Cost Estimation for Large Scale Production of Sheet Metal Parts Using Artificial Neural Networks*

Manfred Geiger; Jürgen Knoblach; Frank Backes

Abstract:
In the field of sheet metal working small and medium sized enterprises (SME) are normally supplier companies. They have to submit valid offers for manufacturing jobs within a short time. The supply price is decisive for getting the manufacturing job. Therefore, a method of quotation costing has been developed to increase the accuracy of cost planning for sheet metal parts. A software system is being developed which implements the algorithms of this method starting with the analysis of the CAD-model. The manufacturing of sheet metal parts in large scale production is mostly done with progressive dies, the cost estimations for such tools are normally based on the plate sequence. To avoid the time and the costs of designing the plate sequence before getting the job, a special calculation method based on Artificial Neural Networks is used for the cost estimation of progressive dies. In connection the direct labour costs are calculated by accounting the estimated resource consumption for tool manufacturing. Fast and precise pricing is done by the system under consideration of material costs, workcenter costs, overhead costs and pricing strategy.

Keywords: *Production Management, Cost Estimating, Sheet Metal Part*

Introduction

At present in the German mechanical engineering industry 1 % to 2 % of the sales volume are spent on writing offers [1]. These high expenses are necessary, because the total production costs must be estimated accurately at the very moment of placing the offer. Due to an increasing number of offer demands and a decreasing transaction rate the expenses per offer have to be reduced. So, the making of a quotation has to be made cost-effective and thereby more economic. Furthermore, advantages over competitors can be achieved by an accelerated tendering.
Parallel to the planning and manufacturing of a product four phases of calculation are carried out in an enterprise. Quotation costing (1) helps to make an estimation of the expected manufacturing costs and to set up the offer price. Preliminary costing (2) and – to an increased extent – production attending calculation (3) are used for cost control during manufacturing. Statistical cost accounting (4) reviews the commercial success of an activity after the production. The accuracy of the available cost information rises from quotation costing to statistical cost accounting. Here, quotation costing is affected with a high risk, because the binding offer decides over the commercial success of the future manufacturing order.
The manufacturing of sheet metal parts in large scale production is mostly done with progressive dies. The design and production of these tools are responsible for an essential part of the manufacturing costs. Because of the high outputs multiplier an accurate estimation is necessary especially in large scale production. Thereby, a special estimation method of these tool costs must be considered. At present, a plate sequence has to be developed for each exact determination of the tool costs, which requires up to four weeks time.
Despite the central economic importance of a binding quotation, many small and medium sized enterprises (SME) practice only a rough estimation for the submission of a tender. This results e.g. in deviations of more than 200 % in the field of quotation costing for progressive dies, without misrepresentation of different enterprise specific overhead rates. On the other hand only 50 % of the enterprises stated that they executed this statistical cost accounting only occasionally or never [2]. In such cases no cost control is given.
In an inquiry, requests for quotations for six progressive die sets

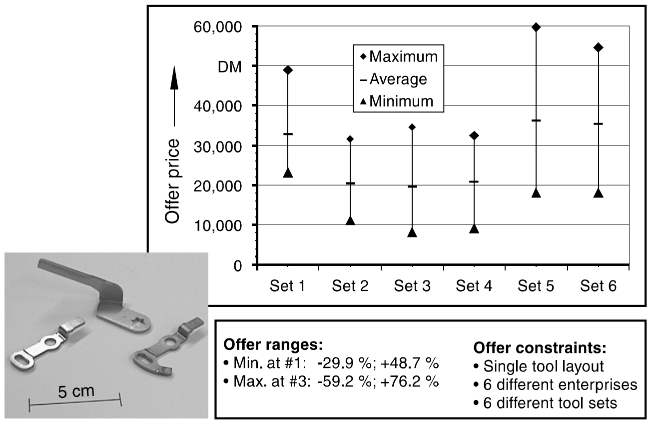

Fig. 1: Offer Price Range for six Sets of Progressive Dies

were sent to toolmaker enterprises. The analysis (fig. 1) reveals variation ranges in the offer prices between -29.9 %/+48.7 % for tool set #1 and -59.2 %/+76.2 % for tool set #3. The variations are related to each average price calculated from the six offers per set. Apart from the different cost structures in the individual enterprises, the price differences were caused by the rough cost estimation. In no case a plate sequence was developed to determine the exact tool structure and thus the costs.
State of the art are calculation sheets for PC-based spreadsheet programs [3]. These calculation sheets are usually specifically designed for the individual enterprise. The input is done manually or via a menu. Connections to internal production planning and control systems and the use of existing databases are impossible. Besides this procedure, there are other methods of calculating sheet metal parts in which the estimation of costs is based on a partially automated operations scheduling [4] or performed using MTM-based [5] or consumption-based cost functions [6]. An integrated software system for offer and job order planning on the base of the hierarchical similarity search was developed in the field of tool and mould making [7].

