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# Ship arrival prediction and its value on daily container terminal operation

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ABSTRACT

Effective prediction of ship arrivals should provide the estimated delay or advance of arrival ships with greater accuracy, and improve the performance of container terminal operations. Therefore, taking Gangji (Yining) Container Terminal (GYCT), China, as an example, this paper resorts to data mining approaches to predict ship arrivals and explore the value of such predicted ship arrivals on the container terminal operation. First, this study applies three data mining approaches, including Back-Propagation network (BP), Classification and Regression Tree (CART) and Random Forest (RF), to estimate the delay or advance of ship arrivals using the collected data of ship arrivals. Then the predictive performance of these three approaches is compared and discussed, it is concluded that RF performs better than BP and CART, and ETA month and ship length are the most important determinants of ship arrivals in GYCT terminal. Finally, series simulation experiments are conducted to assess the value of the ship arrivals predicted by RF model on the improvement on daily operation planning of berth allocation and quay crane assignment in the GYCT terminal. And the results show that incorporating the predicted ship arrivals by RF model is beneficial to improve the performance of operation planning of GYCT terminal.

## 1. Introduction

Planning of container terminal operation (i.e. berth allocation, quay crane assignment, and container handling, transport and storage) are made every day, striving to minimize the port time of ships and resources required to complete handling operations (Brinkmann, 2011). When facing this decision, one main difficulty lies in the uncertainty of ship arrivals. Despite the Estimated Time of Arrival (ETA) are sent to the port 24 h in advance according to contractual obligations, there are still a lot of unexpected factors to cause the deviations of arrival times, which would compel the planners to reset operation planning, and result in the fluster and loss of port operations (Fancello et al., 2011; Hartmann et al., 2011; Moorthy and Teo, 2006). Therefore, planners need to be assisted by providing a qualitative estimate of the delay/advance by determining whether or not an incoming vessel is likely to arrive before or after its scheduled ETA, which is able to support the decision-making process.

In the general planning and layout for a new port, the empirical probability distributions of arrival ships have been widely studied to describe the stochastic of ship arrivals (PIANC, 2014). For example, series of researches demonstrate the number of daily arrival ships and the inter-arrival times between ships generally comply with Poisson distribution and Negative Exponential distribution respectively (Daganzo, 1990; Kozan, 1997; Shabayek and Yeung, 2002; Demirci, 2003; Quy et al., 2008; PIANC, 2014). Moreover, Du et al. (2013) consider that the ship arrival pattern of container terminals varies with constitute of container liner routes: for the container terminals of Ningbo Port and Guangzhou Port serving various container liner routes, the number of daily arrival ships follows Poisson distribution; while for the container terminals of Shenzhen Port and Yantian Port serving single route, the number of daily arrival ships follows Normal distribution. As one of the most import inputs to master planning and layout for the new port, these empirical probability distributions of ship arrivals have been applied to make decisions on port planning and layout. For example, Kia et al. (2002) employ the computer simulation in evaluating the performance of a container terminal on handling techniques and capacity of terminal, based on inter-arrival times of arrival ships regarded as Negative Exponential distribution. Özgüven et al. (2013) focus on the determination of the optimal quay length using a stochastic knapsack model with the arrival pattern of ships taken as Poisson process. Tang et al. (2014, 2016) determine the berth occupancy of a container terminal considering the effect of entrance channel dimensions by an established process-interaction-based simulation model, in which the ship arrivals are described by Negative Exponential distribution.

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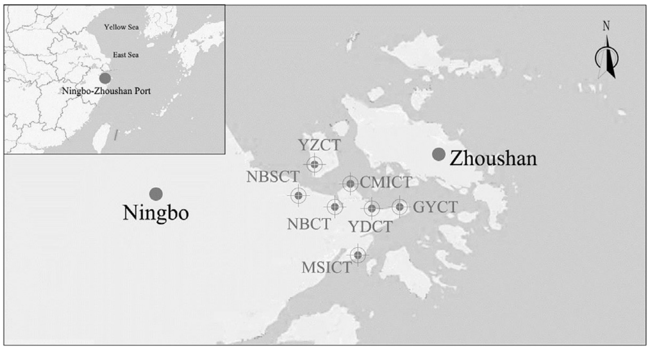


**Fig. 1.** Locations of Ningbo-Zhoushan Port and its main container terminals.

While in decision-making process of port operation planning, to reduce the uncertainty of ship arrivals, the Estimated Time of Arrival (ETA) is sent to the port 24 h in advance according to contractual obligations. However, there are still a lot of unexpected factors to cause the deviations of arrival times, which would result in centralized arrival of ships during a short time window (Hartmann et al., 2011). Therefore, to further reduce the uncertainty of ship arrivals, a series of researches have recently resorted to data mining approaches to predict the ship arrivals. For example, Fancello et al. (2011) first use Neural Networks (NN) model to predict interval time of ship's arrival, then apply the predicted interval time in the proposed model optimizing human resources allocation, and the promising results are achieved to provide support to planners. Pani et al. (2013, 2014) employ both k-means and Ward's method to cluster the daily records of Cagliari International Container Terminal to divide the delay of arrivals into three levels firstly, and employ Classification and Regression Trees (CART), Random Forest (RF), and Naive Bayes (NB) to obtain an estimate of the delay level, and the results show that RF gives the best results with a relative absolute error of 29% comparing the predictive performance of the three models. Pallotta et al. (2013) propose an unsupervised method, Traffic Route Extraction and Anomaly Detection (TREAD), to automatically learn a statistical model for maritime traffic from AIS data, to detect low-likelihood behaviors and predict future positions of ships. Pani et al. (2015) adopt Logistic Regression (LR), CART, and Random Forest (RF), to estimate the deviation of arrival ships in Cagliari International Container Terminal and PSA-Antwerp terminal. Parolas et al. (2016) apply Support Vector Machines (SVM) and Neural Networks (NN) to predict the ETA of container ships calling to the Port of Rotterdam, and the results indicate that both SVM and NN achieve better predictions than the situation that ETA is based on the ship's agent estimations, and SVM models outperform the NN comparing the Mean Absolute Error of models. All these studies have certain significance and the reference value regarding the approaches of data mining on predicting time of arrival ships in some specific ports.

