Cost Estimation of Sheet Metal Parts with Neural Networks

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Abstract

Increasing competition means that the costing of the supply price is one of the central economic questions for suppliers in the manufacturing of sheet metal parts. To obtain a high reliability for cost coverage in the supply price, an accurate costing of the direct costs is necessary.

This paper presents a method for the feature oriented quotation costing of sheet metal parts based on a specifically extended, cost oriented product model. Based on this model, neural networks are used to calculate rapidly the tool costs for progressive dies. A software system supports the cost estimator in tendering by offering an automatic analysis of the CAD-model of the work-piece.

Introduction

The decreasing profit margins and increasing competition make it necessary with respect to target costing[1] to calculate the supply price more and more precisely. To guarantee the selection of the most profitable manufacturing technology, the costs of the alternative manufacturing methods have to be estimated and compared internally.

Despite the central economic importance of a binding quotation, many small and medium sized enterprises (SME) practice only a rough estimate for the submission of a tender. Calculation sheets of PC-based spreadsheet programs are therefore increasingly used to execute the quotation costing[2,3]. These calculation sheets are usually specifically designed for the individual enterprise. The cost feature input is executed manually or via a menu. Connection to an internal production planning and control system and the use of existing databases are not possible. Besides this procedure, there are other methods of calculating sheet metal parts in which the estimate of costs is based on a partially automated operations scheduling[4] or performed using MTM-based cost functions[5].

Position of Quotation Costing

The complete quotation planning procedure is divided into three parts: *technical planning*, *cost planning* and *time scheduling*[6]. "Technical planning" includes product definition and the development of the technical solution. The work-load planning for the workshop is performed within the scope of the time scheduling. The determination of the possible date of delivery depends on this scheduling. The main task of the cost planning with respect to quotation costing is to estimate the manufacturing costs as exactly as possible. For that purpose, all available manufacturing methods for the specific product have to be considered. In this paper only the aspect of quotation costing will be discussed.

