters, inserts etc). The material cost is determined by the overall size of the mould base, the material of the elements and the complexity of mould structure, and finally the manufacturing cost depends on overall size of the mould base and the complexity of mould structure.

The selection of input parameters is a much more difficult problem. The reason for that is because the selected parameters must be satisfied with several conflicting conditions. Only such parameters can be applied that can be determined from any design representation type, like 2D drawing, physical model, 3D CAD model in any format. Every basic property of the product must be selected which has essential effect on mould's structure, size and complexity. The concept of the mould must be developed during quotation, and some characteristic properties must be taken account for accurate results. One of the most important viewpoints in the parameter selection is the clear structure, and avoiding a large number of parameters. In the cost estimation system there are three types of parameters distinguished. The first type means exact numeric values such like overall dimensions of the part. The second type data can be generated from the mould's requirement list, i.e. heat treatment requirements or types of runner system. The parameters of the third set have subjective values, like complexity of mould structure. Although the last type of parameter indicates uncertainty, use of it is unavoidable. The effect of uncertainty can be reduced by a personal user's manual, where the selected values can be illustrated by examples. Based on these rules the input parameters are as follows:

Estimated overall size of mould (MB1, MB2)

Based on parameters mentioned above the overall size of mould is estimated, appropriate to use the standard plate dimensions of material manufacturers, in order to reduce material cost.

Number of cavities (NoC)

Higher number of cavities results more productivity of mould can be obtained, albeit 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; the work expense is increased as well.

Type of injection system (IS)

An injection mould has a standard runner surface or a hot runner system. 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 indicates considerably more costs and purchase time.

Mass of product (M)

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

Complexity of a product (PC)

The complexity of a part is a sophisticated term, it is not so easy to define. 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 drawn up to support users. Do not use the minimum and maximum values of the scale practically, because in the future cost estimation is planned for more simple or more complicated moulds one can have ever before.

Complexity of mould structure (MC)

Complexity of mould structure is scaled from 1 to 10 similarly as mentioned in the former case. A mould structure is simple if it consists of only core and cavity plates and the dividing surface is flat, while a multi-cavity mould with sliders (Figure 1), lifters, two step ejections and threaded insert means very high complexity.

Figure 1: A mould house with two sliders.

Amount of sliders and lifters (AS)

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

Complexity of sliders and lifters (CS)

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

Quantity of deep holes, ribs and cavities (DR)

Deep ribs and cavities increase the cost of mould as they cannot be machined on milling but on EDM. The additional cost will appear in both the planning and manufacturing (the parameter is scaled from 1 to 10).

Quantity of EDM-ed surfaces (EDM)

It is to provide a solid quantity, which cannot be manufactured on a milling machine, but only on an EDM, because of its shapes (weak walls) or material structure (also scaled from 1 to 10). There are several reasons why the application of EDM technology increases the manufacturing cost. First of all, EDM technology requires electrodes which indicate additional tool design and process planning and manufacturing (Figure 2). Secondary the EDM process has low productivity. Thirdly if the product's surface requirements do not allow EDM-ed surface quality, the surface finishing brings additional manual manufacturing.

Figure 2: A complex die-sink EDM electrode causes a high manufacturing cost.

Quality of product's surface (SC)

The product surface must meet design requirements, functionality and manufacturability. A surface structure and quality depends on the mould's manufacturing process. If necessary this structure can be eliminated by manual manufacturing, however super-finishing can also be applied. In several cases the costumer requires special surface structure like leather design. This structure can generally be manufactured by EDM. The natural like design can be machined by electrochemical machining, which needs many manual pre processes, e.g. the milling paths or EDM-ed hard surface layer must be removed.

Heat treatment requirements (HT)

The number of product parts and the abrasive effect of the product material generate heat treatment demands, and so additional manufacturing is required. The effects of a heat treatment indicate additional cost and production time as well as additional transportation, if the heat treatment cannot be managed in the mould shop.

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

4 APPLIED METHODS

There are several methods for solving the cost and time estimations. There are algorithmic solutions to more tasks of pre-processing, like determine of number of cavity, or determine of overall size of the mould base. Several tasks cannot solve in algorithmic way, either it is too complicated like determine of the mould structure, or the task needs just a simple decision of the customer or the designer / project manager, like the number of mould parts.

During previous research of the authors several methods was studied from the viewpoint of applicability in general and detail cost estimation [2]. This method can estimate the project cost and time data based on results of pre-processing. The application of the heuristic approach, the case-based reasoning and the artificial neural network were studied.

