A Time-Series Analysis of Highway Capacity: Case Study of Georgia 400

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1 Introduction

Capacity has been understood as a deterministic traffic volume threshold, above which the flow breaks down into queued or bottleneck conditions with heavy congestion while below which traffic will flow [5]. This indicates if the capacity is 3000 veh/hr, the traffic flows when velocity is 2999 veh/hr, and it is congested when its 3001 veh/hr. However, empirical capacity observations suggest stochastic capacity variations over time which is hardly described in a deterministic manner. Elefteriadou et al. [1] showed the breakdown does not necessarily occurs at the same demand level. Minderhoud et al. [2] investigated the empirical capacity estimation method for uninterrupted flow and recommended the product limit method. Brilon et al. [3] extended this method and suggested a Weibull distribution to describe the stochastic capacity based on empirical observations from Germany. In addition, they applied the stochastic capacity concept to capture travel time reliabilities in freeway networks. This stochastic capacity concept differentiated from the conventional fixed capacity definition is a noticeable advancement by enabling a probabilistic nature of road capacities, however this concept still bears the flaw of its inability to capture how road capacities vary over time (i.e., defining freeway capacity as a time series). As a result of the stochastic capacity concept, the travel time will be stochastic. Therefore, the significant impacts of stochastic capacity on travel time reliability can be conducted.