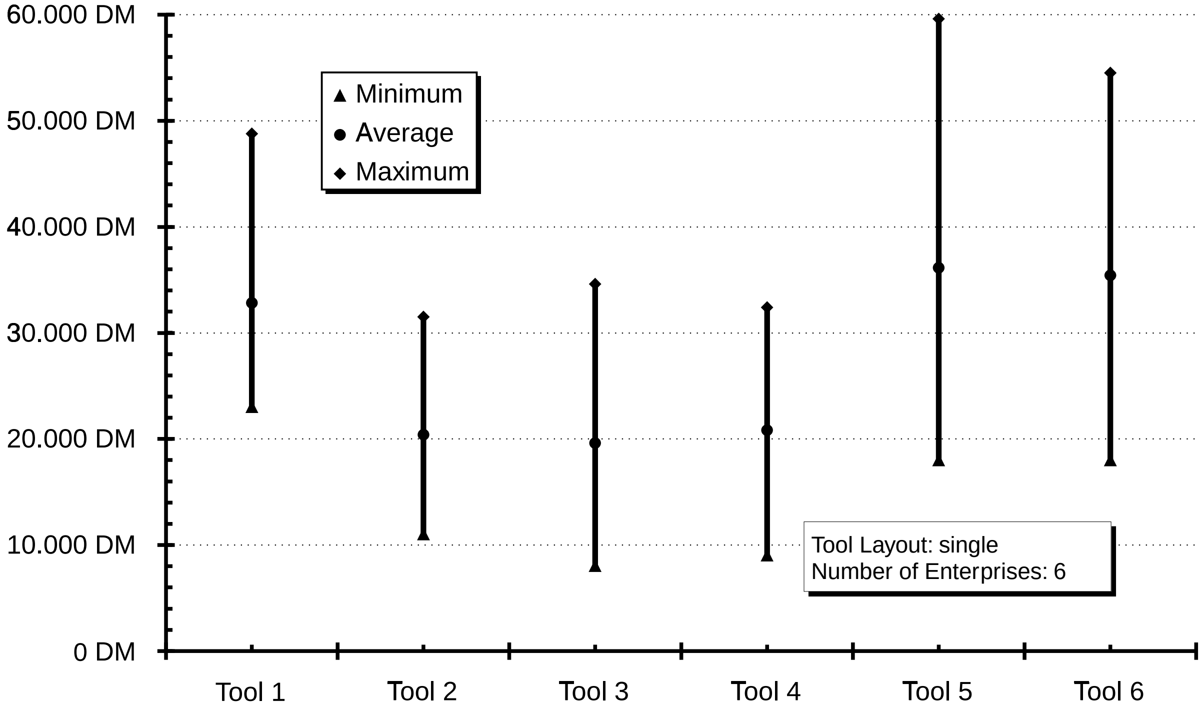


Figure 1: Supply Price Range of Progressive Dies

Quotation costing is used to determine the supply price. Quotation costing differs from the costing attending construction just as much as from the preliminary costing and the costing attending manufacturing. These calculation methods serve to control and reduce costs. Statistical cost accounting serves exclusively the purpose of necessary cost control. In an inquiry by Weber, 50% of the enterprises asked stated that they executed this statistical cost accounting[7,8] only occasionally or never.

Manufacturing with Progressive Dies

The manufacturing of sheet metal parts in large scale production is mostly done with progressive dies. The design and production of such progressive dies leads to an essential part of the manufacturing costs. The quotation costing for this manufacturing technology must integrate a special estimate of the tool costs.

In cooperation with an industry partner, requests for quotations of progressive dies for six different real sheet metal parts were sent to six toolmaker enterprises. The analysis (fig. 1) showed that the range of the offer prices per tool varies between 112% (tool #2) and 332% (tool #5). Apart from the different cost structures in the individual enterprises, the price differences are caused by the rough cost estimate. In no case was a stamping sequence or a strip layout developed in order to determine the exact structure of progressive dies and thus the costs. This is due to the difficulty and the high expenses involved in the generation of the stamping sequence.

Demands on Quotation Costing Systems

To guarantee the successful application of the quotation costing system the following demands have to be fulfilled:

- A high *calculation accuracy* is necessary to provide a reliable base for planning. Interviews with project partners resulted in aiming at a target degree of calculation accuracy of about 10% at minimum.
- The *transparency of cost origin* must be guaranteed, so that a cost estimator can duplicate the pricing process.
- If there are several manufacturing alternatives available, then a *cost comparison of the possible manufacturing methods* has to be supported by the quotation costing system.
- The preparation of an must to be achieved with *as little effort as possible*. Expensive operations scheduling should be avoided for cost reasons.
- The cost estimation must be based on the *existing calculation technique* used in the particular enterprise.
- Different *enterprise-specific influencing variables* must be integrated, e.g. the different allocation of the overhead costs of enterprise-specific key data.
- A connection to existing internal production planning and control systems or databases should be provided.

Apart from the estimated total production costs, the supply price depends also on the pricing policy of the enterprise. This entrepreneurial decision cannot be made automatically by a software system. On the system side, quotation costing is reduced to a determination of the total production costs and the proposal of a supply price. The desired profit and the discount offered must be proposed with reference to customer and order and to be confirmed or modified by a cost estimator.

Description of Short Calculation Techniques

Leopold and Köhler[9] gave a general view of different short calculation techniques. Generally short calculation techniques can be distinguished according to the type of calculation result. Qualitative short calculation techniques return only relative predictions. They are less suited for the estimation of expected manufacturing costs, but they are used as decision support methods for technical designers. Examples of the qualitative techniques are heuristic rules, cost structures, relative costs and marginal batch sizes.

In contrast, quantitative short calculation techniques return results that can be appraised economically. Quantitative short calculation techniques include cost principles based on similarity and on influencing variables. On one hand the regularities of these techniques are extracted from similarity in geometry and manufacturing technologies. On the other hand they are derived from physical, geometrical, technical and organizational influencing variables.

Cost principles based on geometric similarity and cost principles based on geometric variables and variables influencing manufacturing technologies are particularly relevant to a quotation costing system. This is because this data can be derived automatically from a CAD-model or from a product model.

