Transportation Research Part C 86 (2018) 220–244

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Tailored Wakeby-type distribution for random bus headway adherence ratio

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ARTICLE INFO

Keywords:
Bus routeregularity
Headway adherence
Probability distribution estimation
Wakeby distribution
L-moment

ABSTRACT

This paper addresses an interesting and practical bus headway adherence issue for a given public bus route with a number of bus stops. It first defines the random headway adherence ratio (HAR) at a particular bus stop of a specific bus route as the ratio of difference between actual bus headway and scheduled headway with respect to the scheduled headway. This study proceeds to customize a four-step procedure to estimate a probability distribution that can describe the random HAR at each bus stop of the bus route by using the automatic vehicle location (AVL) data. Our real case studies with 44,025 HAR data show that the 19 existing probability distributions including Lognormal, Gamma, Beta and Wakeby are unable to well fit these HAR data. This study thus proposes a tailored Wakeby-type distribution with five parameters. After deriving two fundamental propositions for the tailored Wakeby-type distribution, a tangible *L*-moment based method to estimate those parameters involved the tailored Wakeby distribution is presented. The tailored Wakeby-type distributions can meet our expectation via our real case studies. Finally, applications of the tailored Wakeby-type distribution derived for the random HAR are conducted.

1. Introduction

Public bus as one of the major transport modes plays a vital role in the large Asian cities such as Singapore, Hong Kong, Beijing and Bangkok. Taking Singapore as an example, a city (nation) with a population of 5.3 million people generated around 3.4 million daily bus trips in 2012 that accounted for 50 per cent of the total public transport trips (LTA, 2013). According to the 2012 household interview travel survey of Singapore, about 62 per cent of all commuters' trips during the peak hour periods were made on public transport. The aim and vision in 2013 Land Transport Master Plane of Singapore are to achieve a peak period public transport mode share of 70 per cent in 2020 and 75 per cent by 2030 by providing more connections and integration between public transport modes - bus, train and other forms of travel like cycling. Nevertheless, Singaporeans' overall satisfaction with the public transport system has dipped from 90.3 per cent in 2011 to 88.8 percent in 2012 and the satisfaction levels for bus and rail reliability also fell, according to the latest public transport customer satisfaction survey conducted in October of 2012.

To improve the reliability of public transport, Land Transport Authority (LTA) of Singapore has just implemented a bus service reliability framework (BSRF) for 22 bus routes on a two-year trial since 3 February 2014. Following the quality incentive contract (QIC) of London, the BSRF assesses regularity of bus service by the passengers' excess waiting time (EWT) that is equal to the actual waiting time (AWT) minus the schedule waiting time (SWT). Incentives and penalties are imposed to the relevant bus operators by

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https://doi.org/10.1016/j.trc.2017.11.013
Received 8 September 2017; Received in revised form 11 November 2017; Accepted 11 November 2017

