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Price forecasting using an ACO-based support vector regression ensemble in cloud manufacturing

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ABSTRACT

In a cloud manufacturing environment, deviation of a service price from its value and cost makes on-demand price forecasting a challenging task for the service providers. The main objective of this paper is to present taxonomy of Value Measures and Metrics (VMMs) for pricing decisions over the product life cycle, e.g. the design, manufacturing, and service stages. Furthermore, a parametric pricing approach is proposed to formulate pricing variables, which represent pricing factors and are calculated in terms of VMMs, as well as a regression relation between the pricing variables and price. An Ant Colony Optimization Algorithm (ACO)-based Support Vector Regression (SVR) ensemble is developed to forecast a price. We demonstrate the effectiveness of the proposed methodology with the real-world data of an organization in China. The experimental results show that the proposed method achieves significant generalization performance with the best mean squared error (MSE) and reliable results in randomness of ensemble learning. Thus, the proposed pricing method provides a way to make viable prices for service providers.

1. Introduction

In a cloud manufacturing (CMfg) environment, customers benefit from lower whole-life equipment costs, no upfront capital investments, and flexible services for the personalized demands. However, many industrial manufacturing companies have realized that it is not easy to provide this new model to each of their customers in a profitable way. One of reasons why companies are against a cloud manufacturing paradigm is the prediction of the customer-specific price points when a large number of product varieties are produced in shop floor. Despite these drawbacks, CMfg will continue to play an import role in enhancing organization competitiveness. Therefore, price forecasting is a challenge for organizations in a CMfg system.

Most CMfg services are sold with static pricing or with a combination of long-term contracts and static pricing. Specifically, the customers purchase the resource capacity in a pay-per-use paradigm. Pay-per-use is a pricing plan wherein a customer only pays for what he actually uses, regardless of a concrete service provider. Therefore, the demands for a provider are indefinite. An organization has to manage the price risk of this pricing plan by monitoring each customer case to get the required transparency on the profitability and to clearly understand what needs to be adjusted or changed when the contract needs a renewal. Consequently, much more uncertain factors are brought into the life cycle value formation of a product than ever, and ultimately lead to the uncertainty and time-varying relationship between demand and value. Therefore, forecasting price based on value-added becomes an issue. The problem of price prediction can be defined as a regression problem. Although many machine learning approaches for financial forecasting have been reported by several studies (Burges, 1998), to our best knowledge, there are relatively few effort at predicting price as it is related to a variety of factors and a small number of relevant samples. To address the limitations, we present taxonomy of metrics to measure value added of a product for customers and organizations first; a parametric pricing model is then formulated to forecast a price by an ACO-based SVR ensemble. The main contributions in this paper are as follows:

(1) A pricing model is proposed to describe the mechanism of pricing in a cloud manufacturing environment. From the view of service provider, this pricing model facilitates it to forecast a price of service or product in terms of pay-per-use paradigm.
(2) Classification of VMMs is presented to measure the value and cost of a service or product in the design, manufacturing and service stages. A parametric pricing approach is proposed to predict the price in terms of the pricing factors represented by the VMMs.
(3) An ACO-based SVR ensemble is developed. An ensemble of SVRs is

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constructed by Boosting methodology. The parameters of SVR are selected by ACO. The performance of price forecasting is improved without significant increase of computation time.

The remainder of this paper is organized as follows. Section 2 reviews the related literature. Section 3 describes a pricing model in CMfg. In Section 4, the price prediction approaches with ACO-based SVR ensemble are presented. Finally, in Section 5, the conclusions and research directions for the future are given.

2. Literature review

A pricing plan, describing how products or services should be charged, is a critical factor for most organizations. Many works have been focused on the study of pricing in CMfg. Lartigau, Xu, Nie, and Zhan (2015) built a complete framework for cloud services, and considered the geographical location of manufacturing resources in the service quality measurement. Wang and Zhao (2016) presented a decision-making model of optimal prices with linear programming, aiming at maximizing corporate profits under the market demands, to realize the optimal configuration of resources. Ma and Yang (2015) proposed the optimization model in group buying mode, and the effectiveness of the algorithm was verified by simulation experiment. Peng, Guo, and Shao (2017) analyzed the key factors of transactions and presented a game model of price among participates in CMfg system for small and medium enterprises. And the equilibrium prices between the resource service providers and the Agents were studied with Stackelberg price leadership model. Wei, Zhao, and Shu (2013) proposed a selection method of the manufacturing cloud services depending on trust evaluation. The evaluation time and effect of estimators' loyalty on the service's credibility were also considered. Xiao and Hu (2014) studied the pricing mechanism in aspects of efficiency and fairness and proposed a model of cloud resource pricing and transaction by game strategy. Luo, Sun, Hu, and Wang (2013) proposed a service schema for multi-source information service in cloud business. Ren and van der Schaar (2014) provided a dynamic scheduling and pricing algorithm. By case study, the results indicated that the algorithm could achieve high average profits under average queuing delay. Hsu, Ray, and Li-Hsieh (2014) developed a cloud service adoption model that can deal with adoption intention as well as pricing mechanisms and resource deployment. The effectiveness of the model was verified in 200 Taiwanese firms. Chun and Choi (2014) investigated the optimal pricing plan of a cloud service and analyzed the two pricing plans from the perspective of supplier-subscription pricing and pay-per-use pricing. Besides the above academic studies, many cloud computing service providers have developed and employed a variety of well-established pricing plans (Al-Roomi, Al-Ebrahim, Buqrais, & Ahmad, 2013). The most commonly employed pricing plans include: (1) pay-per-use (i.e. utility-based pricing plan), (2) subscription, (3) auction-based pricing (i.e. dynamic pricing plan), and (4) advertising-based pricing. Among them, pay-per-use for machines and equipment (EaaS, equipment-as-a-service) has become a successful business model in different industries.