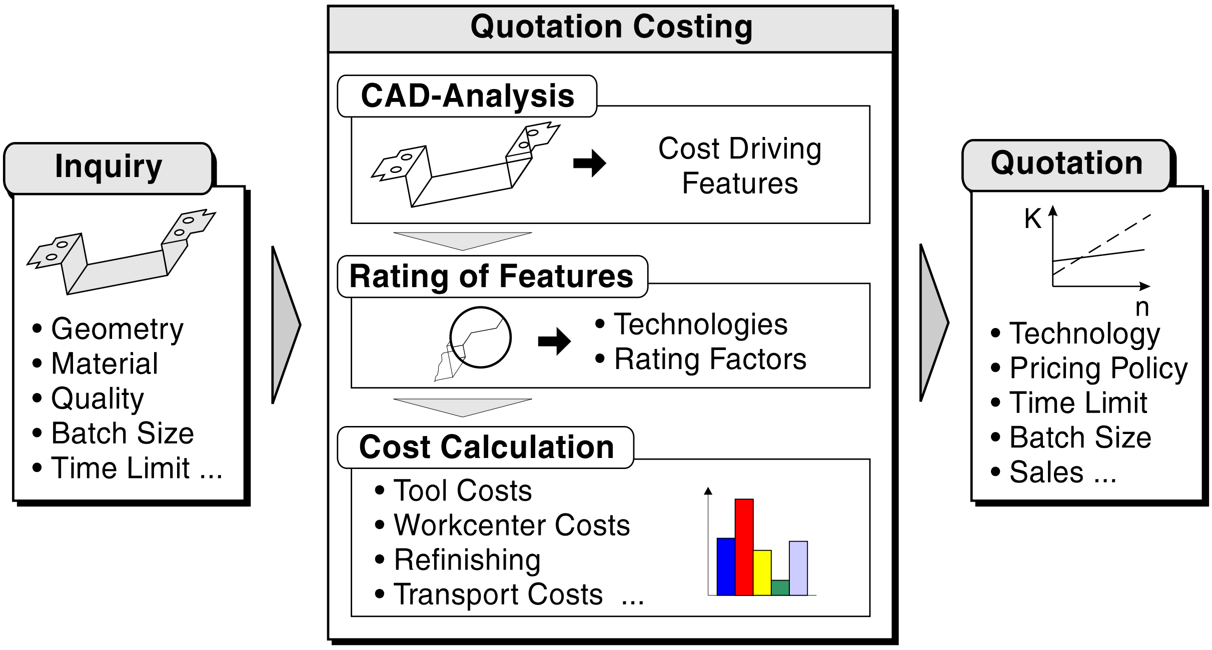


Figure 2: Proceeding of Feature-Oriented Quotation Costing

Method of Feature-Based Quotation Costing

The procedure for cost estimating introduced here is based on cost features. This procedure has been successfully implemented for turned parts[10]. Input data for the feature-based quotation costing (fig. 2) is extracted from the customer's inquiry. These data include workpiece geometry, material, quality of the workpiece and required batch size. The result of the quotation costing is a supply price, in which the product costs are calculated and estimated with relation to the selected manufacturing technique and lot size, the date of delivery and the pricing policy.

The determination of the manufacturing costs is performed in three steps. In the first step the CAD-model is analysed automatically with regard to geometric and technical features. For the recognition of the manufacturing structure of the workpiece, an existing analysis and classification system for sheet metal parts[11] is used. The output of this system is the base for the quotation costing to be implemented. The list of recognized features can be completed interactively. The next step is to assign the features to possible manufacturing techniques. In this step the different features are transformed into technique specific base units. These are machining times, profile lengths or batch sizes. In the third step the base units are transformed into costs. At this point the internal costing technique is applied, the internal key data (workcenter rates, overhead rates, etc.), cost of tools and costs for refinishing, transport, and distribution flow into the cost estimate.