Nomenclature

Symbols

m number of bus stops for the outbound direction of the studied bus route
n number of bus stops for the inbound direction of the studied bus route
A departure-terminal for the outbound bus trip
B departure-terminal for the inbound bus trip
$[T_s,T_e]$ time window under concern
I_A+1 number of scheduled trips departing from terminal A in time window $[T_s,T_e]$
I_B+1 number of scheduled trips departing from terminal B in time window $[T_s,T_e]$
j bus stop j, $j\in[1,2,...,m]$ for outbound direction and $j\in[m+1,m+2,...,m+n]$ for inbound direction
i bus trip i, $i\in[0,1,...,I_A]$ for trips scheduled to depart from terminal A in time window $[T_s,T_e]$, $i\in[0,1,...,I_B]$ for trips scheduled to depart from terminal B in time window $[T_s,T_e]$
τ_i^A scheduled departure time of the ith outbound bus trip from terminal A, $\tau_i^A\in[T_s,T_e]$
τ_i^B scheduled departure time of the ith inbound bus trip from terminal B, $\tau_i^B\in[T_s,T_e]$
h_i^A scheduled bus headways for the ith outbound bus trip from terminal A
h_i^B scheduled bus headways for the ith inbound bus trip from terminal B
w workday, $w\in W$ and W= {Monday,Thuesday, Wednesday, Thursday,Friday}
$H_{i,j}^{w,A}$ actual bus headway of the ith ($i=1,2,...,I_A$) trip at the outbound bus stop j ($j\in\{1,2,...,m\}$) on a particular workday $w\in W$
$H_{i,j}^{w,B}$ actual bus headway of the ith trip ($i=1,2,...,I_B$) at the inbound bus stop j ($j\in\{m+1,m+2,...,m+n\}$) on a particular workday $w\in W$
$t_{i,j}^{w,A}$ actual arrival time at the outbound bus stop j ($j=2,3,...,m$) for the ith trip ($i=1,2,...,I_A$) on a particular workday $w\in W$
$t_{i,1}^{w,A}$ Actual departure time from the first outbound bus stop for the ith trip ($i=1,2,...,I_A$) on a particular workday $w\in W$
$t_{i,j}^{w,B}$ actual arrival time at the inbound bus stop j ($j=m+2,m+3,...,m+n$) for the ith trip ($i=1,2,...,I_B$) on a particular workday $w\in W$
$t_{i,m+1}^{w,B}$ actual departure time from the first inbound bus stop for the ith trip ($i=1,2,...,I_B$) on a particular workday $w\in W$
$HAR_{i,j}^{w,A}$ bus headway adherence ratio at the outbound bus stop j ($j=1,2,...,m$) for the ith ($i=1,2,...,I_A$) trip on a particular workday $w\in W$
$HAR_{i,j}^{w,B}$ bus headway adherence ratio at the inbound bus stop j ($j=m+1,2,...,m+n$) for the ith ($i=1,2,...,I_B$) trip on a particular workday $w\in W$
$L_j^{w,outbound}$ the number of actual bus adherence ratios at the outbound bus stop $j\in\{1,2,...,m\}$ on the workday $w\in W$
$L_j^{w,inbound}$ the number of actual bus adherence ratios at the inbound bus stop $j\in\{m+1,2,...,m+n\}$ on the workday $w\in W$
λ_r L-moment of a random variable ($r=1,2,...$)
α_r probability weighted movements of a random variable ($r=0,1,...$)

comparing the difference between EWT and a predefined baseline EWT because EWT reflects the additional times passenger faces as a result of irregular bus services (LTA, 2014). The EWT at a particular bus stop of a bus route can be characterized by the regularity of actual bus headway at bus stops with respect to the scheduled bus headway, which is referred to as the bus headway adherence (TRB, 2013). The bus headway adherence is, however, determined by a number of factors that are summarized by Liu and Sinha (2007) as follows: (i) road traffic conditions including traffic congestion levels, traffic composition, day-to-day and within-day variation in travel demand and etc., (ii) bus route characteristics including length of a bus route, location of bus stops, provision of bus lanes, number of intersections on the bus route and etc., (iii) passenger characteristics including passenger volume at bus stops, variability in passenger volume and etc., and (v) bus operational characteristics including scheduling system, bus fleet availability, ticketing system, variability in drivers' behavior and experiences, and etc. Some of these factors have high uncertainties varying by the time of day and day of week. To ensure a rational baseline EWT and an achievable incentive standard, it is thus of great practical significance to investigate the bus headway adherence issue from a probabilistic perspective.

A public bus route usually consists of a number of bus stops including two bus terminals, served by a string of buses dispatched from each of these two bus terminals as per a predetermined timetable. The scheduled headway for the bus route is the difference between the departure times of two consecutive buses departing from the same bus terminal. The scheduled headways are uneven in practical even for the peak hours (Ceder, 2007), which calls for a relative index to quantitatively measure the headway adherence and taking both real headway and scheduled headway into consideration. The headway adherence ratio (HAR) is thus proposed to quantify bus headway adherence at a bus stop, which is defined as the ratio of difference between actual headway at the bus stop and the scheduled headway with respect to the scheduled headway for a specific bus trip. A negative (positive) HAR means a percentage of actual headway being less (larger) than the schedule headway. The closer HAR is to zero the better performance of the bus regularity. Above all, the HAR makes performance of the headway adherence comparable for those bus routes with different scheduled headways. It is more reasonable to assume that the HAR is a random variable, called the random HAR hereafter, due to the uncertainty of the aforementioned factors affecting the bus headway adherence. Such an assumption can be further validated by the stochastic bus dwell time at a bus stop (Meng and Qu, 2013; Bian et al., 2015) and random bus travel time (in-vehicle travel time) between two consecutive bus stops (Polus, 1975, 1979). This study aims to derive a type of probability distribution that can