Transportation Research Part C 24 (2012) 256–269

Contents lists available at SciVerse ScienceDirect

Transportation Research Part C

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

Adaptive weigh-in-motion algorithms for truck weight enforcement

Lee D. Han [a], Sung-Seok Ko [b], Zhongren Gu [a], Myong K. Jeong [c,*]

[a] Department of Civil and Environmental Engineering, University of Tennessee, Knoxville, TN 37996-2010, USA
[b] Department of Industrial Engineering, Konkuk University, Seoul 143-701, South Korea
[c] Department of Industrial and Systems Engineering & RUTCOR, Rutgers University Piscataway, NJ 08854, USA

ARTICLE INFO

Article history:
Received 24 September 2010
Received in revised form 8 December 2011
Accepted 29 January 2012

Keywords:
Floating threshold algorithm
Queueing models
Weigh-in-motion (WIM) technology
Weigh stations

ABSTRACT

Weigh stations are the primary weight compliance checkpoints for commercial trucks. In the past decades, states have deployed weigh-in-motion (WIM) technology to reduce delay and increase weight violation enforcement. However, due to limitations on the accuracy and implementation of WIM technology the full potential of WIM has not been realized. To this end, this paper presents an adaptive algorithm that improves the efficiency of WIM-equipped weigh stations based on real-time weigh station queue length, truck demand, weight distribution, and static scale service time. Instead of using one fixed weight threshold value, our proposed floating-threshold control algorithm increases the threshold value based on the queue length at the weigh station to avoid station closure while still identifying the worst weight offenders: the threshold value is lowered when the queue is short to maximize the number of inspection. We develop the queueing models for both the fixed-threshold algorithm and the floating threshold algorithm and derive their mathematical formula to calculate the measures of effectiveness of a weigh system. A simulation model is developed to compare the performance of the proposed adaptive algorithm with a traditional fixed-threshold algorithm under various situations. The simulation results show that an adaptive algorithm yields higher violator capture percentage, lower station closure frequency, and less delay to non-violating trucks.

1. Introduction

Overweight trucks reduce the lifespan of roadways, which translates into an increase in maintenance cost. Increased level of weight enforcement has been shown to discourage weight violations (Taylor et al., 2000) and thereby prolong highway life and achieve savings in roadway maintenance-related expenses. In 2000, some 193 million trucks per year were weighed at these stations (FHWA, 2000), yet a large number of the stations could not handle the heavy traffic resulting in a lower enforcement level and causing delay to truckers and motorists in general. Thus, the efficient operation at the country's 600-plus weigh, which are the primary weight compliance checkpoints for commercial trucks, is of crucial importance stations (McNally, 2005).

When the queue of trucks waiting to be weighed at a weigh station becomes too long due to capacity limitation of the weigh station approach ramps or excessive demand, the operator of the station is forced to close entrance to the weigh station to prevent queues from backing-up onto the mainline and becoming a safety hazard. Weigh station closures may result in an inordinate number of trucks bypassing without compliance checks and, eventually decrease the enforcement level.

State enforcement agencies have sought capacity enhancement options for weigh stations. Among these, weigh-in-motion (WIM) technology, a concept first proposed in 1950s (Lee, 1985), has the potential of significantly improving the operations at

* Corresponding author.
E-mail address: mjeong@rci.rutgers.edu (M.K. Jeong).

0968-090X/$ - see front matter © 2012 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.trc.2012.01.010

weigh stations as it weighs moving trucks, filters out likely non-offenders based on a preset threshold value and, hence, reduces the workload and queue at the more accurate static scale downstream. A typical weigh station configuration with a ramp WIM deployment is shown in Fig. 1 (Oliveira Neto et al., 2009). Trucks with WIM readings over a preset threshold value are directed to the static scale while the rest travel on as directed by the bypass signal. Studies have shown that WIM technology has increased the weight enforcement level and reduced truck delay (Kamyab, 1998; Benekohal et al., 1999; Oliveira Neto et al., 2012).

During the decade ending 2002, the total number of US trucks grew from 60 to 85 million (BTS, 2005), or about 42%, while heavy truck traffic grew from 99.5 to 138.6 million miles per year (FHWA, 2004), or about 39%. Due to this increase in heavy truck traffic many weigh stations cannot handle the increased workload, even when equipped with a WIM system. Consequently, state commercial vehicle enforcement agencies find themselves once again facing the capacity limitation problem at weigh stations.