The recognized features of a sheet metal part form the base of the cost estimate method described here. In this method, the following geometry and technology features are considered:

- *boundary contours shapes* (notches, slots),
- *inside contours shapes* (standard openings like round, square and rectangular holes and particular profiles that need special punching dies),
- *bends*,

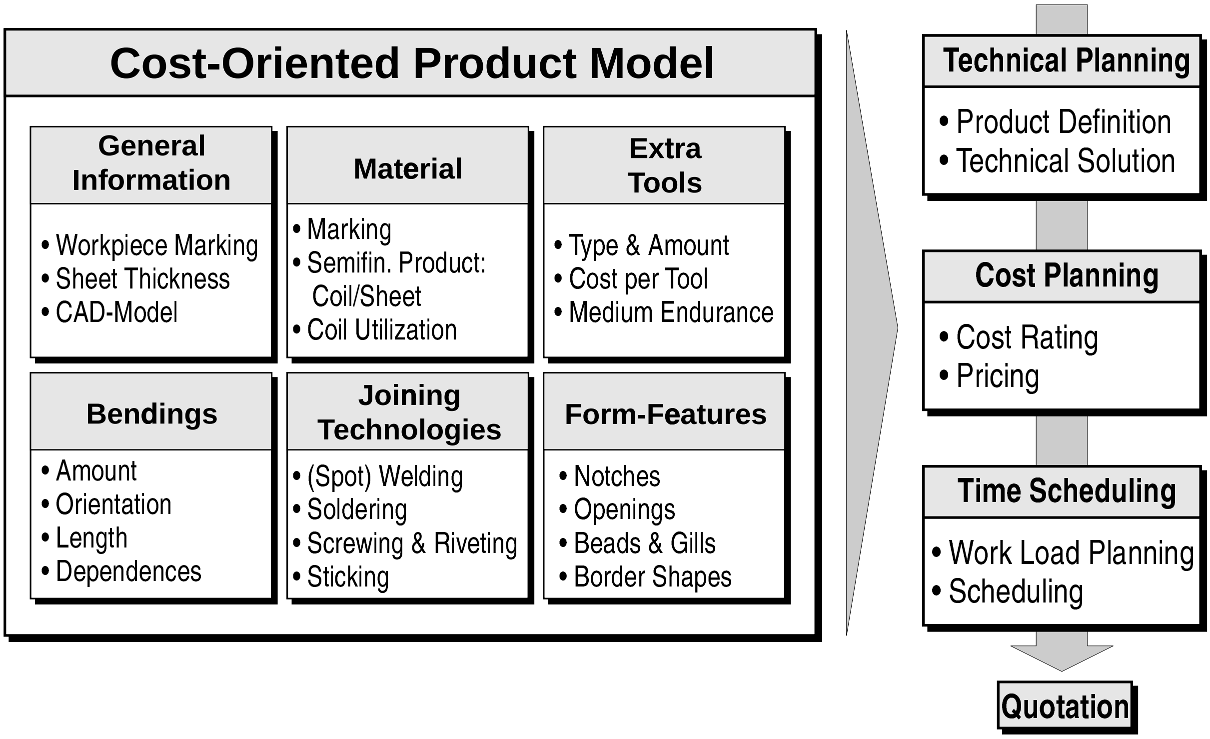
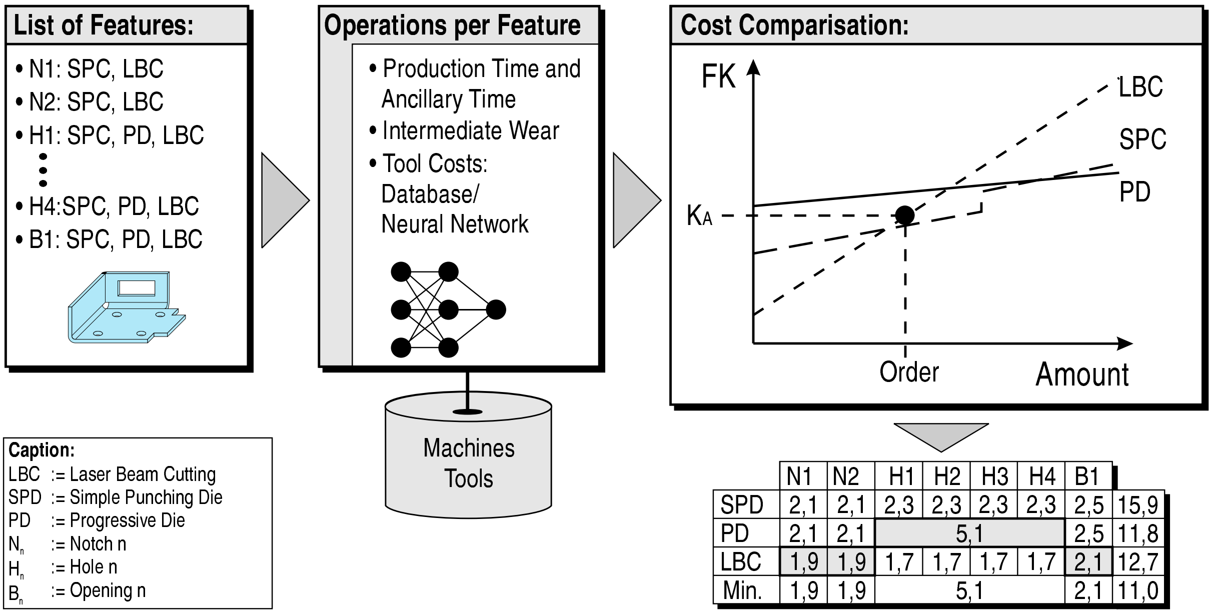