Method of Feature-Based Quotation Costing

The procedure for cost estimating introduced here is based on cost features. This procedure was successfully implemented for turned

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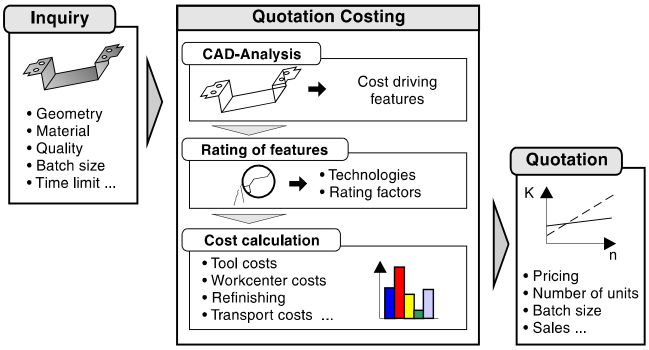
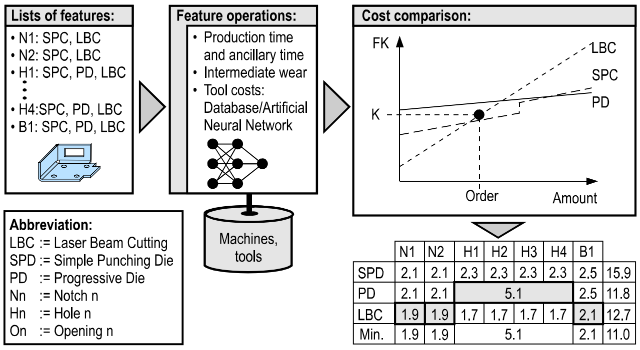


Fig. 2: Proceeding of Feature-Oriented Quotation Costing



	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

Fig. 3: Cost Functions Based on the List of Features

parts [8]. Input data for the feature-based quotation costing (fig. 2) is extracted from the customer‘s inquiry. These data include workpiece 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 automatic recognition of the manufacturing structure of the workpiece, an existing analysis and classification system for sheet metal parts [9] is used. The feature recognition is carried out with analytic geometric analysis, semantic networks and neural networks. 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 estimation.

For the representation of sheet metal parts, a specific product model with a particular scope in the cost-orientated description of geometry- and manufacturing-features was defined and implemented. Various aspects are included in the product model: There are 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 one hand, special information on bends, features and joining techniques 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. 3) is based on the list of features of the piece stored in the product model. In this list, the possible and internally 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 like the velocity. 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 the average tool endurance given for the particular manufacturing method. For each feature, the most profitable manufacturing technology is 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 Progressive Dies:
Application of Artificial Neural Networks

An important aspect in costing is the consideration of the tool costs for progressive dies [10]. The costs of standard tools and previously manufactured tools are stored in a database and are applied to the costing. The costs of new progressive dies are estimated automatically by the use of Artificial Neural Networks (ANN) [11]. In contrast to other solutions [12] the manufacturing costs of the tool set are calculated on the base of workpiece features not on base of the tool layout.

The aim of the calculation is the consumption of working hours in the toolmaker´s shop estimated by ANNs (fig. 4). The input layer is formed by the information derived from the product model of the workpiece, not from the plate sequence. For this purpose, tools already subjected to statistical cost accounting were investigated in two toolmaker enterprises and analysed for use in data systems. Based on the given spectrum of workpieces and the available data, the manufacturing technologies of progressive dies were limited to cutting, bending, punching and stamping. Thus, 41 tools were available.

For the input layer of the ANN, the following features were extracted from the CAD-Model: The number of strokes, the number of tool stages, the number of border elements and stampings (which

