Journal of King Saud University – Engineering Sciences xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Journal of King Saud University – Engineering Sciences

journal homepage: www.sciencedirect.com

Original article

A Gini coefficient based evaluation on the reliability of travel time forecasting

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ARTICLE INFO

Article history:
Received 13 September 2017
Accepted 18 December 2017
Available online xxxx

Keywords:
Travel time
Reliability
Gini coefficient
Buffer time
Buffer index

ABSTRACT

Traffic congestion is one of the most notorious troubles, one that undermines social costs in urbanized areas in the world. Because of the congestion problem, drivers are trying to find the shortest and most reliable paths. Regarding the reliability of travel time, there already exist a few measures, such as Standard Deviation, Buffer Time, and Buffer Index. However, they have fundamental limitations in calculation or in application.

Therefore, we tried to apply the Gini Coefficient, which is a well-known measure of statistical dispersion, which describes the inequality of income or wealth distribution among a nation's residents, as a new measure for evaluating travel time reliability.

In order to verify the new measure, we calculated Gini coefficients of five different expressway sections on $AADT_{day}$ and Chuseok and reviewed the potential advantage of the alternative by comparing the result with those from existing measures.

In the analysis, the new measure showed us reasonable and reliable results and proved its applicability of appraising travel time reliability.

1. Introduction

It is reported that the total cost stemming from traffic congestion in Korea in 2016 reached about $29.3 billion USD (KOTI, 2016). This traffic congestion cost is accepted as one of the notorious social costs that all drivers are concerned with but cannot easily minimize at the individual driver level. Therefore, from the system level, we should agonize over how to minimize traffic congestion on our roads since a minimal amount congestion for individual drivers also means a minimum travel time. To achieve this, modern transportation systems in urbanized cities have adopted various types of travel time forecasting services in their car navigation or route guidance systems and are used in people's daily lives.

Drivers tend to choose the shortest path based on total travel time when they choose their preferred route, but currently, they also place partial emphasis on the reliability of the forecasted travel time, using a guiding system. In other words, from the chosen route a driver usually expects a certain amount of travel time, based on 'users' previous experiences and hopes it will not have a large variation from an average. For example, links which are prone to have traffic accidents and have large and irregular peak hour biases in traffic volumes will not give satisfaction to road users since these links cannot provide reliable travel times to drivers. As a result, drivers will choose another shortest path that may give them a predictable and reliable travel time.

A measure for the reliability of travel time is a very important index in transportation service, and Standard Deviation (SD), Buffer Time (BT), Planning Time, Tardy Trip, On-Time Arrival and unreliability of travel time (Rh) are generally the most representative examples in this regard. In particular, drivers typically use BT in America and SD in the European countries. However, we have a fundamental question whether the SD can be an index that can describe the mean variations in travel time. In a similar manner, BT has a limitation—namely, that it should be based on the users' survey results and therefore has a subjective appraisal process, which may generate a credibility issue.

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Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.jksues.2017.12.001
1018-3639/

The purpose of this study is to use Gini coefficient, which is widely used in the social science field, as an evaluation index for travel time reliability. The Gini coefficient is a measure of the disparity between wealth and income distribution and is used to assess how evenly income is distributed. Drivers who use the same road section will have their respective own travel times, and if it is expressed through the Gini coefficient that these travel times are evenly distributed, it will be possible to estimate the travel time reliability along with a given road.

For this purpose, the Gini coefficient is calculated for sections that are managed as habitually congested areas by the highway authority, as well as for sections that are not. If it is possible to measure the travel time reliability of any road section through the Gini coefficient, based on results from the comprehensive calculation, it is possible to directly judge whether travel times are or are not homogeneous in a group among users who use the same section. This is unlike existing measures, and the Gini coefficient's potential to be utilized as a performance measure for travel time reliability is very high.

Existing measures will be summarized in the following chapter. Chapter Three will explain the outline of a Gini coefficient based on a measure for travel time reliability, which is suggested in this paper. This new measure is tested in Chapter Four. The conclusion of the paper and the recommendations for future investigations are mentioned in Chapter Five.

