Transportation Research Procedia
Volume 15, 2016, Pages 471–482
ISEHP 2016. International Symposium on Enhancing Highway Performance

Shockwave Suppression by Vehicle-to-Vehicle Communication

Nassim Motamedidehkordi[1*], Martin Margreiter[1] and Thomas Benz[2]
[1]*Technische Universität München, Munich, Germany*
[2]*PTV Group, Karlsruhe, Germany*
nassim.motamedidehkordi@tum.de, martin.margreiter@tum.de, thomas.benz@ptvgroup.com

Abstract
The rapid development of wireless communication and information technologies has increased research interests in inter-vehicle communication systems and their effect on traffic flow. One of the most complex traffic phenomena on freeways are shockwaves. Shockwaves are recognized as the sudden, substantial change in the state of the traffic flow, which acts as an active or moving bottleneck. They have significant impact on freeway capacity and safety.
For this study, a microscopic traffic simulation was used to determine the extent to which inter-vehicle communication and change in the driving strategy after the recognition of a shockwave can influence the propagation and dissolving of shockwaves on freeways. We also briefly introduce the shockwave theory and our communication algorithm. Then we present the simulation result with different penetration rates of communicative vehicles, which are randomly dispersed in traffic flow, through performance measures for traffic flow with shockwaves.

Keywords: Shockwaves, vehicle-to-vehicle communication, freeways, simulation, traffic jam ahead warning

1 Introduction

Shockwaves are an important flow processes in traffic flow theory. The speed of the jam front defines the congestion patterns and impacts. They have a great influence on highway capacity, number of rear-end collisions on the freeway, fuel consumption and emissions. Several types of shockwaves can be found depending on the traffic conditions that lead to their formation. These include frontal stationary, forward forming and forward recovery, rear stationary, backward forming, backward recovery shockwaves. So far lots of studies focused on different aspects of shockwaves such as: characteristic of shockwaves based on L-W Fluid Theory (Kuhne, et al., 2000), highway bottleneck queue length and delay time (Smith, et al., 2003), (Munoz, et al., 2002), traffic flow stability (Zhang, 1999), traffic accidents due to shockwaves (Lee, et al., 2010), (Yu, 2012), shockwave prevention control methods (Hegyi, et al., 2005), (Breton, et al., 2002), evaluation of the inter-vehicle communication

[*] Corresponding author

Selection and peer-review under responsibility of the Scientific Programme Committee of ISEHP 2016

doi:10.1016/j.trpro.2016.06.040

(Suijs, et al., 2014) and highly automated vehicles (Motamedidehkordi, et al., 2015) in dynamic traffic flow and propagation of perturbations along the freeway.

By analyzing real vehicle trajectories, Huang and Wu (2013) figured out that the driver reaction time in shockwave situations seemed larger than in normal situations, showing that in shockwave situations drivers' behavior changes. It seemed that during the propagation, downstream drivers recognize that the upstream vehicles are in shockwave situations and adjust their driving behavior accordingly (Huang, et al., 2013). This means that the drivers change their driving towards a shockwave propagation in order to reduce the negative effects. Therefore, the drivers can recognize the shockwave situation by observing their lead vehicles, which leads already to a damping of the shockwave.

The recent development of the internet of things, provides new ideas and ways for shockwave damping solutions. An early recognition of the shockwave is the key to be able to damp the shockwave. Therefore, by telling the drivers in advance, that they might face a shockwave situation, they might adapt their driving behavior prior to reaching the congestion situation.

The paper introduces the analysis of shockwaves on freeways, the development and application of the methods to estimate the shockwave propagation speed and discusses the changes in shockwave characteristics by deploying the vehicle-to-vehicle (V2V) communication technology, specifically the traffic jam ahead warning application.

Section 2 of this paper discusses shockwave theories and state of art V2V communication technologies. Section 3 describes the empirical data used for this study. The simulation framework and the simulation scenarios are presented in section 4. Section 5 presents the result of the simulation and the change in shockwave characteristics for different penetration rates. The last section summarizes the study findings and outlines further research directions.

1.1 Shockwave theory

Shockwaves can be defined as a boundary condition between two traffic states that are characterized by different densities, speeds and/or flow rates on the road. In order to study the congestion patterns and impacts and designing traffic management studies, one needs to understand the formation, the dissolving and the characteristics of shockwaves. The findings on shockwave characteristics and propagation speed can be used to identify the spatial and temporal impacts of a congestion, and to develop and calibrate traffic flow models (Xiao-Yun, et al., 2007).

In real traffic conditions, the behavior of traffic flow is similar to the behavior of fluid waves. We assume that there are two different areas (A and B) with different traffic densities. The border between these two areas is called shockwave front S and the speed of S is v_s. The respective vehicle speeds in area A and B are v_u and v_d. We can calculate the number of vehicles (N) passing by the interface S within the time t as follows:

$$N = (v_u - v_s)k_u t = (v_d - v_s)k_d t \quad (1)$$

Based on the theory of Lighthill-Whitham-Richard (LWR) we can get the speed of the traffic shockwave:

$$v_S = \frac{q_d - q_u}{k_d - k_u} \quad (2)$$

A shockwave describes the conversion of two different traffic conditions and the speed of the shockwave describes the direction and the process of converting. In other words, the speed of the shockwave equals the jump in the flow over the wave divided by the jump in the density. When $v_s > 0$ this means that the shockwave is moving in the direction of traffic, whereas when $v_s < 0$ the shockwave is moving in the opposite direction of traffic and when v = 0, the wave does not move and is stable in its location.