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Emission evaluation of inter-vehicle safety warning information systems

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ABSTRACT

Driver inattentiveness is one of critical factors contributing to vehicle crashes. The inter-vehicle safety warning information system (ISWS) is a technology to enhance driver attentiveness by providing warning messages about upcoming hazards using connected vehicle environments. A novel feature of the proposed ISWS is its ability to detect hazardous driving events, such as abrupt accelerations and lane changes, which are defined as moving hazards with a higher potential of causing crashes. This study evaluated the effectiveness of the ISWS in reducing vehicle emissions and its potential for traffic congestion mitigation. This study included a field experiment that documented actual vehicle maneuvering patterns for abrupt accelerations and lane changes, which were used for more realistic simulation evaluations, in addition to normal accelerations and lane changes. Probe vehicles equipped with customized on-board units consisting of a global positioning system (GPS) device, accelerometer, and gyro sensor were used to obtain the vehicle maneuvering data. A microscopic simulator, VISSIM, was used to simulate a driver's responsive behavior when warning messages were delivered. A motor vehicle emission simulator (MOVES) was then used to estimate vehicle emissions. The results show that reduction in vehicle emissions increased when the ISWS's market penetration rate (MPR) and the congestion level of the traffic conditions increased. The maximum CO and CO_2 emission reductions achieved were approximately 6% and 7%, respectively, under LOS D traffic conditions. The outcomes of this study can be valuable for deriving smarter operational strategies for ISWS to account for environmental impacts.

Introduction

The inter-vehicle safety warning information system (ISWS) is a technology to enhance driver attentiveness by providing warning messages about upcoming hazards using connected vehicle environments. The reliable estimation of an ISWS's effectiveness is necessary to improve the system's functionality and develop new technologies, in addition to establishing and applying relevant policies that can disseminate ISWS technology for the enhancement of safety. The effectiveness of any transportation technology can be evaluated using three major paradigms: traffic operational efficiency, safety and environmental impact. Performance measures including travel time, speed, and delay are usually used to evaluate the

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operational efficiency of transportation systems. Crash frequencies or surrogate safety measures (SSMs) can be applied to quantify safety, and the quantity of vehicle emissions is generally used to measure environmental impact.

The recent interest in vehicle emissions, which is directly associated with the greenhouse effect and public health concerns, has motivated researchers to conduct studies evaluating the effectiveness of transportation technologies in reducing vehicle emissions. Park et al. (2011) developed a lane-changing advisory algorithm by utilizing a variable gap size concept. The results of the evaluation conducted using a VISSIM microscopic traffic simulation showed a 6.4% higher average speed and up to 5.2% reduction in emissions. Tao et al. (2011) evaluated the effectiveness of coordinated signal control in reducing vehicle emissions using global positioning system (GPS) data and emissions data from real-world tests. An interesting finding of this work is that congested traffic conditions with low average speeds have diminished the effectiveness of coordinated control in reducing vehicle emissions. Wu et al. (2010) proposed two types of advanced driving alert systems (ADASs), stationary ADAS and in-vehicle ADAS at intersections. Using the Comprehensive Modal Emission Model (CMEM), the impacts of these two types of ADASs have been evaluated and compared in terms of their fuel consumption and CO_2 emission reductions. As a result, ADAS has been shown to provide fuel and CO_2 savings of up to 40%. Yeo et al. (2010) proposed a simulation-based approach to model a driver's behavior with vehicle-to-vehicle (V2V) hazard alert systems in incident situations on freeways, and applied the model to evaluate the impact of the hazard alert on freeway traffic for a range of operating conditions. However, this study focused only on evaluating the traffic operational efficiency based on analyses of average delay.

ISWS is a promising technology that could be used to prevent crashes in a more proactive manner. ISWSs provide warning messages on upcoming hazards to drivers through vehicle-to-vehicle communications. Vehicles receiving messages then adjust maneuvers, such as deceleration and lane changes, which can cause significant changes to the stability of the traffic stream. An important arising issue is whether ISWS has a positive or negative impact on the reduction of vehicle emissions, which has not been addressed in the literature. This study is mainly focused on evaluating the effectiveness of ISWS in reducing vehicle emissions.

A field experiment was conducted in the present study to collect actual vehicle maneuvering patterns for abrupt accelerations and lane changes, which were used for more realistic simulation evaluations, in addition to normal accelerations and lane changes. Probe vehicles equipped with on-board units consisting of a GPS receiver, accelerometer and gyro sensor were used to obtain data on driving maneuvers. A microscopic simulator, VISSIM, was used to simulate a driver's response behavior when warning messages were delivered. The effects of various parameters associated with the effectiveness of the ISWS at reducing vehicle emissions were investigated, including traffic conditions, market penetration rate (MPR) for ISWS, and upcoming hazard types. A motor vehicle emission simulator (MOVES) was then used to estimate vehicle emissions.

The remainder of the paper is organized as follows: an overview of the proposed methodology, a description of data collection using an IMU and data analysis, simulation evaluations, and lastly a summary of results and future research.

Methodology

The main objective of this study is to evaluate the effectiveness of ISWS at reducing the environmental impact. To accomplish the research objective, two cases, "with ISWS" and "without ISWS", were compared in terms of vehicle emissions. An overview of the proposed ISWS, the evaluation framework based on VISSIM and MOVES, and the scenario design for the simulation environments are presented in the following subsections.

Overview of proposed ISWS

A variety of research has been conducted on maximizing the usefulness of inter-vehicle safety warning information systems (ISWS). Relevant existing studies can be categorized into several groups. First, simulation experiments have been performed to identify the functional requirements of such information systems (Yang and Recker, 2005; Schönhof et al., 2007; Shladover et al., 2007; Mei et al., 2010; Park et al., 2010). The wireless communication range, communication protocols, and market penetration rate (MPR) have been explored using various simulation scenarios. Second, technical issues and lessons learned from the development of prototype systems have been discussed to provide useful insights into field deployments (Wischorf et al., 2005; Oh et al., 2010, 2012). Third, several studies attempt to derive more effective in-vehicle warning information and modalities to trigger more rapid and safer responses from the user (Nowakowski et al., 2008; Chen et al., 2008).

Unlike existing ISWS introduced in the literature, the proposed ISWS is a novel information system in that it is capable of delivering warning information on moving hazards in addition to stationary hazards. Stationary hazards include crashes and stopped vehicles, while moving hazards include hazardous driving events involving vehicles ahead of the subject vehicle receiving warning messages, such as abrupt unsafe acceleration, deceleration, lane changes, and zigzag driving. The authors have proposed an algorithm for operating an ISWS and developed a prototypical implementation in the field in a previous study (Oh et al., 2012). The proposed system works in vehicular network environments, which include V2V and vehicle-to-infrastructure (V2I) communications. An advanced on-board unit (AOBU) detects unsafe driving events after analyzing the data obtained from a GPS device, accelerometer and gyro sensor. A warning message is generated when the AOBU detects an unsafe driving event and includes the type of unsafe driving occurring and the vehicle's location. The generated warning message is then delivered to adjacent vehicles through V2V wireless communications. If vehicles are not within the V2V