The heuristic approach means mathematical formulas, which connect certain input data and the estimated design and manufacturing cost together with production time data. These figures are not deduced in mathematical way, the accuracy of them is proved through experiments. The selected base data is the price of the mould base, which can be determined based on overall size of the mould and the selected materials.

The application of heuristic approach in the everyday work is very simple, if the formulas have been designed and adjusted. For the design of these empirical formulas

several post-calculated mould cost should be analysed, and based on this analysis the formula can be designed and parameters can be adjusted. The structure of the formula can be general, but the parameters must be adapted to the actual design and manufacturing environment. The accuracy of the model depends on the structure of the formula, and the amount of the processed mould.

The essence of the case-based reasoning is to select the most similar mould from a database, which contains cost data of produced moulds, so the design, material and manufacturing cost and time data are known. To analyse the selected mould and plastic part the cost data can be modified, so the estimated data are determined. During the research reported here the problem of similarity estimation has to be solved, because this process will ensure the success of case retrieving. The application of case-based reasoning requires a large database, because the accuracy of the method depends on the size and variety of it. More similar mould is found, the accuracy of the result will increase. The length of time of the development derives from the collection of case-base.

The application of *artificial neural network* is similar to the heuristic approach, because it makes a mathematical connection between input data and mould cost. But in contrast to heuristic formulas, the mathematical formula of artificial neural network is hidden. The functioning is determined by inner weights, which are learned by case-based. The accuracy depends on the variety of the cases.

After the studies, the conclusion is drawn, than one method is not suitable for solve all tasks, we have to combine different methods. Appropriate methods were found for each process, which ensure the effective work.

During the design of system's layout the results of previous research was taken into consideration and the applied methods were selected based on the characteristic of processes. The Figure 3 shows the layout of the system.

For determining the detailed manufacturing cost statistic approach can be applied, but the detected rates are very different in case of different product size and complexity. It shows clearly that dependencies among input and output parameters of the estimation is usually non-linear.
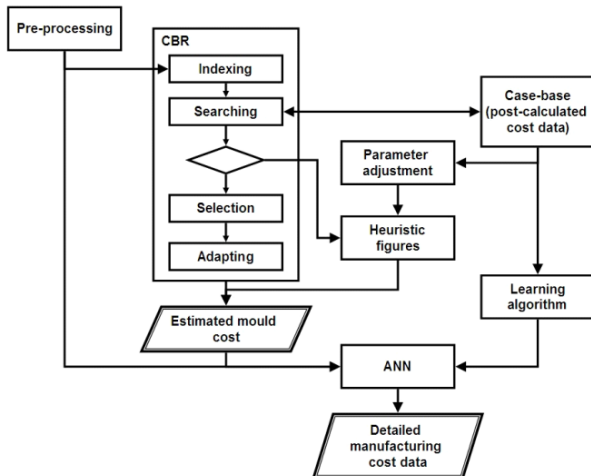

Figure 3: System concept for detailed manufacturing cost and time estimation.

5 COMPARISON OF VARIOUS COST ESTIMATION TECHNIQUES

The application of an artificial neural network for cost estimation which supports a parallel case-based and heuristic cost estimation system were studied. The case-based module calculates an overall project cost based on previous success projects. If there is not an appropriate similar case, the main components of the project cost are calculated by a heuristic formula. The role of the ANN is to generate the detail cost components, divides the manufacturing cost to manufacturing equipment. Each methods use a database, which contains post-calculated data of finished mould design and manufacturing projects.

The collected experience can be a good base of the usable knowledge, which is able to build a knowledge based decision support system. This case-base contains the special knowledge, which characterise the company specific problem solving. Various cost estimation techniques were compared in the analysis, which able to utilize the hidden knowledge. The various methods summarize the knowledge in different way, so the circumstances of the application and the accuracy will be different.

5.1 Cost estimation based on case-based reasoning

During the cost estimation a similar case will selected and adapted. The process of this method is very simple, but there are several details, which mean problems.

The similarity estimation is a key problem of the case retrieval. The main problem is the question of what similarity means and how it can be measured.

The similarity is defined in the system by a numeric value between 0 and 100. Higher value means higher similarity.

