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Evaluating the effectiveness of active vehicle safety systems

Eunbi Jeong, Cheol Oh *

Hanyang University Erica Campus, Department of Transportation and Logistics Engineering, 55 Hanyangdaehak-ro, Sangnok-gu, Ansan 426-791, Republic of Korea

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ABSTRACT

Advanced vehicle safety systems have been widely introduced in transportation systems and are expected to enhance traffic safety. However, these technologies mainly focus on assisting individual vehicles that are equipped with them, and less effort has been made to identify the effect of vehicular technologies on the traffic stream. This study proposed a methodology to assess the effectiveness of active vehicle safety systems (AVSSs), which represent a promising technology to prevent traffic crashes and mitigate injury severity. The proposed AVSS consists of longitudinal and lateral vehicle control systems, which corresponds to the Level 2 vehicle automation presented by the National Highway Safety Administration (NHTSA). The effectiveness evaluation for the proposed technology was conducted in terms of crash potential reduction and congestion mitigation. A microscopic traffic simulator, VISSIM, was used to simulate freeway traffic stream and collect vehicle-maneuvering data. In addition, an external application program interface, VISSIM's COM-interface, was used to implement the AVSS. A surrogate safety assessment model (SSAM) was used to derive indirect safety measures to evaluate the effectiveness of the AVSS. A 16.7-km freeway stretch between the Nakdong and Seonsan interchanges on Korean freeway 45 was selected for the simulation experiments to evaluate the effectiveness of AVSS. A total of five simulation runs for each evaluation scenario were conducted. For the non-incident conditions, the rear-end and lane-change conflicts were reduced by 78.8% and 17.3%, respectively, under the level of service (LOS) D traffic conditions. In addition, the average delay was reduced by 55.5%. However, the system's effectiveness was weakened in the LOS A–C categories. Under incident traffic conditions, the number of rear-end conflicts was reduced by approximately 9.7%. Vehicle delays were reduced by approximately 43.9% with 100% of market penetration rate (MPR). These results imply that from the perspective of traffic operations and control to address the safety and congestion issues of a traffic stream, smarter management strategies that consider both traffic conditions and MPR are required to fully exploit the effectiveness of the AVSS in the field.

1. Introduction

Significant effort has been made in many countries to reduce crashes using advanced transportation systems, which integrate electronic communication, mechanical engineering and automotive engineering (Harrington et al., 2008; McClafferty and German, 2008; Jung and Shin, 2011). An advanced safety vehicle is a new technology to detect hazardous situation among vehicles using various sensor technologies, such as radar, laser, or machine vision. The advanced safety vehicle system consists of two parts: a passive vehicle safety system and an active vehicle safety system. The passive vehicle safety system mitigates the crash severity using a seat belt, airbags, and active head restraints. The active vehicle safety system is a promising technology to more proactively prevent crashes by providing the driver with warning messages in the situation of high crash potential and maneuvering the vehicle when the driver does not respond to the warning.

The effectiveness of an active vehicle safety system must be reliably estimated to improve the system's functionality, develop new technologies, establishing and applying relevant policies. The recent interest in active vehicle safety systems has motivated researchers to evaluate the effectiveness in reducing vehicle crashes (OECD, 2003; Farmer, 2008; Kuehn et al., 2009; Page et al., 2009). A study to evaluate the effectiveness of the advanced driver assistance system (ADAS) has been conducted in Korea and supported by the Ministry of Land, Infrastructure and Transport (2009–2014). Staubach (2009) identified factors which influence and cause

* Corresponding author.
E-mail addresses: jeb0120@hanyang.ac.kr (E. Jeong), cheolo@hanyang.ac.kr (C. Oh).

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errors in traffic accidents. The results of this study suggest that there is safety potential for ADAS, which support the drivers and help to avoid distractions.

In addition, world-wide interests on advanced vehicular technologies for the traffic safety enhancement have been arising. As a representative example, National Highway Traffic Safety Administration (NHTSA) under U.S. government has recently released vehicle automation levels based on vehicular technologies (NHTSA, 2013). The level of vehicle automation consists of 5 levels such as Level 0(No automation), Level 1(Function-specific automation), Level 2(Combined-function automation), Level 3(Limited self-driving automation), and Level 4(Full self-driving automation). Many recent studies have dealt with the effectiveness evaluation of vehicular technologies of single system. For example, various commercialized adaptive cruise control (ACC) and automatic emergency braking systems (AEBS) technologies, which are well-known longitudinal maneuvering control systems, have been evaluated in terms of traffic safety benefits (MarkVollrath et al., 2011; Fildes et al., 2015; Pariota et al., 2016). Noort et al. (2012) introduced a method for aggregation-based safety impact assessment of the ADAS using data from the field operational test (FOT) and external data sources such as accident statistics. The results based on a sample of FOT data showed that the adaptive cruise control (ACC) reduced the fatality risk by 9%. In addition, lateral vehicle systems such as blind spot detection systems (BSDS) and lane departure warning systems (LDWS) have shown significant safety benefits (Chun et al., 2013; Hickman et al., 2015). Jeong and Oh (2013) proposed a methodology for quantifying the effectiveness of the ADAS and applied the methodology to the lane departure warning system (LDWS) and automatic emergency braking system (AEBS). Based on Gyeonggi province crash data, the LDWS reduced about approximately 10–14% of the relevant crashes, and the AEBS could prevent approximately 50% of the total rear-end crashes. The impact of active vehicle safety systems on the change in driving behavior was also been investigated based on both simulation and actual data. For example, Vollrath et al. (2011) conducted driving simulation experiments to examine the impact of automated vehicle systems such ACC on driving behavior. McLaughlin et al. (2008) proposed a methodology for evaluating the performance of collision avoidance systems using naturalistic driving data. However, these existing studies only focused on the limited evaluation of safety benefits from the perspective of an individual vehicle level. Also, effectiveness evaluations conducted by existing studies were focused on a single active vehicle safety system. We are not aware of any study dealing with evaluations for combined-function vehicle automation. These limitations motivated our study.