Figure 3: Components of the Cost-Oriented Product Model

- *joining techniques* (screwing, rivetting, (spot) welding, soldering and sticking),
- *border shapes* (fold, double-fold, rolled borders, with an insert if necessary),
- *gills* and *beads* (open and enclosed).

For the representation of a sheet metal component in the memory of a computer, a specific product model for sheet metal parts with a particular scope in cost-orientated description of geometry- and manufacturing-features has been defined and implemented (fig. 3). Various aspects are included in the product model: There are the usual details such as objects for components, sheet thickness, expansion of the developed sheet, information on the material and the exact geometrical model. On the other hand, special information on bends, features and joining techniques mentioned above are included. In addition there are items for information about extra tools (type and number, costs per tool, and medium endurance) and costs for indirect functional areas, e.g. the construction department for production facilities or the operations scheduling.

The determination of the cost-orientated base units (fig. 4) is based on the list of features of the piece stored in the product model. In this list, the possible and internal existing manufacturing technologies are related to the recognized or defined features. All features are rated as cost-oriented base units in relation to the possible manufacturing methods. This means that the cost drivers are derived according to the technology. For example, in the case of profile cutting by nibbling or laser beam cutting the processing time is estimated depending on the profile length, numbers of holes und the general process parameters. Cost functions depending on the lot size are formed on the basis of these base units together with the key data of the processing equipment. The cost function is discontinuous due to an average tool endurance given for the particular manufacturing method. For each feature, the most profitable manufacturing technology is



	N1	N2	H1	H2	H3	H4	B1	
SPD	2,1	2,1	2,3	2,3	2,3	2,3	2,5	15,9
PD	2,1	2,1	5,1				2,5	11,8
LBC	1,9	1,9	1,7	1,7	1,7	1,7	2,1	12,7
Min.	1,9	1,9	5,1				2,1	11,0

Figure 4: Cost Functions Based on the List of Features

selected by comparing the results of the cost functions of the different manufacturing methods. A table shows the most profitable choice of the possible manufacturing technologies.

Costing of Extra Tools: Application of Neural Networks

An important aspect in costing is the consideration of the costs of tools. The costs of standard tools and previously manufactured extra tools are stored in a database and are applied to the costing. The costs of new progressive dies are estimated automatically by means of neural networks[12]. Neural networks are a method of artificial intelligence. They consist of neurons arranged in several layers. Signals become weighted in the individual neurons by different factors and are transmitted to the next layer. The storage of knowledge is achieved by balancing the weights through different learning algorithms. The most important algorithms are backpropagation, quickprop and resilient propagation. The number of training iterations required is refered to as the number of “epochs”. The topology of neural networks in general is arranged in three layers. In the first layer (“input layer”), one neuron is required for each input value. In the third layer (“output layer”) there must also be one neuron for each output value. The middle layer (“hidden layer”), in which the processing of information is performed, has a particular structure for the specific adaptation to each individual problem.