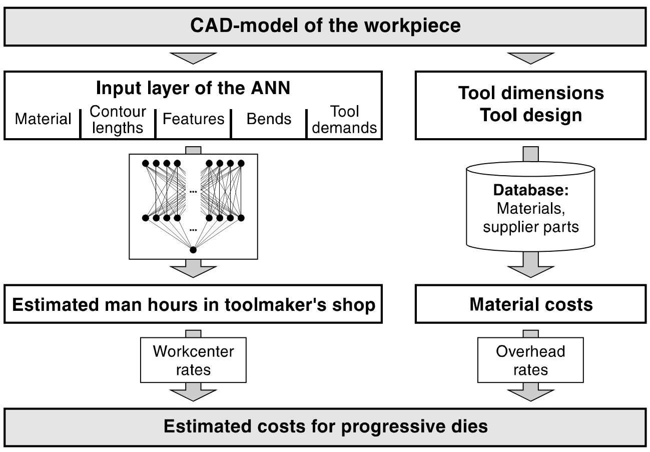


Fig. 4: Neural Networks for Cost Estimation of Progressive Dies

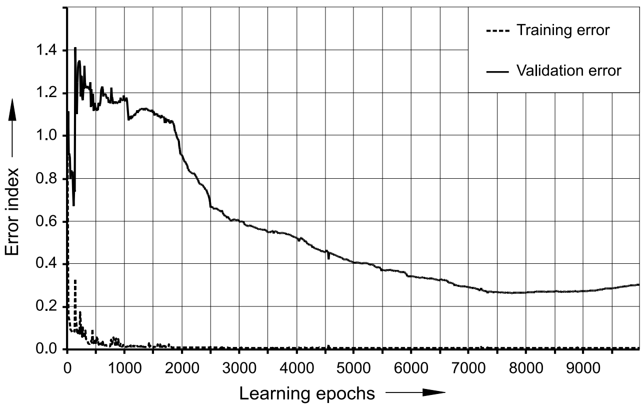


Fig. 5: Error Indices for the 16-15-15-6-1 Neural Network

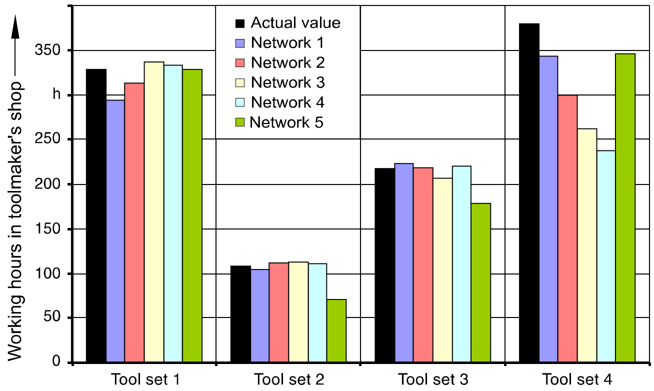


Fig. 6: Calculation Accuracy of Artificial Neural Networks

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.

The determination of the ANN´s topology has been done in two steps: In the first step, the network topology was approximated by the use of the „FlexNet" algorithm with separated data sets for each enterprise. The „FlexNet" algorithm is an option of the applied ANN toolbox „FAST" [13] which considers 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% (training error index: 0.004422, validation error index: 0.40297).

In the second step, systematic variations of the number of hidden layers and of the number of neurons per hidden layer were applied. In this investigations an ANN with three hidden layers of the topology 16-15-15-6-1 gave the best results. A training error index of 0.00741855 and a validation error index of 0.21164967 were achieved with this network (fig. 5). The validation of this network was done with four workpieces. The costing results of these tools were unknown to the ANN. Thereby, calculation accuracies between 2.5 % and 10.8 % were gained (fig. 6, table 1). This accuracy was achieved on a base of 16 data sets for the training of the ANN.

Finally the data sets of the two investigated enterprises were mixed together. The same two steps for the determination of an optimized network structure were executed. The training results with validation errors of more then 1.0 (fig. 7) show that the networks cannot be trained on the mixed data sets. A comparison between the investigated toolmaker's shops showed a lot of differences in methods and organization structures. The networks are not able to generalize between the differences of the two enterprises. They have to be specifically trained for each enterprise.

Network No.	*Layer Topology of the ANN*	*Minimum Deviation*	*Maximum Deviation*	*Average Deviation*
1	16-15-15-6-1	2.5 %	10.8 %	6.7 %
2	16-15-15-9-1	0.5 %	21.3 %	7.4 %
3	16-3-1	2.5 %	-30.9 %	10.5 %
4	16-18-18-9-1	1.5 %	37.5 %	10.5 %
5	16-18-18-9-1	0.2 %	-34.9 %	15.4 %

Table 1: Network Verification with four Unknown Tool Sets

An approximate estimation of direct material costs for progressive dies by ANNs is impractical, because the possible requirements of the customer for used materials and used components are too numerous. A reliable information base is not available. For the estimation of direct materials, a database-based calculation sheet is used for the estimation of direct material and vendor part costs. On this sheet the desired components can be selected manually 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 estimation of the material costs. 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.