In summary, the above research works focus on pricing form the aspects of market and economics; and most of them are related to the pricing of cloud computing services. Few research works study the pricing of CMfg. Moreover, the existing relevant pricing methodology for manufacturing enterprises aims at quote, regardless of value added formation of a service.

Since the cloud manufacturing is a new paradigm, VMMs are collected from various businesses related to the value (or cost) formation for a product. And the data obtained from these actual activities are usually insufficient and incomplete. In the case, we employ SVR to forecast a price, due to SVR higher performance than other machine learning methods in a small size samples.

Support Vector Machine (SVM) proposed by Cortes and Vapnik (1995) was used in statistical analysis. SVM is widely utilized in both classification and regression problems (Loutas, Roulias, & Georgoulas, 2013). However, training of a SVR becomes a difficult problem as real-valued variables may exhibit chaotic behavior, local non-stationarity and high levels of noise (Avnimelech & Intrator, 1999). In this case, the SVRs can be constructed an ensemble to improve the performance. The ensemble of predictors (i.e. a weak learning machine or simply a machine) is often called a committee machine. Boosting is the one of popular committee machines that combine the outputs from different predictors to improve overall accuracy.

Therefore, a price methodology in CMfg is proposed for pay-per-use paradigm, and focuses on improving the performance of regression. We investigate the effectiveness of the proposed method through experiments on the price prediction.

3. Pricing model in cloud manufacturing

In CMfg, customers demand reliability from enterprises through the cloud providers, i.e. they can purchase a service whenever they need it and rationing is not tolerated. The provider focuses on implementing a price scheme to maximize its revenue, while still fulfilling the value-added of the demanders and enterprises. The enterprises determine the quotation of a product or service using the only resources selected by the cloud provider, according to the pay-per-use paradigm. Forecasting a price for specific resources becomes an issue for an enterprise, since the full cost of a service is tricky to obtain in the case of a variety of products processing on it.

In this paper, a pricing model is proposed by measuring the value added in the process of order products as the value of products may have substantial pricing effects, besides the cost. For this reason, we first set the value-related measures and matrices (i.e. VMMs) to measure the value added and cost incurred of the resources. Due to the VMMs variety, caused by requested services ranging from product design, manufacturing, testing, management, and all other stages of the product life cycle, and interrelationship between them, we should pay more attention on the critical pricing factors. A parametric pricing model is therefore developed and facilitates an enterprise for price making-decision and forecasting a price with the change of customer demand.

The model requires the detailed information about the value formation related to design, production and service stages, which can be collected through analyzing the utilized resources of services, as seen in Fig. 1.

3.1. Pricing measures and metrics

Referring to the market-based approach, the process, by which the price of a service or product is determined, is influenced by various factors. They include customer needs, underlying product concept and its life-cycle, etc. These factors are evaluated and measured by VMMs, demonstrating the significance of suitable VMMs in pricing decision-making. With the cloud manufacturing characteristics— i.e. on-demand, large diversity of resources and the numerous offers, VMMs (as shown in Table 1) are divided into two layers so that pricing decision can be aligned with the goal of value-added for the service demanders and providers. In the first layer, the three business stages (i.e. design, manufacturing and service) related to pricing are included. In each item of the first layer, many sub-metrics, covering financial and none-financial performance measures and metrics are comprised in the second layer. These VMMs are collected according to the literature review and the questionnaire from enterprises, and should conform to the existing performance metrics of every business, making them viable in CMfg.

(1) Design stage: Decision-making at this stage is usually relied on whether design, determining approximately 80% cost of a product, can create values for customers and enterprises. The VMMs have been suggested for pricing: product-related measures (e.g.