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Simulation-based Variable Speed Limit Systems Modelling: An Overview and A Case Study on Istanbul Freeways

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Abstract

Modern transportation systems aim at maximizing the use of available resources in a sustainable manner to deliver efficient and safe movement of traffic. Variable Speed Limit (VSL) system is one of the techniques adopted in order to improve mobility. In this study, we analyse this system using simulation techniques on a 5.2 kilometre section of Istanbul Freeway D100. Being one of the most congested cities in the world, Istanbul freeways provide an excellent opportunity to test the potential benefits of VSL systems. Latest advancements along with comprehensive literature of this field based on simulation are included in this study. Microscopic traffic simulation software VISSIM is used along with MATLAB to implement VSL algorithm based on volume, occupancy and average speed. Remote Traffic Microwave Sensor (RTMS) data is provided by Istanbul municipality which is used to calibrate VISSIM.Scenarios with and without VSL system were simulated for morning hours. It is concluded that driver compliance to VSLs is an important factor for better results. Although 100% driver Compliance Level (CL) for VSL results in significantly higher improvement in performance compared to lower compliance, it is not a practical approach therefore results at 75% and 50% CL has been discussed in this study. Evaluation of network performance is done in terms of Total Travel Time (TTT) in network along with volume, speed and occupancy. Results show reduction in TTT and occupancy level along with improvement in average speed and volume. Fuel consumption and emissions is also found to be reduced in the network indicating sustainable and environmental friendly mobility.

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Keywords: Variable Speed Limits systems, Congestion, Compliance Level

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1. Introduction

Growing traffic on freeways in modern times have created a need for a system which can manage traffic efficiently without expanding the infrastructure. As the world moves towards sustainable development, using resources efficiently is the need of the hour. Modern transportation systems aim at maximizing the use of available resources in a sustainable manner to deliver efficient and safe movement. Freeways were developed to provide high speed non-stop routes for vehicular traffic by separating conflicting traffic streams and limiting access to freeway. Traffic congestions on freeways cause delay, waste of fossils and safety hazards. Intelligent Transportation Systems (ITS) are used in modern transport facilities to minimize these problems. One of the techniques is Variable Speed Limit (VSL) systems in which speed of traffic stream is decreased in small values in order to harmonize the traffic flow before traffic breakdowns. There are various control algorithms which further optimize the performance of VSL system. Microscopic traffic simulation software provide an excellent platform to develop, test and improve the control strategies. The following sections discuss works on VSL systems and microscopic simulations. The effects of VSL system operation on traffic stream is also discussed. Methodology and control strategy is discussed in section 3.Finally a case study on Istanbul freeway network is completed in the last section. Benefits of VSL systems such as improvement in average volume and average speed along with reduction in occupancy and Total Travel Time (TTT) is presented along with reduction in emissions and fuel consumptions. Comparison of results for VSL system is done with 50% and 75% driver compliance level.

2. Literature review

VSL techniques for freeway management have already been implemented in countries like Netherlands, UK, Denmark, and Australia. It is found to have lowered the level of congestion and emissions. There are several VSL algorithms used on freeways which are mainly based on variables of occupancy, speed and volumes. Critical values are defined in control algorithm at which VSL system actuates. In order to reduce the propagation of shockwaves during congestion, the desired speed is reduced upstream at critical values. METANET simulation models were developed for the VSL system (Hegyi et al., 2005) but were not implemented. Algorithms based on average occupancy thresholds are implemented on I-4 in Orlando, Florida while flow based algorithms were implemented on M25 Motorway in England and E6 motorway in Mölndal, Sweden.Studies have shown that VSL systems have helped in reducing Total Travel Time (TTT) in network and smoothened traffic flow (Abdel-Aty et al. 2006).Total Time Spent (TTS) in network was found to be 17.4% lower when proposed VSL was applied in coordination with ramp metering in a hypothetical section by Hegyi et al.(2005). Benefits of VSL were also documented by Papageorgiou et al. (2008). Safety levels were found to increase with VSL techniques on steep bottleneck of mountainous sections using microscopic simulation software VISSIM for simulation and calibration(Yu and Abdel-Aty 2014).Safety benefits of VSL were also realized by developing a crash model (Abdel-Aty et al.2006). Reduction of secondary collision in low visibility weather conditions was shown by Li et al. (2014) using a modified car following model. Co-operative VSL system (C-VSLS) is a strategy which decreases the involvement of the driver by directly communicating the speed to the vehicle (Grumert et al. 2015). Grumert et al.(2015) used study open source microscopic simulation software SUMO was used with Python. Results were better than conventional VSL systems in terms of steady flow and emissions. Reduction in CO level was 2.66% better than conventional VSL system in Grumert et al. (2015). However, the results were subjected to penetration level. At 70% penetration level due to rapid lane changing behaviour of non C-VSLS vehicles when C-VSLS equipped vehicles decelerate congestion might develop. Similar studies were conducted by Cao et al.(2015) and Khondaker and Kattan (2015) by using micro simulation.Greenhouse emissions were minimized with use of Fuel Consumption-Aware Variable Speed Limit strategies (FC-VSL) (Liu et al.2012). Similar in approach with previous strategies, FC-VSL aims at harmonizing flow which results in lower fuel consumption thus decreasing carbon footprint. Khondaker and Kattan (2015) reported 14.8% reduction in average fuel consumption using VSL in connected environment. A study on the effect of VSL on traffic flow characteristic (Allaby et al.2007) concluded that VSL showed desirable results with moderate to high congestion while producing undesirable results sparingly congested scenarios. Allaby et al.(2007) made modifications in the algorithm and concluded that there were scenarios where VSL was not needed but actuated due to small disturbance in flow. This triggering of VSL did not allow the traffic flow to recover as it would have done in case of non VSL scenario. Modification by included increasing the threshold speed at which VSL kicks in and decreasing the number of VSL upstream of congestion point which get actuated. However, driver compliance level was taken same for VSL and non