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Simulation-based construction productivity forecast using Neural-Network-Driven Fuzzy Reasoning

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A R T I C L E   I N F O

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A B S T R A C T

Fuzzy models and Artificial Neural Network (ANN) systems are two well-known areas of soft-computing that have significantly helped researchers with decision-making under uncertainties. Uncertainty, an ever-present factor in construction projects, has made such intelligent systems very attractive to the construction industry. Estimating the productivity of construction operations, as a basic element of project planning and control, has become a remarkable target for forecasting models. A glimpse into this interdisciplinary field of research exposes the need for a system, that (1) models the effect of qualitative and quantitative variables on construction productivity with an improved accuracy of estimation and (2) has the ability to deal with both crisp and fuzzy input variables in one single framework. Neural-Network-Driven Fuzzy Reasoning (NNDFR), as one of the hybrid intelligent structures, displays a great potential for modeling datasets among which clear clusters are recognizable. The weakness of NNDFR in auto-tuning the design of fuzzy membership functions along with this model's insufficient attention to the optimization of number of clusters has created an area for further research. In this paper, the parameters (fuzzifier and number of clusters) of the proposed system are optimized by using Genetic Algorithm (GA) to fine-tune the system for the highest possible level of accuracy that can be exploited for productivity estimation. The proposed model is also capable of dealing with a combination of crisp and fuzzy input variables by using a hybrid modeling approach based on the application of the alpha-cut technique. The developed model helps researchers and practitioners use historical data to forecast the productivity of construction operations with a level of accuracy greater than what could be offered by traditional techniques.

1. Introduction

"Simulation is the imitation of the operation of a real-world process" [3]. It can provide a probabilistic approach to handle the uncertainties of a problem. Simulation is a powerful tool that can be applied to different aspects of construction management, such as productivity estimation, risk management, scheduling, and resource planning. Most research in construction simulation has mainly focused on simulation modeling with little emphasis on the qualitative variables that affect the simulation process itself. However, over the past few years, researchers have begun to employ different soft computing techniques to forecast productivity of construction operations based on several qualitative and quantitative factors. The productivity estimation of construction operations, as a decision criterion in project planning and control, has become an interesting target for forecasting models. Fuzzy models and Artificial Neural Network (ANN) systems have provided effective tools for addressing uncertainties in decision-making [10]. Uncertainty, as an ineradicable part of construction projects, justifies the utilization of such intelligent systems in the construction industry. In the past few years, these systems have been widely applied to develop forecasting models in the construction industry.

The integration of basic soft computing techniques, such as ANNs, fuzzy logic and Evolutionary Algorithms (EAs), has allowed researchers to create more efficient forecasting models. In such integrative models, the limitations of one method can be compensated for by other methods, and has led to the development of a variety of hybrid intelligent structures. Selecting an appropriate structure that offers the highest accuracy is a decision based on the application area and the inherent features of the data at hand.

One of the structures that has been considered as a notable introductory step to today's innovative neuro-fuzzy systems, is Neural-Network-Driven Fuzzy Reasoning (NNDFR). Capitalizing on the self-learning ability of ANN, this model succeeded to present a state-of-the-art method for the fuzzification and development of an inference procedure for a conventional fuzzy system. Its structure is established based on separate independent self-learning functional relationships controlled by a specific number of control rules. This architecture of the model provides a great potential for modeling datasets among which clear clusters are recognizable. However, the accuracy of the model's responses is highly sensitive to its

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parameters. In this structure, the two parameters that need to be optimally defined are the number of clusters and the fuzziness of the membership functions. This optimization requires an appropriate algorithm in addition to some modifications to the conventional structure of NNDFR.

The more comprehensively we study the variables that affect the final modeling outputs, the greater the number of variables that must be considered. As a result, it is very likely to have a combination of linguistic terms (qualitatively described factors) and crisp values (quantitatively described factors) in any modeling process [12]. These situations are very common in construction simulation where the limited data provided for some factors can only be explained by using linguistic terms [32]. Many researchers have tried to find a way to estimate the output of these generalized models using both types of input values. Therefore, an efficient forecasting model is one that is capable of dealing with both types of input variables. With respect to the above-mentioned problems and motivations, the overall objective of this research is to develop a hybrid intelligent system for estimating productivity of construction operations considering several qualitative and quantitative factors. This research therefore aims to:

1) Develop a modified NNDFR model with optimized parameters; and
2) Improve the developed model so that it can simultaneously deal with crisp values and fuzzy numbers.

