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Estimating the cost of vertical high-speed machining centres, a comparison between multiple regression analysis and the neural networks approach

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ABSTRACT

This paper focuses on the machine-tool selection problem, which consists of choosing the most suitable machine to satisfy the needs of a manufacturing company. The final decision affects the performance of the production system. Selecting an inadequate machine can negatively affect the company's results. For this reason, this is an important process that may imply some difficulties for the decision-maker.

The objective of this work was to develop a cost model for vertical high-speed machining (HSM) centres based on machine characteristics. It is important to determine the cost of the machine tool, which is based on the tool's characteristics and needs to satisfy both the buyer and the manufacturer.

In order to determine the main machine specifications associated with machine cost, a preliminary analysis was conducted with entry-level vertical HSM centres. As a result, two models were developed: one from the buyer's point of view and the other from the manufacturer's point of view. The cost estimation models were developed using two different techniques: multiple regression analysis (MRA) and artificial neural networks (ANN). The paper then examines the performance of the models, and compares the models' outputs to determine which model offers the best results. Cost estimation is important to determine the machine costs that adapt best to the characteristics of manufacturing factories.

The correlation obtained by the multilayer ANN models is better than the one obtained by MRA. Applying the proposed cost models will help the user (engineers or machine manufacturers) to determine the approximate machine cost based on its characteristics when they select a vertical HSM centre.

1. Introduction

Metal cutting is one of the manufacturing processes most widely used for producing the final shape of products, and its technology continues to progress in parallel with developments in materials, computers and sensors. Over the last years there have been constant innovation and technological advances in all the production system fields (Altintas, 2000). New technologies have been introduced in the market, which have led to the development of new metal cutting concepts, e.g. high-speed machining (HSM).

HSM is defined as machining that uses average spindle speeds greater than 1047 rad/s (10,000 rpm), which can generate surface speeds in excess of 6 m/s. This high-speed process produces heterogeneous plastic flow with severely localized stresses that result in extreme rates of plastic deformation (up to 106 s^{-1}), high thermal gradients

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(100 °C/mm) and high heating rates (105 °C/s) (Campbell et al., 2006).

Selecting a machine tool is an important decision-making process for many manufacturing companies. Inappropriate machines can negatively affect the overall performance of a production system. An improper selection can negatively affect productivity, precision, flexibility and the company's responsive manufacturing capabilities (Arslan et al., 2004). This choice is usually made without considering the adjusted price, which represents the manufacturing characteristics.

The lack of a standard format in machine catalogues, the large number of factors to be considered, the new machine tools and the advance in the technology further complicates the problem. For a proper and effective evaluation, the decision-maker may need to analyse a large amount of data and consider many factors. The decision-maker should be an expert, or at least be very familiar with the machine properties, in order to select the most suitable machine from among the alternatives in accordance with an available budget. This becomes a very time-consuming decision process (Arslan et al., 2004).

Therefore, a simplified and practical approach is needed for the machine selection process. There are several approaches to cost estimation that use statistics and linear regression analysis (developed since the 1970s), based on the potential of artificial intelligence, such as expert systems (developed since the 1980s) or based on an alternative branch of artificial intelligence, such as artificial neural networks (ANNs). For this reason, it is possible to find studies on cost estimation carried out in a large range of fields that compare the performance level between the estimates produced by multiple regression analyses, MRA, and ANN. Shtub and Versano (1999) propose a cost estimating system for the steel pipe bending industry. Edwards et al. (2000) present an analysis for predicting construction plant maintenance costs. Kim et al. (2004) introduce cost estimating models in the construction field. Cavalieri et al. (2004) focus their studies on the automotive industry and Zhang and Fuh (1998) make early cost predictions for packaging products.

This paper contains two of the above-mentioned approaches. Several models have been developed to predict or obtain an approximate idea of the market cost of vertical HSM centres by linear regression analysis and ANNs. These models are based on statistical studies carried out using the characteristics of the vertical HSM centres available on the market.

The purpose of this study is to compare the accuracy of these estimating techniques for estimating vertical HSM centre costs, by comparing the ANN artificial intelligence method with MRA. Cost estimation is important to determine the price of vertical high-speed machine tools based on their characteristics. This knowledge makes selecting an appropriate machine easier.

This paper is organized as follows. In Section 2 the previous work carried out to develop the cost models is presented. In Sections 3 and 4 MRA and ANN cost models are explained, respectively. Section 5 makes a performance comparison of these methodologies and, finally, conclusions are presented. The paper uses the nomenclature shown in Table 1 to help readers understand the proposed models better.

Table 1
Nomenclature and data range

Nomenclature		Acquire data range
V	Work volume (m^3)	0.084–5.437
Ar	Work area (m^2)	0.3–7.5
L	Table loading capacity (kg)	300–32,000
W	Weight (Kg)	3400–32,000
A	Positioning accuracy (μm)	2.5–12
R	Positioning repeatability (μm)	0.7–10
X, Y, Z	Linear axis *X, Y, Z*, travel (mm)	350–5000
Vfrx, Vfry, Vfrz	Rapid traverse *X, Y, Z* (m/min)	18–120
Vfcx, Vfcy, Vfcz	*X, Y, Z*, feed force speed (m/min)	10–90
S	Max. spindle speed (rpm)	10,000–36,000
P	Power (kW)	9–55
T	Torque (Nm)	12.5–199
E	Number of axis	3–5
Ma	Market cost (€)	56,000–642,000
Mm	Predicted market cost (€)	

2. Description of the approach

2.1. The sample

The most important characteristics that should be considered in a machine selection process were identified based on previous works (Guzmán Bacre, 2005) and investigations carried out with several suppliers. Twenty characteristics were identified and separated into two groups. One group consists of 19 characteristics that make up the independent variables of the statistical studies and the other group consists of the unique dependent variable, the cost.

Following Bacre's method, the 19 characteristics considered for each machine were classified into three groups:

(a) *Geometric characteristics:* work volume, work area, table loading capacity, weight, linear *X*-axis travel, linear *Y*-axis travel and linear *Z*-axis travel.
(b) *Axis characteristics:* positioning accuracy, positioning repeatability, number of axes, rapid traverse in the *X* axis, rapid traverse in the *Y* axis, rapid traverse in the *Z* axis and feed force speed also in three axes.
(c) *Spindle characteristics:* maximum spindle speed, power and torque.

The nomenclature specifies all the variables of the study, the denominations used to simplify their notation and their units.

In this work 35 complete information samples of vertical HSM characteristics were obtained. This information was obtained from the databases of the companies which collaborated with the study. Personnel from several real machine tool trademarks were individually interviewed to obtain data. The interview focussed on obtaining all the information about the vertical high-speed machine tool available in the catalogues as well as the