The formula consists of two parts. The first takes the size of mould base into consideration (CSF_1 - Case Similarity Factor), and the second part expresses the effect of other parameters (CSF_2). In the indexing process – besides the mould base size – additional ten parameters were defined (P_j, j= 1 to 10) to describe the properties of the product and the mould. The index i means the number of the case in the case base. As the sizes of mould bases have standard values, mould base size categories (MBSC) are defined. 18 categories were defined based on standard set.

$$CSF_i = 100 - CSF_{1\_i} - CSF_{2\_i} \tag{1}$$

$$CSF_{1\_i} = (\Delta MBSC_1 + \Delta MBSC_2) \cdot W_1 \tag{2}$$

$$\Delta MBSC_1 = \left| MBSC_{1\_new} - MBSC_{1\_case\_i} \right| \tag{3}$$

$$\Delta MBSC_2 = \left| MBSC_{2\_new} - MBSC_{2\_case\_i} \right| \tag{4}$$

$$CSF_{2\_i} = \sum_{j=1}^{10} \left| P_{j\_new} - P_{ij\_case} \right| \cdot W_{2j} \tag{5}$$

The weights are determined based on industrial experiences. We study the effects of defined parameters on manufacturing time and cost data with contribution of several industrial partners.

5.2 Cost estimation based on heuristic approach

Based on collected cases, the connection between the project description data and mould cost can be detected.

The first suggested formula is very simple; it was designed for fast manual use. It takes the type of runner

system, complexity of the mould and the price of the mould base into consideration.

The structure of the applied mathematical function is the next:

$$C_{mould} = C_{m\_base} \cdot C_1 \cdot C_2 \cdot C_3 \qquad (6)$$

where:

C_{mould} : cost of the mould

C_{m_base} : price of the mould base

C_1 : cost factor of the runner system,

$C_1 = f (C_{mould}$, type of runner system)

C_2 : cost factor of design and manufacturing,

$C_2 = f (C_{mould}$, complexity of the mould)

C_3 : cost factor of components,

$C_3 = f (C_{mould}$, complexity of the mould)

This suggested formula is very simple, but cannot characterise the influence of each factors deeply. In order to more detail formula the mathematical and statistical software can be applied. This software suitable to identify the values of several parameters based on database. The Minitab v14 was applied to design a more complicate but more sophisticate formula. Based on the analysis some input parameters were eliminated, because they have not got significant influence to the result. Of course if the case base contains other data maybe the formula contains other input parameters. So this formula valid for the tested case base, but the method is suitable for create a appropriate formula in every case.

The suggested formula, based on our statistical study is the next:

$$C_{mould} = e^{C + C_1 \cdot MB1 + C_2 \cdot MB2 + C_3 \cdot IS + C_4 \cdot PC + C_5 \cdot MC + C_6 \cdot EDM} \qquad (7)$$

C=8.48, C1=0.00088, C2=0.00125

C3=0.16800, C4=0.04840, C5=0.05080

C6=-0.01610

The Figure 4 shows the difference between the original and the estimated cost data.
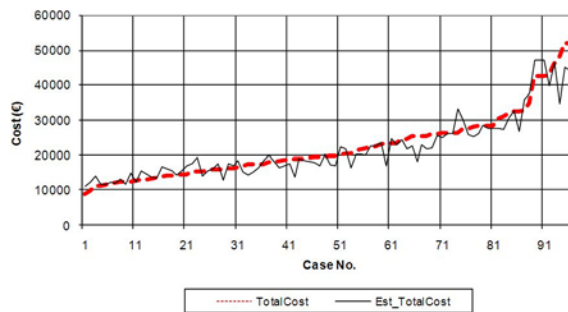

Figure 4: Comparison of the estimated and the original cost data

5.3 Cost estimation based on artificial neural networks

An Artificial Neural Network (ANN) model based system called Neureca2 developed by the authors [5] was applied to estimate various tool production costs. It is based on above appointed descriptive features of the tool to be produced; these are already available in the quotation phase. Altogether thirteen description parameters were

selected as inputs for the estimation. Some of these parameters can be specified simply based on the given CAD model others are to be specified easily and quickly by an expert preparing the quotation, it a key specimen of the approach proposed. The ANN model estimates the total cost of the produced tool, moreover beyond this also thirteen other cost types:

- Total cost
- Material cost
- CAD (Design) cost
- CAM cost
- NC milling cost
- Milling cost
- Turning cost
- Drilling cost
- Grinding cost
- EDM die-sinking cost
- EDM wire cost
- Polishing cost
- Fitting cost
- Assembly cost