For progressive dies, the input layer is formed by the information derived from the features of the product model (fig. 5). The aim of the investigation was to have the consumption of working hours in the toolmaker´s shop estimated by neural networks. For this purpose, tools already subjected to statistical cost accounting were investigated in three toolmaker enterprises and analysed for use in data systems. This work was rendered difficult by the fact that the enterprise only had documentation of direct materials and the total number of hours required for toolmaking. Based on the given spectrum of workpieces, the manufacturing technologies of progressive dies were limited to cutting, bending, punching and stamping. Thus, a starting point of 41 tools from three enterprises was available.

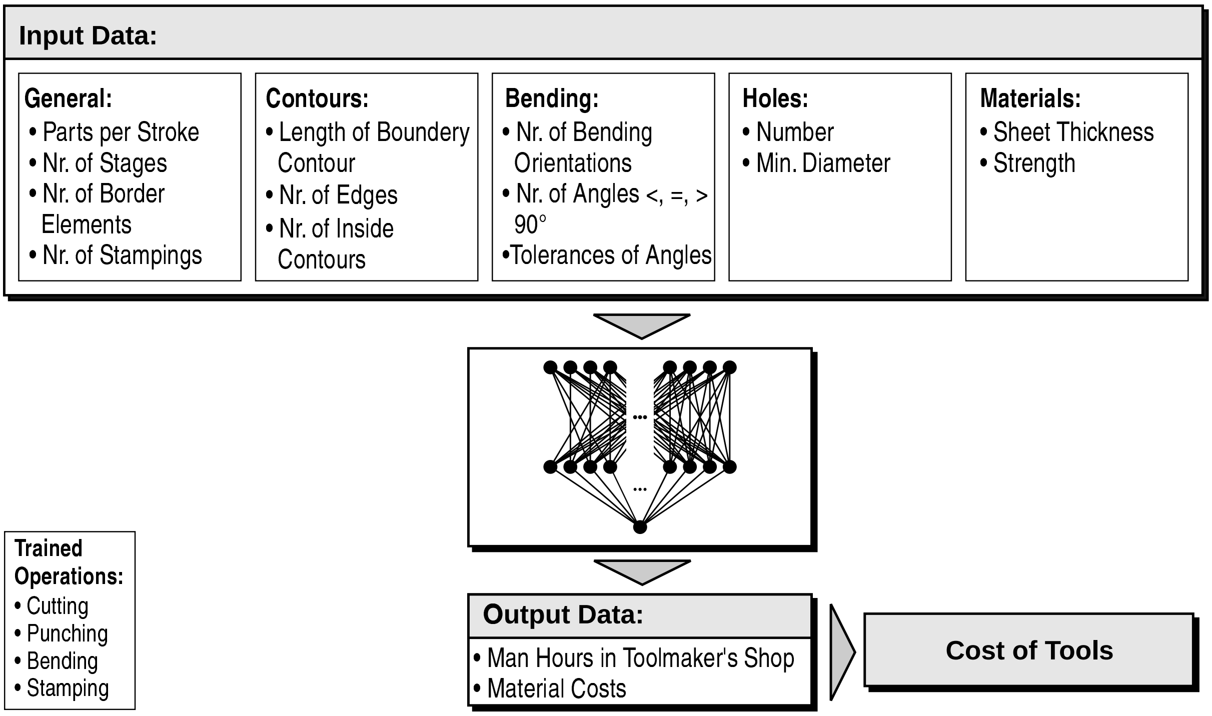


Figure 5: Neural Networks for Cost Estimation of Progressive Dies

For the input layer of the neural network, the following features were extracted: The number of strokes, the number of tool stages, the number of border elements and stampings (which generally determine the costs). For the description of the contour complexity, the lengths of boundary and inside contours and the number of inside contours are used. Bends are characterized by the number of the different bending directions, the tolerances of angles and the number of angles differentiated according to "< 90°", "= 90°" and "> 90°". The material used is described by strength and sheet thickness.