The main objective of this study is to evaluate the effectiveness of active vehicle safety systems (AVSSs) that include longitudinal and lateral vehicle control technologies. This combined system corresponds to the Level 2 vehicle automation proposed by the National Highway Traffic Safety Administration (NHTSA). For example, adaptive cruise control system (ACC) and automatic emergency braking system (AEBS) can be fallen into the category of longitudinal control systems. The lateral control systems include lane-changing control system (LCCS) in support of blind spot detection system (BSDS) and lane keeping assistance system (LKAS). The effectiveness of any transportation technology can be evaluated using two major paradigms: traffic operational efficiency and safety benefit. Performance measures including travel time, speed, and delay are usually used to evaluate the operational efficiency of transportation systems. The crash frequencies or surrogate safety measures (SSMs) can be applied to quantify the safety benefit. A microscopic traffic simulator, VISSIM, was used to simulate a traffic stream and collect the vehicle trajectory data. In addition, an external application program interface, which is the VISSIM's COM-interface, was used to implement the AVSS. A set of parameters associated with the effectiveness of the systems at alleviating traffic safety was investigated, including traffic conditions and the market penetration rate (MPR) for the AVSS. A surrogate safety assessment model (SSAM) developed by the Federal Highway Administration (FHWA) (2008a,b) was used to derive surrogate safety measures for estimating the effectiveness of the safety benefit in this study.

The remainder of the paper is organized as follows: an introduction of the active vehicle safety systems, a description of the evaluation procedure and data analysis, simulation evaluations, and a summary of the results and future research.

2. Active vehicle safety systems (AVSSs)

The active vehicle safety system (AVSS) is a new technology that can control the vehicle maneuvering by monitoring the hazardous situation with the front and adjacent vehicles. The AVSS is a promising technology to prevent crashes and decrease the crash severity. The AVSSs have various functions: provide warning information on upcoming hazards to the drivers, control the vehicle to avoid crashes, and provide additional information such as incident and traffic information. The purpose of AVSSs is to reduce the driving workload of the drivers, prevent crashes by leading faster driver's response in hazardous situations. Various sensor technologies are applied in this system such as radar, laser or machine vision. The front and adjacent vehicles are continuously monitored using these sensors.

An AVSS consists of two parts: longitudinal-maneuvering systems and lateral-maneuvering systems. The longitudinal-maneuvering systems capture the interaction between a pair of the subject and the front vehicles. A lateral-maneuvering systems control the vehicle in lane-changing maneuvering by checking whether the current situation is safe or not for lane-change. The AVSS algorithm abstracted the representative vehicle control system which is longitudinal and lateral vehicle control system such as ACC, AEBS, and LCCS.

2.1. Longitudinal-maneuvering control system

There are various longitudinal-maneuvering control systems such as the adaptive cruise control (ACC) and automatic emergency braking system (AEBS) to enhance traffic safety between the subject and the front vehicles. The ACC reduces the driver workload in dense traffic (Bayly et al., 2007). The ACC can secure a safety distance from a front vehicle that travels the same lane. An ACC-equipped vehicle adjusts the speed to ensure a safety distance based on a preset target speed. The AEBS is a pre-crash system, which reduces the stopping distances by maximizing the braking force in an emergency situation. The actuation principle of the AEBS consists of three steps. First, the sensors identify the interaction with the front vehicle and detect hazardous situations. Second, in-vehicle devices provide a driver with the visual or auditory warning information. When the driver does not respond to the provided warning information, the system automatically reduces the vehicle speed to prevent the accident. Longitudinal-maneuvering control systems are useful for preventing rear-end crashes. The abstraction technologies of ACC and AEBS were used to implement the longitudinal-maneuvering control system of the AVSS algorithm.

2.2. Lateral-Maneuvering control system

Lateral-maneuvering control systems monitor the lateral blind spot of the subject vehicle. When vehicles traveling in adjacent lanes are detected, the warning information is delivered to the drivers of the subject vehicle. The BSDS provides visual and auditory warnings when the driver changes the lane without perception