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A neuro-fuzzy combination model based on singular spectrum analysis for air transport demand forecasting

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ABSTRACT

Air transport demand forecasting is receiving increasing attention, especially because of intrinsic difficulties and practical applications. Total passengers are used as a proxy for air transport demand. However, the air passenger time series usually has a complex behavior due to their irregularity, high volatility and seasonality. This paper proposes a new hybrid approach, combining singular spectrum analysis (SSA), adaptive-network-based fuzzy inference system (ANFIS) and improved particle swarm optimization (IPSO), for short-term air passenger traffic prediction. The SSA is used for identifying and extracting the trend and seasonality of air transport demand and the artificial intelligence technologies, including ANFIS and IPSO, are utilized to deal with the irregularity and volatility of the demand. The HK air passenger data are collected to establish and validate the forecasting model. Empirical results clearly points to the enormous potential that the proposed approach possesses in air transport demand forecasting and can be considered as a viable alternative.

1. Introduction

The air transport industry has experienced significant growth over the past few decades due to the rapid growth of international trade and increases in travel opportunities. Given the huge amount and effort for airport construction and difficulties for switching the usage of airport once constructed, accurate forecast of demand for an airport is of crucial importance for its construction, investment and management (Flyvbjerg et al., 2005). It helps make decisions regarding the development of airport master plans with respect both to airside (runways, taxiways, aprons, technological devices) and landside (boarding/landing area, waiting rooms, etc.), thereby ensures the improvement of services to air passengers. Total passengers are used as a proxy for air transport demand in this paper.

To deal with the complex behavior of air passenger traffic time series, which results from the characteristics of its irregularity, high volatility and seasonality, in this study we propose a novel hybrid approach by combining SSA for data preprocessing, ANFIS and IPSO that can provide the most accurate prediction of the air passenger throughput. This hybrid system has advantages of both neural networks (e.g., learning capabilities, optimization capabilities) and fuzzy systems (e.g., human-like 'IF–THEN' rules, and ease of incorporating expert knowledge available sometimes in linguistic terms). To reduce the opportunity of trapping in a local optimum and failing to converge to the best position, a PSO based improved algorithm is proposed and used to optimize the ANFIS, tuning the membership functions required to achieve a lower error. The proposed HSAI (hybrid SSA–ANFIS–IPSO) approach is examined on the air transport market of Hong Kong. It has been concluded that the Hong Kong market has a hard nonlinear behavior and time variant functional relationship, which is a good market is with sufficient complexity for a real world case study. The effectiveness regarding forecasting performances of proposed approach is demonstrated through comparing with ARIMA, MLP, WNN, TSK-NFIS, CD, and SSA approaches.

In general, there are two groups of methods for air transport demand forecasting, one is qualitative and the other is quantitative. Qualitative methods, e.g., market surveys, Delphi method and expert meetings, etc. analyze the characteristics of the air transport market to determine empirically how the usage of an airport varies across different sectors of the population. Combining with estimations of

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social economic changes these methods forecast the future development of air transport demand mainly depending on the experts' experience, knowledge and analytical skills (Yeung et al., 2010). On the other hand, quantitative methods usually establish mathematical forecasting models based on historical statistical data. Since the latter are more objective and precise, they have drawn more and more attentions. According to the difference of quantitative forecasting methods, they can be divided into three categories: time series, causal analysis and combination forecasting.

Time series methods, establishing a mathematical model only by historical data, include ARIMA/SARIMA (Tsui et al., 2014), exponential smoothing (Samagaio and Wolters, 2010), gray theory (Hsu and Wen, 2000), seasonal adjustment method (Aston and Koopman, 2006), fuzzy system method (Chen and Chen, 2011), Holt–Winters (Bermúdez et al., 2007), etc. Time series methods assume that all the factors that determined the development of demand in the past, will continue to operate in the same way in the future. However, future airport demand deduced by projection of historical data does not contain the circumstance that the various economic and other external conditions influence the development of demand. Causal analysis methods examine the correlation between the airport demand and a series of variables which affect the development of demand including socio-economical and transport system variables and build a forecasting model. These variables are expressed as the impact of changes within the economic environment on traffic. Such methods include regression analysis (Abed et al., 2001), causality test (Fernandes and Pacheco, 2010), logit model (Garrow and Koppelman, 2004), gravity model (Grosche et al., 2007), system dynamics (Suryani et al., 2010), etc. Combination forecasting tries to obtain better forecasting performance by integrating several different methods (Xiao et al., 2012a). Some researchers have compared different forecasting methods (Wang et al., 2010; Fildes et al., 2011). Unfortunately, there is no one technology or method that is able to consistently outperform under any conditions.