As mentioned above the correct selection of the topology of the neural network and of the learning algorithm used, is decisive for the quality of the neural network. By means of the "FlexNet" algorithm, an option of the applied neural networks toolbox "FAST"[13], a highly optimized network topology was approximated under consideration of the learning algorithms backpropagation, quickprop and resilient propagation. In the studies with "FlexNet", networks with 16 input neurons and three hidden layers gave the best results under the application of the quickprop algorithm with a calculation accuracy of ca. 25% (learning error index: 0.004422, test error index: 0.40297). These results were reached after the starting data had been separated according to toolmaker enterprise. The largest subset of an enterprise with 18 tools formed the basis for further research.

In the further course of studies aiming at an improvement of the calculation accuracy of the neural network, another 82 network variants were investigated manually. In this investigation, systematic variations of the number of hidden layers and of the number of neurons per hidden layer were applied. At the present stage of work, a neural network with three hidden layers of the topology 18-18-3 gives the best results. With this network a learning error index of 0.002499 and a test error index of 0.26171 were achieved after a learning phase of 7770 epochs (fig. 6). In the

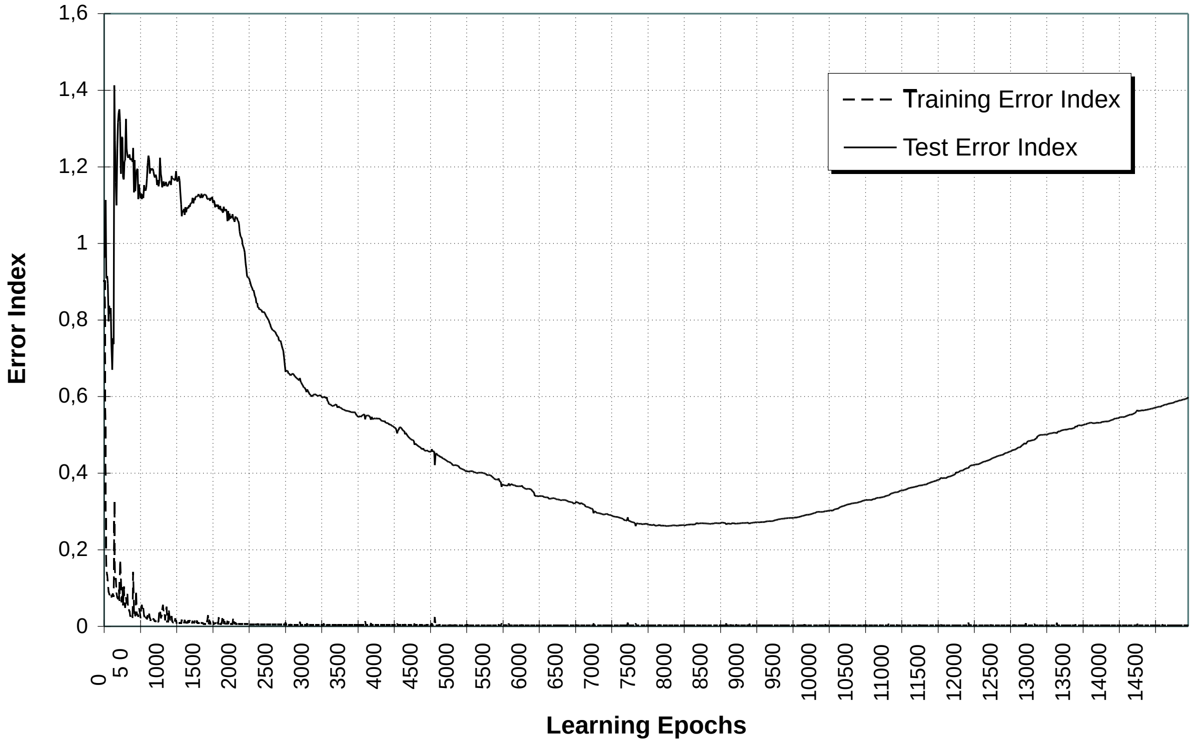


Figure 6: Error Indices for the 16-18-18-3-1 Neural Network

validation of the network with unknown workpieces, calculation accuracies between 6,7% and 12,5% were gained. The aim of the current research is to increase and to confirm the calculation accuracy by enlarging the amount of input data.

