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Optimization of lane-changing distribution for a motorway weaving segment

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Abstract

The traffic in a weaving segment is subject to lane-changing turbulence in excess of that normally present on basic motorway segments. Empirical studies have observed a lane-changing concentration problem, as traffic flow increases, which can cause flow break down and congestion. This paper focuses on the lane-changing concentration problem in weaving segments. A Cooperative Intelligent Transport System (C-ITS) advisory has been shown to alleviate such a lane-changing concentration problem. The advisory aims to distribute the lane-changing along the weaving segment. Unlike previous methods in the literature, where weaving vehicles are assigned according to fixed distributions, this paper proposes an algorithm to optimize the lane-changing distribution. The proposed optimization algorithm was developed based on particle swarm optimization. The optimized lane-changing distribution for a one-sided motorway weaving segment using microscopic simulation has been evaluated. The initial results show that the proposed algorithm could be used as a successful optimization technique for the lane- changing concentration problem.

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Keywords: Cooperative Intelligent Transport Systems (C-ITS); Weaving segment; Lane-changing distribution; Particle swarm optimization.

1. Introduction

Weaving segments, a common design for motorways, are formed when merge segments are closely followed by diverge segments (TRB, 2010). Weaving is generally defined as the crossing of two or more traffic streams travelling in the same direction along a significant length of motorway without the aid of traffic control devices (TRB, 2010).

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Weaving segments require intense lane-changing maneuvers for drivers to access the lane appropriate for their desired exit. weaving segments therefore involve complex vehicle interactions, which presents safety and operational problems. The traffic in a weaving segment is subject to lane-changing turbulence in excess of that normally present on basic motorway segments (TRB, 2010). Empirical studies have shown that drivers tend to perform lane changes soon after they enter the segment as the traffic volume increases (Cassidy and May, 1991). The lane-changing concentration problem can cause bottlenecks, which leads to congestion.

Recent advancements in the field of cooperative intelligent transport systems (C -ITS) have enabled vehicles to send and receive real-time information (Weiss, 2011). Vehicle to vehicle (V2V) and vehicle to roadside infrastructure (V2I) communications have been extensively tested in real-world applications. In recent field trails, C- ITS applications have been shown to provide traffic safety, efficiency and environmental benefits (Green et al., 2014). One of the distinct benefits of C-ITS is that it offers individual traffic control, which differs from that offered by conventional ITS controls (such as variable message signs and variable speed limits). Therefore, C -ITS applications can be implemented to control and/or guide vehicles at a more refined level.

This paper focuses on the lane-changing concentration problem on motorway[1] weaving segments and how C-ITS can be implemented to reduce this problem. A C-ITS advisory is a potential application that can improve the flow by using V2I technology. The objective of a C-ITS advisory is to alleviate the problem by aiming to distribute the lane- changing in order to better utilize the existing infrastructure.

Mai, Jiang and Chung (2016) used a C-ITS-based lane-changing advisory in order to improve the lane-changing concentration problem on weaving segments by evenly fixing the lane-changing distributions over the length. However, no sophisticated optimization technique was involved to seek the optimal solution for the distribution.

The aim of this paper is to demonstrate how to optimize the distribution by using optimization techniques. It is proposed that an optimization algorithm, based on particle swarm optimization (PSO), be implemented to improve the lane-changing distribution. The proposed method was evaluated for a basic one-sided ramp motorway weaving segment with a short-length weaving configuration of 400m between merging and diverging segments. The evaluation method for the implementation of the optimization algorithm on the lane-changing distribution was traffic simulation.

The paper is structured as follows. Firstly, a literature review on the motorway weaving problem is presented. Secondly, the case study is presented. Thirdly, the proposed optimization algorithm is presented. Lastly, the experimental settings, results and findings are discussed, followed by the conclusion.

2. Literature review

This section briefly reviews the literature related to the lane-changing concentration problem in motorway weaving segments. The problem has been observed in several empirical studies.

Early research by Cassidy and May (1991) analyzed the traffic flow behavior in individual lanes of a weaving segment. Their research showed that a high concentration of lane-changing maneuvers occurred near the weaving entrance. The majority of lane changes were made before a reference point, 76m from the merge gore of a 445m section. Their analysis suggested that as the weaving flow increased, weaving vehicles become more anxious to change lanes over shorter travelled distances. They suggested that this increased feeling of pressure may encourage motorists to perform lane-change maneuvers as soon as possible. Therefore, this behavior may result in increased turbulence in the weaving area, decreasing weaving area capacity and becoming more vulnerable to congestion. Research by Kwon, Lau and Aswegan (2000) showed similar weaving behavior for a short one-sided weaving section of 129m.

[1] “ motorway” and “ freeway” are used interchangeably.

They found that as the weaving flow began to increase, the diverging vehicles began to change to the auxiliary