In monitoring the changes in seasonal patterns and business cycles, short-term forecasts often yield better results than long-term forecasts (Franses and Van Dijk, 2005). Short-term forecasts cover one or two years are essential for daily airport operation activities involving the acquisition of additional equipment and material, allocation and arrangement of workers and machines. However, it is extremely difficult to forecast short-term throughput by traditional methods such as the ARIMA model, the GARCH model, the stochastic volatility (SV) model, the stochastic volatility with exogenous variables (SVX) model, the vector autoregressive process (VAR) and the fractionally integrated GARCH (FIGARCH) model, etc. due to its typical non-stationarity, irregularity and noise. In these traditional models, we need to assume a functional relationship between input and output and try to fit the data as per that relationship. This particularly hampers our efforts, since the predictors of economic fields form multidimensional input space and the relationship between input and output is essentially nonlinear (Xiao et al., 2014, 2013). The limitation of many traditional forecasting models has encouraged academic researchers and business practitioners to develop more effective forecasting models. As a result, models using artificial intelligence techniques (AIs) have been recognized as more effective than conventional statistical forecasting models (Yu et al., 2010). AI is a generalized term that encompasses the fields of artificial neural networks (ANNs), fuzzy logic, evolutionary computation, machine learning and probability reasoning, etc. AIs can simultaneously handle the non-linear data of multidimensional input space. Furthermore, AIs do not require an explicitly well defined relationship between input and output as they determine their own relationships based on input and output values (Xiao et al., 2012b). However, drawbacks of AIs include the inherent implicitor hidden input/output data relationship and the possibility of overly excessive computational requirements. Among AI, ANNs have been developed numerous types as a most popular forecasting tool and widely used in various forecasting applications including air transport demand. For example, Aburto and Weber (2007) proposed a sequential hybrid forecasting system (SHFS) for demand prediction, which combines ARIMA and neural network models. Empirical results showed that SHFS outperformed 6 other techniques, including naive forecasting, seasonal naive forecasting, unconditional average, pure SARIMAX process, pure multilayer perceptron and additive hybrid forecasting model. Alekseev and Seixas (2009) developed an artificial neural forecasting model for air transport passenger analysis. It is found that neural processing outperforms the traditional econometric approach and offers generalization on time series behavior. However, there have been few attempts to use neural networks in air transport demand forecasting. Generally speaking, an ANN is suitable for modeling a short-term nonlinear pattern of the annual energy consumption, while traditional approaches such as exponential smoothing, moving average, and ARIMA have good performances when the trend in the time series is stable.

Air transport demand is highly uncertain and very difficult to forecast. Fitting the annual throughput within a future year with a distribution function is not easy, implying that a stochastic approach might not be suitable. To that end, many studies proposed a fuzzy approach to forecast the demand in an industry (Duru et al., 2012; Chen, 2012). Moreover, some literatures were devoted to decision making under fuzzy demand forecasts (Petrovic et al., 2006; Purwanto et al., 2012). Therefore, it is reasonable to propose a fuzzy approach to forecast air transport demand.

Like the ANN, a fuzzy system is a nonlinear mapping of an input vector into a scalar output, but it can deal with numerical values and linguistic knowledge. ANNs have the advantage over the fuzzy models that knowledge is automatically acquired during the learning process. Unfortunately, this knowledge cannot be interpreted as a kind of black-box technique. Fuzzy systems can be understood through their rules, but these rules are difficult to construct when the system has too many variables and their relations are complex (Rodriguez and Anders, 2004). Therefore, hybrid models that combine both ANNs and fuzzy systems can be expected to improve the forecasting accuracy as natural complementary tools due to have the advantages of each of them (Chen and Lin, 2008). In the fuzzy-neural approach, ANNs extract automatically fuzzy rules from original data and, the membership functions are adaptively adjusted.

The original data in the real world such as air transport throughput contain distracting behavioral patterns which can hamper ANNs from extracting more complex structures in the time series (Nelson et al., 1999). Previous studies have focused on the importance of decomposition as a preprocessing task in time series modeling and suggested that decomposition can significantly improve forecast performance. Consequently, the separation of salient components in the original time series which can facilitate the training and learning of an ANN has become an essential process prior to data analysis and forecast. Since the seminal work of Persons (1919), a large number of decomposition approaches and application have been developed (Choi et al., 2011; Theodosiou, 2011). In this study, singular spectrum analysis (SSA) is used as preprocessing method to obtain the different information at various scales conveyed in the underlying dynamics.

Although there are many studies on hybrid forecasting, novel approaches are still required in order to improve forecasting performance and reduce the uncertainty in air transport demand forecasting. For this purpose, this paper describes a novel hybrid approach for short-term air transport demand forecasting by combining SSA for