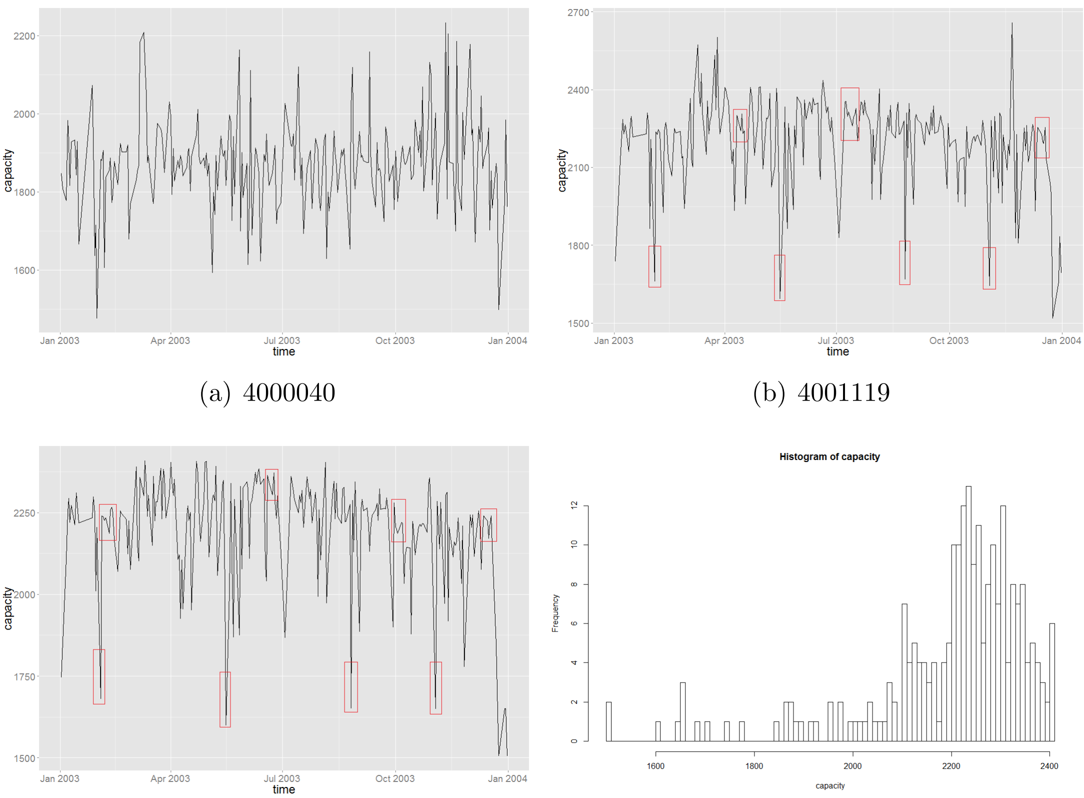
1.1 Objective

The purpose of this research is to provide a stochastic analysis of highway capacities using empirical data from Georgia state route 400 as evidences. This problem is an intricate one as highway capacity depends on diverse dynamic factors, such as weather conditions, vehicle composition, heterogeneous driver behavior and static factors, including road geometric conditions, vehicle characteristics. Accurate modeling of capacity variation has to take these numerous factors into consideration, which may require substantial empirical data to unveil the underlying capacity variation patterns. Since the capacity changes day by day and form a series according to the time, we can look the capacity changing from a different perspective, namely, the time series. In this paper, a time series method for modeling the capacity series will be developed, also, the suggested approach with a case study and experimental results would be illustrated.

1.2 Motivation

The impetus to model highway capacity as a stochastic process is largely motivated by the fact that empirical highway capacity observations show stochastic variations over an extended observation duration as is verified from Figure 1. A stochastic analysis of highway capacity is essential to understand the freeway bottleneck breakdown, congestion dynamics, and prediction of travel time reliability [4]. Capacity is typically defined as the maximum amount or number that can be contained or accommodated. According to the current published version of the Highway Capacity Manual (HCM) 2010, the capacity of a system element is defined as “the maximum sustainable hourly flow rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given time period, under prevailing roadway, environmental, traffic and control conditions. Highway capacity can be expressed either in vehicle or person. Without further clarification, the capacity herein is vehicle capacity by default unless otherwise specified.

2 Empirical Capacity



(a) 4000040 (b) 4001119

(c) 4001118 (d) 4001118

FIGURE 1 Capacity variation patterns on basic freeway segment from multiple Georgia 400 detectors over a whole year's weekday observations

2.1 Estimation of Empirical Capacities

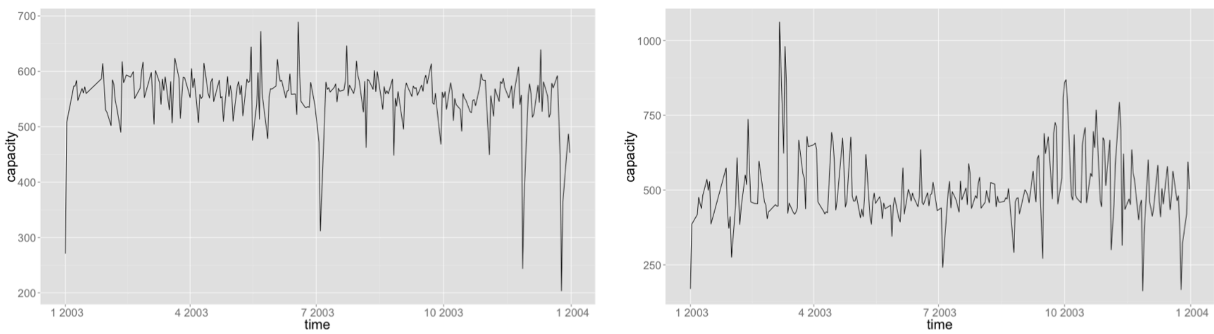
According to HCM, capacity is the maximum hourly rate at which vehicles pass a point at a given time period. When estimating capacity from empirical data, the 15 minutes flow rate is usually used. In the original GA400 dataset, traffic was reported every 20 seconds regarding the vehicle counts (i.e., cars, vans, and trucks). A passenger car equivalent factor is used to convert the number of heavy vehicles to the equivalent number of passenger cars. The 15 minutes flow rate is scaled up to an hourly rate by multiplying 4, and the capacity of this location is estimated by the maximum hourly rate of each day. Repeat this process for every single weekday over the year 2003, a series of highway capacities and its variations over time is therefore obtained and this capacity variation trend can be described by a time series analysis. Next, the empirical capacity variations are presented at the freeway basic segment and the freeway on/off-ramps.