2. Literature review

2.1. Construction simulation

Many construction and engineering projects consist of repetitive activities, such as earthmoving projects. A considerable amount of time, money and effort can be saved in any project if the right decisions are made at the planning stage. Because of the stochastic nature of cyclic construction processes, historical data gathered from previous projects can assist planning engineers in making a better estimation about the predicted productivity rates [11]. In traditional estimation methods, planning engineers manually adjust productivity records to establish the expected values. The estimation and understanding of the production aspects of projects have been a crucial task for researchers and practitioners in construction engineering and management. Given the increasing complexity and size of projects, planning and decision making in this area is likely to become either impossible or very inaccurate. Several researchers have proposed using computer simulation to model particular systems and estimate their performance in a virtual environment.

Simulation is one of the most widely used techniques in operational and managerial research [18]. Construction simulation is the process of developing computer-based models that represent real-world construction systems in order to investigate their underlying behavior [2]. Construction simulation is a powerful tool that can be used by a construction company for several tasks, such as productivity measurement, risk analysis, resource planning, and the design and analysis of construction methods [34]. Among all these applications, productivity measurement might be considered the most important factor in construction planning and control. Most research in construction simulation has mainly focused on simulation modeling with a limited emphasis on evaluating the qualitative variables that affect the simulation process itself [9]. Although some studies have investigated the effect of qualitative and quantitative factors on different aspects of construction processes, there is still a lack of research in this area.

2.2. Productivity assessment

The fierce competition in the construction industry propels all stakeholders to improve their productivity, which explains why productivity estimation has attracted so much attention in both industry and academia. Today, productivity management is recognized as a major project management concern in the construction industry [30]. The rate of construction productivity varies from one project to another due to the environmental and managerial conditions. The considerable impact of these project-specific factors on productivity reinforces their importance in productivity estimation simulations [29]. These project-specific factors affect productivity both positively and negatively.

The scheduled overtime, change orders, materials management, weather and human factors were identified by Park [29] as the main factors that influence the productivity rate. The identification of these factors is a preliminary step in creating a model for productivity estimation. The most common approach for productivity estimation is to use the historical data from previous similar projects as a baseline for new projects.

For example, Moselhi et al. [24] developed a decision support system called WEATHER to examine the impact of weather conditions on the productivity of construction operations. The developed model estimates the construction productivity, activity durations, and weather patterns in different modes to improve the accuracy of the planning and scheduling [24]. Given that in this framework only weather factors are taken into account, other complementary models are needed for the consideration of other external factors.

Moselhi et al. [26] investigated 57 different construction projects in order to study the impacts of change orders on the productivity of construction projects. They discovered a direct correlation between the labor component of change orders and the productivity loss in all types of projects [26].

Regression model is the most common statistical model for productivity estimation when considering specific factors [33,36]. Hanna et al. [13] developed a regression model to investigate the effect of change orders on construction productivity. Koehn and Brown [20] employed some non-linear equations to examine the effect of weather changes on the productivity rate. The learning curve theory is another important theory in productivity estimation. According to the learning curve theory, the productivity of a repetitive process gradually increases thanks to the increasing familiarity with the process, improved management, and more efficient application of tools and equipment [27]. In most cases, there is no pre-identified functional relation between variables affecting the level of productivity and their outputs. In addition, there is no guarantee that simple models such as linear regression can satisfy the expected accuracy of a forecasting model. In the wake of these limitations, researchers have considered the application of Artificial Intelligence (AI) systems to model complex relationships between a set of dependent and independent variables.

2.3. AI systems

ANN is a mathematical model for finding patterns among datasets where there are complex relationships between the inputs and outputs. ANN attempts to simulate the structure and operation of the human neural network system. The ability to learn from examples has made this technique a very useful tool in data modeling [21]. Since ANN acts like a "black-box" and cannot explain the reasoning process, it is well suited to problems where the underlying reasons and the quality of input–output relations are not being studied [9].

In the past few decades, ANN has been applied extensively in forecasting models in the construction industry. Researchers applied this technique in many aspects of construction management in order to benefit from its advantages over conventional modeling methods. Cash flow prediction, risk analysis, resource optimization, tendering outcome prediction and productivity assessment are only a few examples of ANN applications in the construction industry [4,22,25,41].

Fuzzy logic [40], on the other hand, was introduced as a response to the need for a systematic reasoning that better conforms to human logic. The main goal of fuzzy logic is to connect an input space to an output