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 expenses spent on the introduction of a quotation costing system must be kept on a low level, job order costing was retained as a basis. It was then expanded with methods of Activity-Based Costing by considering workcenter rates or resource consumption oriented cost functions to manufacturing steps and to the manufacturing of features. Workcenter rates and cost functions are taken into account as full costing rates and variable costing rates. The different rates are used for a comparison between fixed and variable costs for a sheet metal part. This dual calculation strategy allows a simple determina

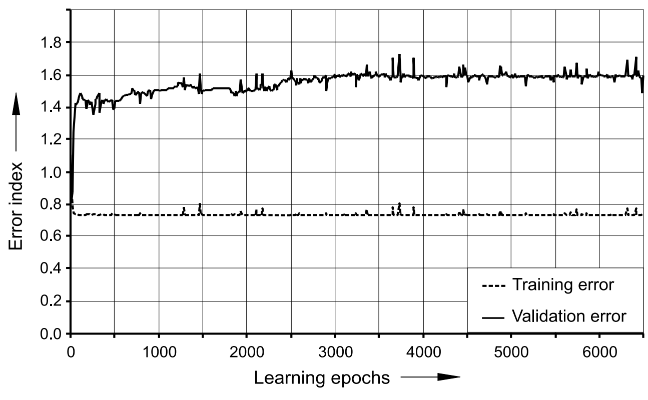


Fig. 7: Training Results of Artificial Neural Networks with Data Sets from two Enterprises (FlexNet-Algorithm)

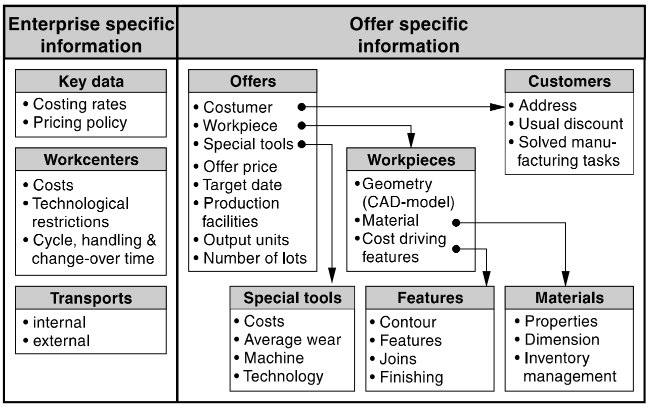


Fig. 8: Database Structure for Offer Management

tion of the profit aimed at as well as the contribution margin for a manufacturing task using methods of contribution costing.

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 considered in special cost functions. These are divided into weight-depending costs (e.g. for heat treatment) and area-depending costs (e.g. for purifying and coating).

Database Structure for Offer Management

For the management of the data needed for quotation costing a special database structure (fig. 8) was developed and implemented. The structure is divided into two parts: an enterprise specific and an offer/order specific section.

The enterprise specific part primarily contains the key data of the enterprise, e.g. overhead rates for different departments or default values for the pricing policy. Additionally in the workcenter database the workcenter rate (variable costing/full costing), information about technical restrictions (volume of working area, maximum workpiece weight) and machining times (cycle, change-over and handling time) are stored.

The offer specific data are distributed over several small databases to avoid redundant information in the storage. The customer database contains usual administration information as well as a proposal for a discount and information about solved manufacturing tasks. Within the workpiece database geometric information and cost information of statistical cost accounted products is managed. The handling of cost driving features of workpieces (e.g. recognized form features, contour length) is done in a special feature database. Additionally there are special databases for given tenders (e.g. date of delivery, batch size or price), materials (e.g. costs, availability, strength) and special tools (costs or average wear). All databases are linked together in a relational database model for an effective use.

Conclusions

A feature oriented method for the quotation costing of sheet metal parts is described and implemented in 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. Therefore, a cost orientated product model was 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.

Cost calculation is based on job order costing, expanded with the workcenter costing. Workcenter rates are taken into account with full costing rates and variable costing rates. Based upon this methods of contribution costing are integrated in the cost estimate sheet to support the cost estimator calculating the profit contribution of an order.

The estimation of tool costs for progressive dies is based on the use of enterprise-specific trained Artificial Neural Networks. The necessary data are extracted from the workpiece not from the tool layout. This cost determination is done without the generation of a plate sequence. With this method the workcenter costs in the toolmaker‘s shop can be calculated. Direct material costs and costs for supplied parts are considered by the use of a database. Within the investigated range of workpieces calculation accuracies between 5 % and 15 % can be achieved.

These introduced methods are implemented in a quotation costing system for personal computers with the operating system MS-Windows. The standards SQL and ODBC are used as database interfaces, so that different database systems may be applied in the system.

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