2.2 Capacity Variations on Basic Freeway Segment

As shown by Figure 1, the capacity does fluctuate on a daily basis within an interval: approximately 1600 to 2400 vehs/hr/ln for freeway basic segment, and from 250 to 750 vehs/hr/ln for freeway on/off-ramps. It is meaningful to describe the how capacities are distributed as is shown in Figure 1 (d). A Weibull distribution has been suggested and used in previous studies to describe it, however the statistical distribution fails to capture the capacity variations over time if there are interests to predict the future capacity changes. Therefore, a time-series analysis is adopted to bridge this gap which is appealing for prediction purposes.

2.3 Capacity Variations at On/Off-Ramps

The capacity variation pattern at the freeway on/off-ramps is explored to reveal that this capacity variation pattern is not unique to basic freeway segments. The pattern is observed and verified in Figure 2. Therefore, the modeling and analysis methodology for a stochastic analysis of capacity variations on freeway basic segments is transferable to on/off-ramps.



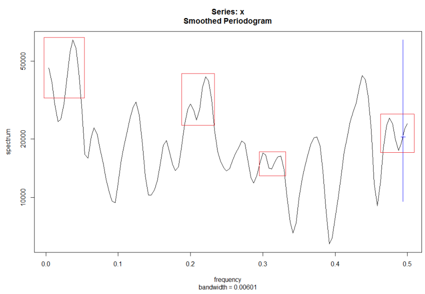
(a) On-ramp (b) Off-ramp

FIGURE 2 Capacity variations at on/off-ramp from Georgia 400 over a year's weekday observations

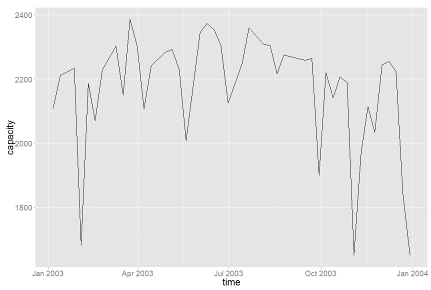
3 Preliminary Results

3.1 Initial Spectral Analysis

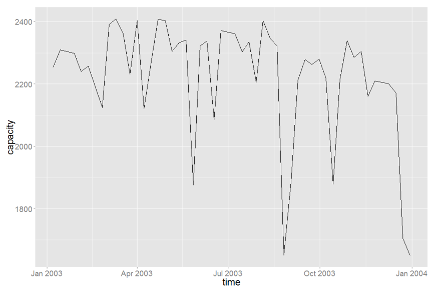
A case study is designed to demonstrate the methodology using the GA400 dataset. Since the Auto-Correlation Function (ACF) and Partial Auto-Correlation Function (PACF) did not suggest an obvious fit to a certain model. To investigate seasonality over the whole year 2003, a spectral analysis is employed to explore the trend in the capacity series to assess the seasonality characteristics of how capacity essentially varies over time for all the weekdays as is shown in Figure 3. The Figure 3 (a) shows a smoothed spectrum from the capacity series estimated from one detector on GA400. In order to show how the seasonality is somehow related to how capacity changes on a particular weekday (i.e., Mon, Tue, Wed, Thu, and Fri), the individual capacity series are plotted from Monday to Friday as is shown in Figure 3.