The ANN model built up is presented in the Figure 5. The ANN model built up for estimating fourteen different cost types of injection moulding (outputs on the right side) considering thirteen input parameters given in an early design phase (inputs on the left side). The ANN Error Calculator window shows the worst error of the costs estimation.
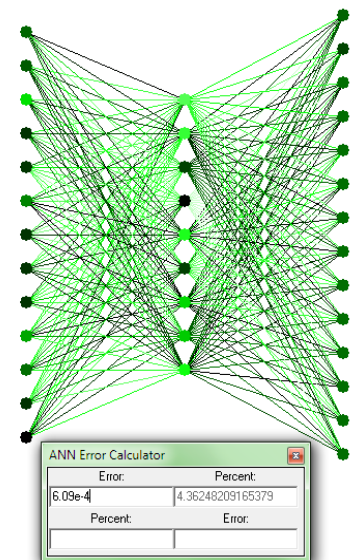

Figure 5: The ANN model built up for estimating fourteen different cost types of injection moulding.

The ANN model was trained using a set of previously designed and manufactured tools and the estimation capabilities were tested on another new set of also designed and produced tools set showing the promising application of the methodology for the detailed cost estimation. Data from 80 production projects were applied for training and 16 for testing the ANN estimation capabilities. The estimated and real curves of various costs types are close to each-other on the training data set indicating promising modelling results in Figure 6 for training.
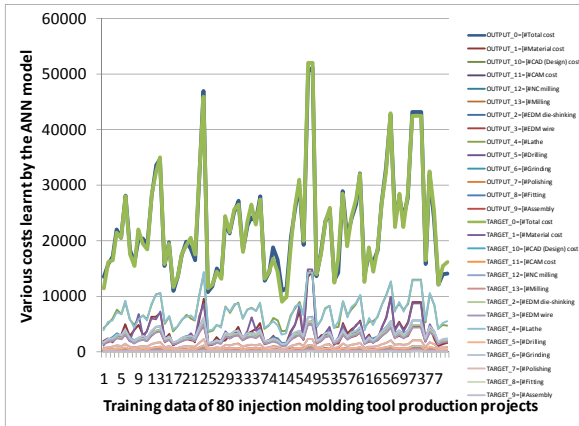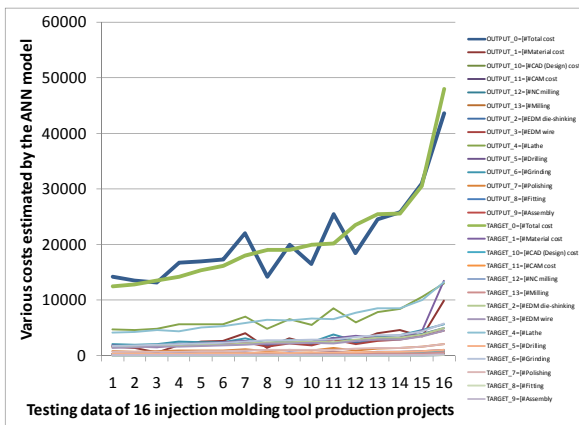
Figure 6: Accuracy of the ANN model building phase: various estimated and real costs of 80 different injection moulding tool production projects.

The real estimation accuracy of the ANN model built up is measured through its application on injection moulding tool projects that were not seen before. The Figure 7. highlights the cost estimation results of 16 different project cases. The estimated and real curves of various costs types are close to each-other on the testing data set proving that the ANN based estimation is applicable.

Figure 7: Accuracy of the ANN model application phase: various estimated and real costs of 16 different injection moulding tool production projects.

The above curves proves that the proposed method is able to estimate the total production costs, the total cost of the injection moulding tool production is estimated with average of 12% error, while the other cost estimation errors were measured between 12% and 13% except the material cost estimation where the estimation error was 24%.

6   SUMMARY

The mould cost estimation is a basic process at every mould manufacturer. The accuracy of the results is a key problem. The experimental system proposed would like to combine the experiences and the science to increase the productivity of mould cost estimation. The case-based reasoning and the heuristic formulas utilises the potentialities of the past, and the artificial neural network can extend the knowledge of cases. Various estimation techniques were analyzed and compared resulting that the artificial neural network based estimation gives the most accurate approach indicating that the dependencies among the considered parameters and the costs are typically nonlinear and their type are also unknown.

7   ACHNOWLEDGEMENT

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