Developed on these previous researches, this study aims to investigate the prediction performances of Back-Propagation network (BP), Classification and Regression Tree (CART) and Random Forest (RF) on predicting the ship arrivals of Ningbo Ganji (Yining) Container Terminal (GYCT), Ningbo-Zhoushan Port, China. Moreover, this paper also explores the potential improvement of ship arrival predictions on the daily operation of GYCT terminal, to fully evaluate the availability of the ship arrival prediction.

The remainder of this paper is organized as follows. Section 2 makes a brief introduction of Ningbo-Zhoushan Port and GYCT terminal, and analyzes the characteristics of ship arrivals and delays. Section 3 summarizes the data-mining models applied to predict the delay of ship arrivals, and analyzes the impact of input variables on predictive performance. Section 4 conducts simulation experiments to explore the value of ship arrivals prediction on daily container terminal operation. And the conclusions and further research are addressed in Section 5.

**Table 1**
Collected data and their description.

| Variable type | Variable |
|---|---|
| Ship feature | Ship name, ship type, length (m) |
| Ship position | Last Estimated Arrival Time (YYYY/MM/DD/HH:MM) |
| | Actual Arrival Time (YYYY/MM/DD/HH:MM) |
| Ship service | Route type (Trunk/External feeder/Internal feeder/Barge feeder/ Domestic trade line) |

## 2. Study case and data statistics analysis

### 2.1. Background

Ningbo-Zhoushan Port, located in the intersection of Silk Road Economic Belt and 21st –Century Maritime Silk Road, is the world's fourth-largest container port in terms of throughput. As of July 2017, Ningbo-Zhoushan Port owns 236 routes, including 114 ocean trunks like the Mediterranean Sea routes, Europe routes, West America routes, South Africa routes, Middle East routes, 70 near-sea feeder routes like West Asia routes, as well as 20 internal feeder routes and 32 domestic trade routes (NBZC, 2017). Fig. 1 shows the main container terminals in Ningbo-Zhoushan Port, including Ningbo Beilun International Container Terminal (NBCT), Ningbo Second Container Terminal (NBSCT), Ningbo Ganji (Yining) Container Terminal (GYCT), Ningbo Yuandong Container Terminal (YDCT), Ningbo Meishan-Island International Container Terminal (MSICT), China Merchants International Container Terminal (CMICT), and Zhoushan Yongzhou Container Terminals (YZCT). In this study, the GYCT terminal is selected as a study case, due to the integrity and availability of collected data of ship arrivals. The GYCT terminal has five 150,000-DWT (Deadweight Ton) modern container berths, and the annual container throughput reaches over 5 million TEUs, with total frontage length of 1,700 m, 23 quay cranes and 72 yard cranes. And GYCT terminal uses a three 8-h shift system to meet the demands of port operation in a 24-h workday. The first shift also known as day shift starts 8 a.m., and ends 4 p.m.; the second shift, or swing shift, starts when first shift ends, which is usually around 4 p.m., and it ends around midnight; and the third shift, or night shift, covers the hours from around 0 a.m.–8 a.m.

In China, terminal operation planning is performed at five main sublevels that differ in the type of decision and time horizon, including monthly operation planning, 10-day operation planning, weekly operation planning, daily operation planning and single ship operation planning (Yu, 2007). In this case, we focus on the daily operation planning, which addresses the specific allocation of resources (berths and quay cranes), and the time horizon is about 24 h. Therefore, to explore the ship arrivals for daily operation planning, we collected data on vessel arrivals from June 1, 2008 to May 31, 2009, including 2066 containerships arriving at GYCT terminal. These attributes of each ship arrival include ship name, ship type, ship length, Estimated Time of Arrival (ETA), Actual Time of Arrival (ATA) and route type. Considering more than 2000 arrivals collected, the available variables are divided into 3 main classes, as listed in Table 1.

(1) Ship feature (name, length, type). These variables are indicators of the vessel physical structure and directly affect the sailing times. And the length also provides information concerning berth occupancy.
(2) Ship position (ATA and ETA). These variables give indication about the positions of the vessel from the time it arrives at the pilot point to unberthing time. This variable of ETAs is updated several times, generally, including a month, a week, 48 h and 24 h in advance. This study focuses on the last ETA 24 h before ships arrival. Following the researches of Fancello et al. (2011) and Pani et al. (2014, 2015), the ATAs and ETAs in this study are expressed

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