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Forecasting the productivity of a virtual enterprise by agent-based fuzzy collaborative intelligence—With Facebook as an example

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ABSTRACT

Since the Internet bubble, firms that focus on virtual enterprises have sought to enhance productivity. To achieve this goal, a firm must evaluate its present productivity and estimate its future productivity. To overcome the considerable uncertainty in estimates of productivity, we propose an agent-based fuzzy collaborative intelligence approach that predicts productivity. First, a fuzzy learning model is built and used to estimate future productivity. Subsequently, the fuzzy learning model is fitted by several agents with diverse settings; those agents produce different productivity forecasts. Fuzzy intersection is then applied to determine the narrowest range that contains the actual value from the fuzzy forecasts. Finally, a back-propagation network derives a representative value from the fuzzy forecasts. The real-world case of Facebook is used to demonstrate the applicability of the proposed methodology.

1. Introduction

A collaborative fuzzy-neural approach is presented in this study to forecast the productivity of a virtual enterprise; such forecasts are important for the following reasons [38]:

(1) An enterprise's productivity is directly related to its financial performance.
(2) Bailey [1] contended that employees often perform below their maximum potential, and therefore measuring productivity is important.
(3) Productivity is extremely important for the sustainable development of an enterprise that can survive the present era of globalization. In the development of new e-commerce models, productivity and sustainable profitability are two key considerations [16,17].

Wright [44] studied the impact of learning on productivity in the aircraft manufacturing industry. In recent years, the development of data warehouses has enabled researchers to look more directly at productivity [3]. Bandyopadhyay et al. [2] designed an integrated information system that increased productive decision making for topics such as administration, payroll, recruiting, training, and performance analysis. Hatami-Marbini et al. [24] wrote that health care organizations must continuously improve their productivity in order to maintain long-term growth and profitability.

To evaluate productivity, one divides a fixed output by the required input. The units of input and output may be different. Both input and output can be made up of a number of different items that need to be integrated somehow; an integrated measure of diverse productivity factors is called "composite productivity." The most widely used measure of productivity is labor productivity [4]. With well-trained employees, enterprise productivity usually increases over time, but there is a limit. For these reasons, the improvement in productivity can be seen as a learning process. The productivity of an enterprise should be compared with that enterprise's past productivity levels, and with competitors' productivity levels.

Brandt et al. [4] proposed a formula that uses input and output estimates to predict the long-term productivity, but because the estimates are nontrivial, Brandt's formula does not simplify this problem. In particular, the long-term outputs are affected by price fluctuations, and are very difficult to estimate. Further, productivity is affected by many factors including standardization, quality differences, scrap rates, new workers, layoffs, incentive plans, *etc.* [38], and therefore there is a considerable degree of uncertainty in the long-term productivity.

This study describes how to predict the productivity of a virtual enterprise, and uses Facebook as an illustrative example. As the world's largest social networking site, Facebook has attracted the attention of many researchers in e-commerce related fields.

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Most studies have focused on how to enhance social networking through the applications of Facebook. For example, Zhang et al. [45] explored how some users integrated their online interactions and offline activities, and found that Facebook intensified the popularity of social identities. Rodríguez et al. [34] proposed a model for calculating the strength of social ties based on interaction information and derived the deployment of an interaction network for Facebook from this model. Notably, Thusoo et al. [40] described the systems that are used by Facebook to implement a data warehouse that stores more than 15PB of data and loads more than 60TB of new data every day. Clearly, the productivity of Facebook is affected by the amount of data, the number of users, the number of requests, and other factors. Automated operations significantly enhance the productivity of a virtual enterprise like Facebook. However, if Facebook intends to serve an ever-increasing number of users, then Facebook must relentlessly improve its productivity. Further, Facebook's profitability models are limited, so there are relatively few ways in which Facebook can try to increase its productivity. Wolff [43] stated that Facebook will be unable to survive in a competitive market due to its over-dependence on conventional advertising. Further, physical enterprises can only be attacked directly by dangerous physical attacks, but virtual enterprises are subject to hacker attacks. Companies must defend against hacker attacks, but such defenses waste corporate productivity [26]. In practice, there is much debate about whether the use of Facebook will enhance or reduce the productivity of an enterprise [23].