An approximate estimate of the cost of direct materials for progressive dies by neural networks seems impractical, because the possible requirements of the customer for materials and single components to be used, are too numerous. A reliable information base was not available. For the estimate of direct materials, a flexible calculation sheet common at the present state of engineering was used to estimate the cost of direct materials and vendor parts. On this sheet the desired components can be selected by the cost estimator.

The costing of the tools is finally achieved by the calculation of the consumption of hours in the toolmaker´s shop, multiplied by the specific workcenter rate and an estimate of the cost of the material. Then, the costs per workpiece are calculated using the estimated costs of tools and the workcenter rate of the press connected with the number of strokes and the costs of materials. Overhead costs are calculated with the cost estimate sheet described below. At the present state of implementation, the costs of the other types of new extra tools still need to be fed by the cost estimator manually.

Cost Estimate Sheet

Classic job order costing as it is usually done in small and medium sized enterprises, has the disadvantage of high overhead rates in enterprises with a high degree of automation[14]. Since the expense spent on the introduction of a quotation costing system needs to be kept on a low level, job order costing was retained as a basis. It was then supplemented in the direction of target costing[15] by considering workcenter rates oriented to the manufacturing steps.

The starting points for the costing are the order in combination with the product model including the lot size and the number of subcontracts. In the cost estimate sheet the costs for each order (e.g. costs for the construction of the production facilities, operations scheduling or extra tools) are considered once in the costing. The number of subcontracts forms the factor for the consideration of the costs per subcontract (e.g. for change over of tools) and the distribution expenses. Finally for each workpiece, the material costs including the waste, the manufacturing costs across all manufacturing steps, the costs for finishing and transport are considered.

To increase the accuracy of costing, the system also includes the costs for the internal transport and the transport between different branches. The costs for heat treatments and surface treatments of the workpiece are also considered in special cost functions. These are divided into weight-dependent costs (e.g. for heat treatment) and area-dependent costs (e.g. for purifying and coating)

Software-System for Quotation Costing

At the moment a computer-aided modular system for quotation costing of sheet metal parts is being developed and implemented at the Chair of Manufacturing Technology. The original CAD-model of the workpiece is supplemented towards a cost oriented product model in the module “feature analysis” by evaluating the form features with cost information. In the “inference module” a relationship between features and possible manufacturing methods is established. The basis of the costing is a database interface accessible from different databases (e.g. CAD-models, manufacturing methods with machines and their key data, data from orders).

Communication with the user (cost estimator) takes place through an interactive user interface. During the data input, the definition of the order and the features of the sheet metal parts can be entered and completed. The maintenance of the database is also carried out by means of this interface. The “data output” module presents the results of the costing graphically. The “model-viewer” module displays the CAD-model of the workpiece.

The implementation of the quotation costing system is being developed for personal computers with the operating system MS-Windows, so that the application requires no special hardware expenses. The standards SQL and ODBC are used as database interfaces, so that different database systems may be applied.

Conclusion

In this article, a feature oriented method for the quotation costing of sheet metal parts is described. This is at present being transformed into a software system. By means of this system, it will become possible to calculate offers quickly, to make costing transparent and to consider enterprise-specific key data. To achieve this, a cost orientated product model has been developed and implemented, in which geometric features are transformed into costing features. With the aid of these costing features, the direct costs can be deducted. The determination of cost functions illustrates graphically the dependance of costs from the lot size. A costing technique based on neural networks is presently being implemented for the cost estimate of progressive dies. This technique can determine costs with sufficient accuracy without establishing a stamping sequence. At the present state of development the cost estimate for progressive dies allows an accuracy of between 5% and 15% for the spectrum of workpieces investigated. Methods of contribution costing will be integrated in the cost estimate sheet to support the cost estimator by calculating the profit contribution of an order. To conclude the research project, a verification of the system with real workpieces will be carried out in co-operation with the project partners

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