Although WIM technology has been widely deployed and the preset filtering threshold value plays an integral part in its application, few studies have explored the selection of threshold values. To fully utilize the WIM technology and enhance the operational efficiency at WIM sites, this paper presents an adaptive algorithm using a floating threshold value that rises and falls with the queue length at the static weigh scale. The proposed adaptive floating algorithm would reduce, if not eliminate, station closures when the queue grows long but still identifies the weight violators. The threshold value is lowered when the queue is short to fully utilize the capacity at the static and, more accurate, scale. We develop the queueing models to analyze both a fixed-threshold algorithm and a floating threshold algorithm and derive their mathematical formula to calculate the measures of effectiveness of a system. A simulation model based on a real-world ramp WIM weigh station site is also developed to compare the performance of the proposed algorithm with the traditional fixed-threshold algorithm. The results, which strongly support the proposed adaptive algorithm, are also presented.

2. Background

2.1. A traditional fixed-thresholding algorithm

Under a fixed-thresholding algorithm, an operator sorts passing trucks based on the weights of a WIM scale and a preset threshold value. As shown in Fig. 1, if a truck's weight is over the threshold, the truck is directed to a static scale for further inspection; otherwise, it bypasses the static scale. Due to the accuracy limitation and other technical challenges of WIM, the weight of the truck as reported by the WIM scale is often inaccurate. In fact, WIM accuracy could be 5, 10, or even well over 15% off the trucks real weight depending on the type of WIM and if it had been calibrated frequently (Taylor and Bergan, 1993).

Obviously if WIM were highly accurate, one would not need a static scale for weight enforcement. The inaccuracy inherent to the current WIM technology makes selecting a preset threshold a challenge. For example, if the probability of distribution of a weight of a truck follows the normal distribution and the regulation for truck gross weight is, say, 80 kips, by selecting a preset WIM threshold value, ω_{TH}, of exactly 80 kips, a slightly overweigh truck, at 80.1 kips, would have a near 50% probability of bypassing (see the light-colored hashed area in Fig. 2), which is undesirable. To make sure most weight violators are caught, one might consider lowering ω_{TH}, to say 75 kips. While this would indeed reduce the probability this particular overweight truck might bypass the static scale to a more desirable 5% (see the dark hashed area), many trucks not over the weight limit are now likely to be sent to the static scale. This not only waste the time of truckers but also reduce the efficiency of the weigh station. When a large number of trucks, overweigh or not, are directed to the static scale, the queue grows quickly, which eventually leads to station closure.

On the other hand, raising ω_{TH} to, say, 85 kips, would increase the likelihood a truck directed to the static scale is indeed a weight violator and reduced the probability of long queues and station closures. Yet many overweight trucks may also receive WIM readings lower than the preset ω_{TH} and bypass the static scale.

The trade-off of high and low threshold values is understood but not thoroughly researched. Some researchers still used the legal weight limit as the threshold value (Trischuk et al., 2002) even though Taylor and Bergan (1993) published that the lower the WIM accuracy the higher the value of the sorting threshold must be. A simple rule is that to set the threshold equal

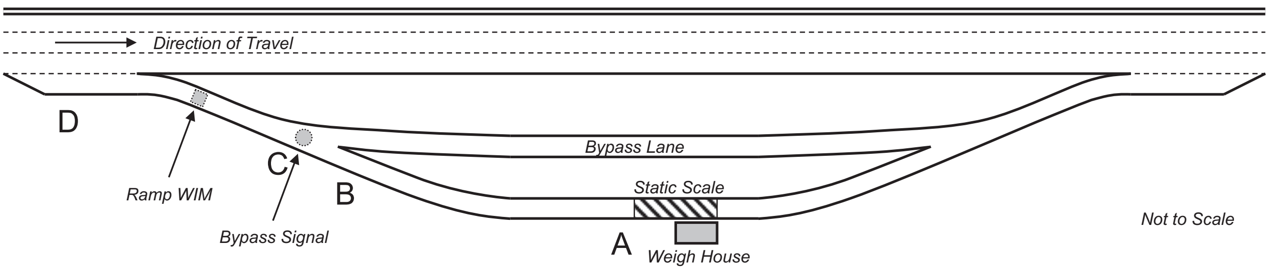

Fig. 1. A pre-sort ramp WIM configuration.