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Estimation of electrical power consumption in subway station design by intelligent approach

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HIGHLIGHTS

- ▶ We estimate the power consumption of subway stations by multilayer perceptron.
- ▶ Data collected from Observatory and 19 subway stations are used for model training.
- ▶ Number of hidden neurons of the model is investigated by sensitivity test.
- ▶ Correlation coefficient is used to describe the prediction performance.
- ▶ The coefficient of correlation, with 95% confidence level, can reach 0.96 or higher.

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ABSTRACT

According to the records of Hong Kong rail operator, MTR Corporation, the weekly electrical consumption of each railway station ranges from 18 MWh to 230 MWh. Since the electrical consumption of stations is a major factor in the planning of infrastructure, a good prediction of the electrical consumption will greatly assist in the design of the station infrastructure. This study develops an intelligent approach to predict the energy consumption of railway stations. Multi-layered Perceptron (MLP) is adopted to mimic the non-linear correlation between energy consumption, the spatial design of the station, meteorological factors and also the usage of the 19 stations selected. Coefficient of correlation is obtained between the MLP predicted results and the actual collected data to evaluate the performance of the prediction. We apply statistical approach to assess the performance of the developed MLP model. It shows that minimum coefficient of correlation is 0.96 with a 95% confidence level which is considered sufficient for engineering application. This approach is also adopted to predict the profile of the weekly electrical consumption of a selected station. The predicted profile reasonably agrees with that of the actual consumption. This study develops a useful tool to estimate the electrical power consumption of new MTR stations.

1. Introduction

Subway system provides an economic and convenient transportation to the public for travelling within their cities. Especially for metropolitan cities, majority peoples are relying on the subway system in their daily lives. The extensive use of subway system initiates the engineers and scientists' research on the energy consumptions of the subway stations. Ampofo et al. [1] studied the braking system of the trains and provided evidence that the ambient condition of the subway station is significantly adverse by the heat created from the braking mechanisms of the trains. For the facilities of a subway station, a prediction model was developed by Ma et al. [2] to estimate the energy consumption of the escalators. Energy audit was conducted by Fu and Deng [3] on the Guangzhou railway station. Based on the results, they successfully identified the potential energy conservation measures on the air-conditioning system, power equipment system and lighting system of the station. These pioneer works show that the prediction of energy consumption of a subway station is non-linear in nature. They applied different mathematical models to simulate the energy consumption. This paper presents the information of the energy consumptions of the subway stations in Hong Kong. It also proposes to adopt the artificial neural network model to mimic the non-linear behavior of the energy system of the subway stations in Hong Kong by using the historical data of the stations.

Carrying more than 4.4 million passengers every weekday, the MTR is regarded as one of the world's leading railways for safety, reliability, customer service and cost efficiency. The MTR Corporation was established in 1975 as the Mass Transit Railway Corporation

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with a mission to construct and operate, under prudent commercial principles, an urban metro system to help meet Hong Kong's public transport requirements.

Apart from railway operations in Hong Kong, the MTR Corporation is also involved in a wide range of businesses, including property development and management, international rail operations joint ventures and consultancy services, advertising, and telecommunication services. The new urban hub with comprehensive residential and commercial developments above Kowloon Station is developed by the MTR Corporation. Some of the MTR's property developments have become landmarks of Hong Kong, such as the shopping mall, Elements, and the commercial complexes, International Commerce Center and the International Financial Center, Hong Kong's two tallest buildings. With MTR's proficiency in railway operation, the Corporation now operates outside Hong Kong including Beijing Metro Line 4, Shenzhen Metro Line 4, and Stockholm Metro in Sweden. MTR Corporation has also formed joint venture companies in the United Kingdom and Australia to operate the London Overground and the Melbourne Metro rail networks respectively.

MTR currently operates 10 heavy rail commuter lines and 11 routes on a light rail network. The MTR network spreads over the urban areas, and links the heart of Hong Kong with Hong Kong International Airport, Hong Kong Disneyland Theme Park, and the boundary with the Mainland of China.

Furthermore, MTR Corporation is extending its network with five new railway lines in Hong Kong. These include the Guangzhou-Shenzhen-Hong Kong Express Rail Link, the West Island Line, South Island Line (East), Shatin to Central Link and Kwun Tong Line Extension.