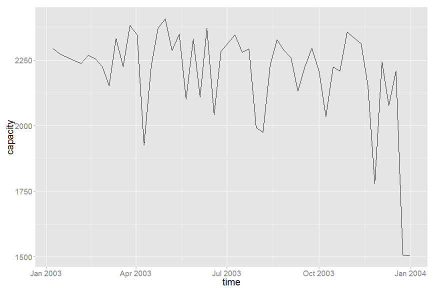
(a) Spectral



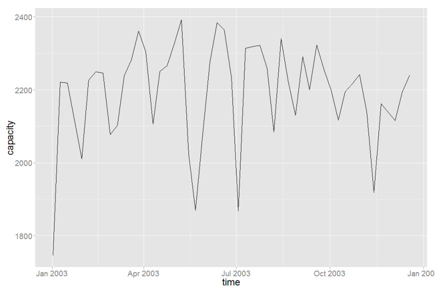
(b) Monday



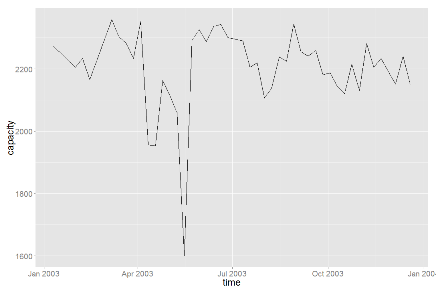
(c) Tuesday



(d) Wednesday



(e) Thursday



(f) Friday

FIGURE 3 Spectral Analysis and Mon-Friday capacity series

3.2 Initial Time-series Analysis

After conducting the spectral analysis, there are peaks shown on the priodogram, it reaches the highest point at $\omega = 0.05$. Let $T = 2\pi/\omega$, one gets $T \approx 20$, which is approximately a month excluding the weekends. (The data set is weekday data, so around 20 days one month). Fit the capacity variations with an ARIMA$(0, 1, 1) \times (1, 0, 0)_{20}$ model, the AIC indicates the lowest value, which seems suggesting a monthly seasonality on the capacity variation. In addition, residual is fairly close to the white noise, which shows the proposed model describes the original data faithfully. As a result, a short-term forecasting of highway capacities can be performed to predict future capacity changes, in Figure 4 (right).

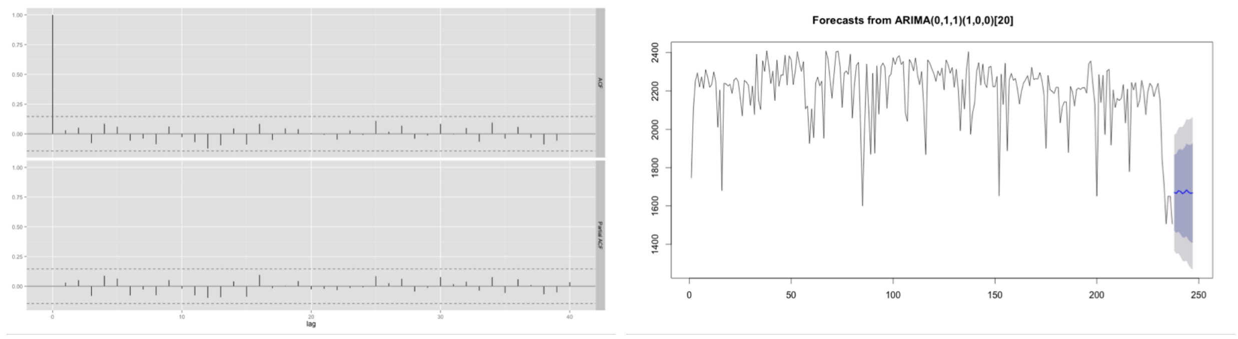


FIGURE 4 Model residual's ACF & PACF (left) & 10 days short-term forecasting (right)

4 Conclusion

A preliminary stochastic time series analysis of highway capacities is provided and verified from the empirical observations both from basic freeway segments and on/off-ramps of Georgia state route 400. Modeling capacities as a stochastic time series instead of a statistical distribution function has obvious benefits to traffic operations analysis by knowing the temporal dimension of how capacity changed over time (existing) and how capacity might change in the near future (i.e., short-term prediction).

References

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