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Is Machine Learning a Magic Wand?

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Machine Learning for Hotel Revenue Management

In recent years, machine learning has been at the leading edge of revenue management practices in the hospitality industry. Machine learning is the study of computer algorithms that automatically learn from data to find hidden patterns or insights (Mitchell, 1997). Machine-learning algorithms build a model based on sample data, known as "training data," in order to make predictions or decisions without being explicitly programmed to do so (Wikipedia, 2021). The basic idea of machine learning is that computers could learn from data and automatically develop a model by generalizing the pattern learned from the data. Machine-learning techniques are widely used in many application areas such as self-driving cars, speech recognition, and image processing, where conventional algorithms may not be able to solve the complex, often large-scale problems. With recent growth in machine-learning technologies supported by big data, state-of-art revenue management systems are using machine-learning models in various revenue management areas including demand forecasting, pricing, market segmentation, and customized guest services (Alexsoft, 2018; Blengini, et al., 2020; Boulton, 2018; Gulcu & Sanli, 2017; Reuters, 2019).

Leveraging advances in machine-learning technology, revenue management systems are highly automated. With data-driven demand forecasts and machine-recommended pricing, revenue managers no longer punch numbers into spreadsheets. Machine learning is at revenue managers' fingertips, and a question is, “Is machine learning a magic wand?”

Case Study: Comparative Analysis of Machine Learning and Pickup Models for Hotel-Demand Forecasting

Demand forecasting is one of the most prominent revenue management fields where machine-learning techniques are widely adopted. While traditional forecasting models are based on certain mathematical or statistical formulas, machine learning does not require underlying theoretical models to capture complicated relationships of factors that may determine demand (Lee, et al., 2020). Traditional forecasting techniques such as time-series models can only consider a few demand factors. On the other hand, machine-learning models allow for more data from heterogeneous data sources such as social media, web search traffic, and customer reviews to be combined into the forecast. Due to its flexible structure and use of large data supported by computation power, the machine-learning approach achieves high prediction accuracy in demand forecasting.

In order to test forecasting accuracy of machine-learning models, we collected two years of daily booking data from three hotels. For better forecasting results, we explored several different machine learning algorithms. Originated from computer science, machine learning refers to a number of algorithms. Among many machine-learning algorithms, neural networks, including its sub-category deep learning, are the most popular algorithms used in hotel revenue management, especially for dynamic pricing and demand forecasting. Inspired by the biological neural networks that constitute brains, neural network approach provides highly flexible modeling capabilities to process complex relationships in large data sets (Lee, et al., 2020). In particular, due to improved computing power and increased data availability, more complex neural network structures called, “deep learning,” often offer the highest level of prediction performance.

We compared the performance of deep learning models with traditional models. For a benchmark, we used pickup models, which are simple, yet popular in the hospitality industry. The main idea of pickup models is to estimate the increments of bookings to come and then aggregate these increments into the early realizations (pickups) to obtain a forecast of the final demand (Lee, 2018; Zakhary, et al., 2008). To assess the performance of forecasting models, we use the Mean Absolute Error (MAE) as error

measures. The absolute error is the absolute value of the difference between the forecasted value and the actual value.

Table 1. Comparison of Average MAE - Deep Learning and Pickup Model

	Deep Learning	Pickup
Hotel 1	10.69	9.93
Hotel 2	14.62	14.03
Hotel 3	17.13	15.97

We applied the deep learning method along with the pickup approach to the validation data of the three hotels. For performance validation, we consider a booking horizon of four weeks prior to arrival at the hotel. Table 1 reports the average MAEs obtained from the validation data. The results show that the deep learning model does not outperform the traditional pickup models.

This empirical result seems at odds with common beliefs on machine learning. Why did the most advanced machine-learning technology fail to achieve higher accuracy than the simple traditional approach? There are some cases that may make a problem (or data) a bad candidate for a machine-learning application. If the needed task is driven by a simple factor, not necessarily involving multiple complicated factors, machine-learning algorithms may not perform better than simple approaches. In this specific case of the three hotels, their demand patterns can be explained primarily through the pickups and considering other factors may include simply additional noises in the model.

On one hand, if there exists a theoretical or practical model that explains the data well, there is less motivation to develop machine-learning models. For example, when the room demand follows a regular seasonality pattern and shows small variation, a simple time-series technique may be a better candidate than complicated machine-learning models. On the other hand, if there is no true underlying pattern in the data, a machine-learning algorithm may try to describe noises (or random fluctuations) and make an overly complex model to explain idiosyncrasies in the training data, which is called overfitting. The overfitted model is useful in reference only to its initial training data set, and not to any other data sets. If we feed the overfitted model new data, its accuracy will end up being poor. Machine-learning is often vulnerable to overfitting issues as machine-learning models are capable of describing complex patterns. When data have large random variations with no underlying patterns, a simple aggregate approach may produce better results than advanced machine-learning models.

How to Take Advantage of Machine Learning for Revenue Management

There are many different applications of machine learning in revenue management, and a common question is: “How can hotels take advantage of machine-learning technology for revenue management?” One of the common denominators is that hotels need to

understand the nature of the problem. Machine-learning techniques typically show very good performance in prediction problems. Machine learning inherently produces a "black box" model where gaining insight on relationships and effects becomes nearly impossible (Gulcu & Sanli, 2017). If the purpose of the needed task is to gain human-interpretable explanations on relationships and effects, theoretical or descriptive models such as regression analysis may be better options. For example, revenue managers need to know "Why is summer demand higher than other seasons?" and "What is the most significant factor driving the summer demand?" For answering these types of questions, machine learning is not the go-to solution.

Another common denominator is that hotels should know if the data are a good candidate for machine learning. Exploratory data analysis such as data visualization and descriptive statistics is an essential process of performing initial investigations on data, through which hotels can obtain early insights into potential use of machine learning. Machine learning is a powerful technology to capture hidden patterns and solve complicated problems, of which theoretical/mathematical models cannot be written down. On the other hand, if the data shows clear patterns or has a simple and practical way to describe, there are not many benefits to developing machine-learning models.

Machine learning does not refer to a single algorithm. Different algorithms have different characteristics with different capabilities to solve different types of problems. Machine-learning development process involves selecting the appropriate methodology. An algorithm itself cannot solve the problem or automatically provide insights into the problem. Machine-learning technology is not a magic wand to solve any problem without human intervention. The performance of machine-learning models depends on the human modelers' expertise. Insights of revenue managers and data scientist are essential throughout the entire machine-learning development process including what kind of data (e.g., time series, booking pace, market behavior, and macroeconomic indicators) to use, what variables to use, what specific algorithm to use, and how to determine the parameters for the selected algorithm.

As machine-learning experiences a renewed push in the hospitality industry, there is a growing demand for machine-learning literacy. While good analytical skills are important, the ability to integrate new sources of data generation from machine learning has also played a key role (Blengini, et al., 2020). Most importantly, understanding of the general process and characteristics of machine learning is even more critical in driving smart pricing decisions and strategies.

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