Existing MTR stations have on-going extension and improvement plans. New pedestrian subways and entrances are introduced to connect nearby developments, and to provide more convenient access for customers. Station assets are refurbished as needed and sustainable technologies are applied to improve customer services in a socially responsible manner.

Up to August 2010, MTR has 152 heavy rail stations and light rail stops. And thus, a tool to estimate energy consumption is vital to the development of a sustainable management system, as it can be used to minimize energy waste, and that will have significant impact on the performance of station buildings.

2. Pioneer works on energy consumption analysis and prediction

Following the oil embargo of 1973, both the political and scientific communities began to pay more attention to opportunities to improve energy efficiency. Recently, Basbous et al. [4] developed a novel combustion engine to improve fuel consumption for electricity production. Kaldellis et al. [5] developed a numerical algorithm to calculate the maximum wind power contributing to an electrical generation system. For understanding the contributions of domestic components to the increase in domestic energy consumption in UK, Kilpatrick et al. [6] developed a methodology to filter the domestic energy consumption profile into standby profile, cold profile, heating element profile and residual profile. Possible energy saving opportunities can then be identified from the profiles. Work on energy consumption forecast has become more and more popular, as energy demand has grown dramatically when compared with past decades. According to Kadoshin et al. [7], this effect is related to two main factors, namely increase in population and economic development. Besides, more stakeholders have aligned their objectives with green values, and become more conscious on sustainable energy use. Forecasting energy consumption would allow a better understanding of the actual demand in the future. Based on the pioneer research works on energy consumption forecast [8], the majority of the building energy predictions are done for town planning as well as renewable energy development purposes, such that appropriate measures can be implemented to utilize energy use, and to ensure the ability to backup with an adequate energy supply reservoir.

Development of forecasting model for energy consumption has a long history. In 1978, Uri [9] forecasted energy consumption by combining the econometric model and time-series forecasting model to predict the peak load of a specific utility based on economic and weather-related parameters. In 1986, Deeble and Probert [10] had developed a linear correlation to forecast annual energy consumption. In the following year, Bodger and Tay [11] had used growth factor based on past energy consumption to predict New Zealand's electricity consumption. In recent years, different types of model had been adopted to predict energy consumption, namely autoregressive integrated moving average (ARIMA) model [12], econometric model [13], artificial neural network (ANN) model [14] etc. Computer modeling and simulation software like TRNSYS [15] was also used to assist in the energy consumption analysis in Cyprus. Tang et al. [16] developed an ensemble empirical model decomposition based least square support vector machine learning paradigm for nuclear energy consumption forecasting. Gutierrez et al. [17] developed a stochastic diffusion process to model the electricity consumption in Morocco. The factors of gross domestic product, final domestic consumption and gross fixed capital formation were taken as inputs of the model.

3. Intelligent approach

According to Zhang et al. [18], ANN can be used to predict relationships that are unknown or complex, as it is capable of capturing fine details of the function relationship via a 'learning' process, also known as 'training' of the network function in ANN, from historical data. More importantly, ANN is a popular approach to predict non-linear functions in the past decade. Among different models of ANN, Multi-layered Perceptron (MLP) [19] is one of the most widely used ANN model for forecasting due to its simple and flexible nature [8,20]. It is a supervised learning model with feed forward connectivity. Also, MLP has been mathematically proven to be a universal function approximator [21,22]. The MLP is proposed to be adopted to predict the energy consumption of subway stations in this study.

The MLP has been successfully applied to different areas including weather, market trends, electrical and thermal load predictions in (something missing here?) [23]. It was also applied to predict bankruptcy, stock prices, international airline passenger traffic, rainfall, transportation, water demand and wind pressure profile [18]. A lot of studies have been conducted to compare the forecasting performance of traditional statistical model against MLP under different conditions, and many of them have proven that MLP outperformed traditional statistical models, especially forecasts for monthly [24], quarterly [25] or even daily [18] time series data. Countries like Saudi Arabia and Singapore have already used MLP to predict their energy consumption as well [8].

Yalcintas and Akkurt [26] employed MLP to mimic the total chiller plant power of a 42-storey commercial building in downtown Honolulu, Hawaii. Their independent input variables mainly consisted of climate data, and the model output was chiller plant power consumption. The input parameters used in the MLP model included dry bulb temperature, wet bulb temperature, dew point temperature, relative humidity percentage, wind speed, and wind direction. The hour of the day was recorded to account for variations in occupancy throughout the day. However, data on