2. Current measures for travel time reliability

2.1. Study on the reliability of travel time

Recently the reliability issue of travel time has become a very important factor in evaluating the traffic condition of a given road. Users want and expect to be provided with stable and reliable travel times. If there is a large variation in travel time, a driver will be less satisfied with the chosen route. In other words, the reliability of the travel time can be considered as an important factor in evaluating the traffic condition of the relevant section of road.

In previous studies, the reliability of travel time has been defined as follows: 1) Wakabayashi and Iida (1992) defined travel time reliability as the probability of reaching a destination within the travel time provided to the driver; 2) Chang and Kang (2008) included the punctuality of public transportation into travel time reliability of a personal transportation mode; and 3) Yu and Choi (2012) introduced the concept of uncertainty of traffic information as a performance index to explain the variation of travel time, something not easily predictable. That is, travel time reliability means a degree of maintaining a constant value without fluctuation of travel time in a certain section of highway. Although the reliability of travel time has been recognized as a key measure for evaluating the quality of any transportation service, due to the ambiguity of the appraisal method, until now in Korea there have been few cases that applied to the real world as performance measures.

The Federal Highway Administration (FHWA) in America has been conducting the Strategic Highway Research Program 2 (SHRP2) since 2005, with the aim of improving road safety, retrofitting infrastructure, and reducing traffic congestion. In the program, 26 projects related to travel time reliability were conducted from 2007 to 2015.

The National Academy of Sciences (2014) reveals in its SHRP2 L02 report that the travel time reliability monitoring system should have four functions: a measure of travel time, characterization of travel time reliability, identification, and understanding of reliability fluctuation factors. It also promotes Planning Time and Buffer Index as measures of travel time reliability according to the purpose of a trip.

In the UK, Steer Davies Gleave (1993) used the standard deviation of travel time measured on the northern London ring road as a gauge of reliability to measure the level of travel time variability and to develop a forecasting model. The Department of Transport (2014) defined reliability as a variation of travel time that drivers cannot predict, and in the case of passenger traffic, the standard deviation was adopted as the reliability measure.

The EU countries prefer to use the standard deviation for the travel time reliability measure. Conversely, the USA prefers the Buffer Index. The FHWA (2011) even concluded that some statistics, such as standard deviation and the coefficient of variation, are not effective as measures of travel time reliability, although they are being used for that purpose in some places. This is because these statistics are not only difficult for non-experts such as policymakers and the general public to understand, but also unreasonable since they are based on giving the same weight to vehicle travel time for early and late arrivals.

2.2. Existing measures

As mentioned in the previous section, standard deviation (SD) is used as one of the representative reliability measures for evaluating the uncertainty of travel time. The SD was first used as a reliability index in the Netherlands and was later accepted as a type of performance measure in the EU. The SD as a reliability measure is given in Eq. (1):

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(TT_i - \overline{TT_i})^2} \quad (1)$$

where,

σ: standard deviation for travel time
TOD: time of day
DOW: day of week
TT_i: travel time for the ith observation
$\overline{TT_i}$: average travel time of the observations

Another definition of the standard deviation for travel time reliability, by Transfund (2004), is that travel time reliability is an unpredictable variation in travel time which drivers experience every hour of the day. Therefore, travel time reliability should be calculated by total traffic, and total network variability can be calculated as the sum of total travel time variations in the network. Another way to calculate the standard deviation is to apply the following prediction model by using the volume to capacity ratio (v/c):

$$\sigma = s_0 + \frac{(s - s_0)}{1 + e^{b\left(\frac{v}{c} - a\right)}} \quad (2)$$

where,

σ: standard deviation (min)
s_0: standard deviation for under-saturated condition (min)
s: maximum standard deviation for saturated condition (min)
v/c: estimated traffic volume to capacity ratio using PCE
a: intermediate value of the v/c function
b: slope of the v/c function

The second most widely used indicator is buffer time (BT). The basic concept of BT is an extra time or a time allowance required for on-time arrival due to the uncertainty of travel time on a particular trip. Lint and Tu (2008) proposed the basic formula of BT as Eq. (3), which represents the extra travel time ratio for the on-time arrival:

$$BT = TT_p - TT_{50} \quad (3)$$