Forecasting the productivity of Facebook is difficult for several reasons:

(1) Measurement of productivity is straightforward in physical enterprises due to the high degree of uniformity of products and services. Virtual enterprises do not necessarily deliver highly uniform services.
(2) Very few articles have mentioned how to assess the productivity of similar virtual enterprises.
(3) The fluctuations in the network economy are large and difficult to grasp, which makes it difficult to predict the productivity of an Internet-based enterprise in the long term.

To solve these problems, this study adopts the following strategies:

(1) Productivity basically follows a learning process [4], so a learning model can be established for it, and that model can be used to predict future productivity.
(2) A fuzzy value is used to represent an uncertain forecast of productivity. A fuzzy value has a range, and therefore is able to appropriately express a concept of uncertainty [8].
(3) An agent-based fuzzy collaborative intelligence approach is proposed to enhance the precision and accuracy of the productivity forecasting. Here accuracy means the forecasted values should be as close as possible to the actual values, and precision means an interval that contains the actual value must be as narrow as possible. For example [14] proposed a fuzzy collaborative intelligence approach to predict the foreign exchange rate between NTD and USD, which outperformed the autoregressive integrated moving average (ARIMA) approach with regard to forecasting accuracy by reducing the mean absolute percentage error by 28%.

In the agent-based fuzzy collaborative intelligence approach, a group of agents is formed. Each agent applies a fuzzy linear regression equation to forecast the productivity of a virtual enterprise. There are various ways of fitting a fuzzy linear equation, and during the fitting process some parameters need a subjective setting. The forecasts obtained by the agents may be very different, and therefore a collaboration mechanism must aggregate the forecasts. In the proposed methodology, fuzzy intersection and back propagation network approaches are applied to aggregate the forecasting results. In theory, an agent can also refer to the settings of other agents to modify its own. Such an aggregation and referencing process may be time-consuming, and that is one reason why this study uses agents rather than human experts. Another motivation for the use of agents is that it can be difficult to find a sufficient number of domain experts for the forecasting task.

Table 1
The number of adjustable parameters for fitting a fuzzy linear regression equation.

Number of adjustable parameters	Methods
1	[13,31,39]
2	[22]
4	[9,14,15,19]
6	The proposed methodology

This agent-based fuzzy collaborative intelligence approach has the following innovative characteristics:

(1) The proposed method is the first to consider the uncertainty in the long-term productivity.
(2) Multiple agents assess the productivity from diverse points of view to ensure that no parts are ignored when solving the problem.
(3) Three nonlinear programming models are used to fit the fuzzy linear regression equation, which contains six adjustable parameters, so the agents can express their opinions with tremendous flexibility (see Table 1).
(4) Software agents are used instead of real experts, and the collaboration process is automated. A systematic procedure is established in the proposed methodology to increase the number of agents, so as to optimize the forecasting performance. The agents are also free to choose the values of parameters. Both these tasks are done without expert intervention. Thus this system does not merely automate a static body of expert knowledge; this system provides a resilient, adaptive artificial intelligence.

The differences between the proposed methodology and some existing methods are compared in Table 2.

The rest of this paper is organized as follows. 'Related work' reviews the literature related to fuzzy collaborative forecasting and productivity forecasting. The problems faced by the existing methods are also discussed. 'Methodology' describes the forecasting method from the point of view of learning. To this end, a fuzzy productivity learning model is established. The real-world case of Facebook is used to demonstrate the application of the proposed methodology. Finally, some concluding remarks and a view to the future are given in 'A real case'.

2. Related work

Fuzzy collaborative intelligence has become an important field of research, and new applications of fuzzy collaborative intelligence and systems are expected to appear [28,29]. In addition, seeing a problem from various perspectives ensures that no parts are ignored when solving the problem. Although there have been some articles about fuzzy collaborative intelligence and systems (*e.g.* [27,28]), there have been very few directly related to fuzzy collaborative forecasting.

In the limited literature about fuzzy collaborative intelligence and systems, Shai and Reich [35,36] defined the concept of infused design as an approach for establishing effective collaboration between designers from different engineering fields. Büyüközkan