Transportation Research Part C 51 (2015) 196–209

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Operation of signalized diamond interchanges with frontage roads using dynamic reversible lane control

Jing Zhao [a], Yue Liu [b,*], Xiaoguang Yang [c,1]

[a] University of Shanghai for Science and Technology, 516 Jungong Road, Shanghai, PR China
[b] Department of Civil and Environmental Engineering, University of Wisconsin at Milwaukee, P.O. Box 784, Milwaukee, WI, United States
[c] Key Laboratory of Road and Traffic Engineering of the Ministry of Education, 4800 Cao'an Road, Shanghai, PR China

ARTICLE INFO

Article history:
Received 14 May 2013
Received in revised form 23 October 2014
Accepted 30 November 2014
Available online 29 December 2014

Keywords:
Signalized diamond interchange
Capacity
Reversible lane
Binary-Mixed-Integer-Linear-Program

ABSTRACT

Signalized diamond interchanges (SDI), connecting major highways and surface streets in urban and suburban areas, are probably the most widely used interchange patterns. The limited storage space between the two closely joined intersections coupled with heavy traffic volumes may easily oversaturate the facility and cause spillback problems, especially with the presence of frontage roads. This paper presents an innovative design and operational model for SDI by dynamically reversing certain lanes in the internal link on a regular basis with the deployment of overhead reversible lane control signs. A Binary-Mixed-Integer-Linear-Program (BMILP) is formulated to simultaneously optimize lane markings, dynamic usage of the reversible lane, and signal timings for the new SDI system. Results from extensive numerical analyses reveal the promising property of the proposed design and operational model in expanding capacity and reducing congestion at the SDI with frontage roads.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Diamond interchanges are the probably the most commonly used interchange patterns in urban and suburban areas, connecting major highways and surface streets with two closely spaced intersections. When traffic demand is high, intersections need to be signalized and may become the bottleneck due to the limited spacing between them. Therefore, signalized intersections are often the key operational elements within the interchange system (Fang and Elefteriadou, 2006).

Spacing between intersections at a diamond interchange typically ranges from less than 120 m to 240 m or more (TRB, 2000). Such proximity creates a number of interactive effects that complicate the operation (Xu et al., 2010). It limits the storage capacity available for queued turning vehicles and may induce spillback problems on the internal link. Blockages and delays due to queue spillback can then prevent vehicles at the upstream intersection from reaching the downstream stop line, resulting in inefficient utilization of green times. During traffic demand peak periods, such interactions may finally cause traffic gridlock at adjacent intersections. To address these challenges, it is essential to develop more efficient lane utilization and signal control strategies to operate the two closely space signalized intersections.

In review of literature, this unique operational problem at diamond interchanges was conventionally addressed by optimizing signal control plans (Messer and Chang, 1987; Chaudhary and Chu, 2000; Tian, 2004), falling into two general

* Corresponding author. Tel.: +1 414 229 3857.
E-mail addresses: jing_zhao_traffic@163.com (J. Zhao), yueliu1980@gmail.com (Y. Liu), yangxg@mail.tongji.edu.cn (X. Yang).
[1] Tel./fax: +86 (21) 6958 9475.

http://dx.doi.org/10.1016/j.trc.2014.11.010
0968-090X/© 2014 Elsevier Ltd. All rights reserved.

categories: namely the three-phase control (Munjal, 1971; Messer et al., 1977) and the four-phase control (Engelbrecht et al., 2001; Engelbrecht and Barnes, 2003; Gordon and Tighe, 2005; Pham et al., 2011). As shown in Fig. 1, the three-phase control treats the diamond interchange as two separate intersections, each having three phases. One phase is for through movements on the surface street, the second for through and left movements from the internal links and the third for ramp movements. Three-phase operation is efficient if turning traffic volumes are light, and can minimize the cycle length. However, as turning volumes increase, this plan can lead to internal queue spillback and operational breakdown (Gordon and Tighe, 2005). The four-phase control could avoid most queuing problems by giving each of the four approaches from which interchange traffic originates a clear phase through both intersections. However, because it requires four phases, longer cycle lengths are needed which may reduce the capacity of the intersection (Fang, 2004). Moreover, it generally decreases the effective green time per cycle ratio for major movements, resulting higher expected delays than a three-phase control plan (TRB, 2000; Nelson et al., 2000).

When a diamond interchange is oversaturated with high left-turn demand, the conventional treatment of providing left-turn bays with protected left-turn phases may not be sufficient to avoid long delays. Researchers have been looking for unconventional interchange designs to squeeze more capacity out of a diamond interchange with oversaturated traffic conditions. As one of the most popular unconventional interchange designs, Diverging Diamond Interchange (DDI) has received increasing attention in recent years due to its cost-effectiveness over a traditional diamond interchange design. The key logic of DDI is to provide efficient navigation for both left-turn and through movements between highway ramps, and to accommodate left-turning movements onto the arterial without using a left-turn bay (Yang et al., 2013). As shown in Fig. 2, the reverse operations of the through traffic between two ramp terminals in a DDI design allow its left-turn traffic flows from the freeway off-ramps to the opposing flows at each sub-intersection (Edara et al., 2005). With such an assignment of flow movements, a DDI design can significantly reduce the number of traffic conflict points. And there is a great potential of the DDI to yield a better performance over the conventional SDI in increasing capacity and reducing delay primarily due to its efficient two-phase signal operation (Chlewicki, 2003; Bared et al., 2005; Smith and Speth, 2008; Bared, 2009; Maji et al., 2013). However, the DDI concept also has some disadvantages, such as: (a) most of these analyses are based on the assumption that the freeway frontage roads do not exist, or there is no need to facilitate vehicular travel between the freeway off-ramp and on-ramp, for a signalized diamond interchanges with frontage roads (SDI-FR), a third phase should be added to accommodate the through movements on the frontage roads (Martinez and Cheu, 2012), hence the advantages of DDI are undermined; (b) it requires additional construction and permanent changes in layout, which cannot be turned on and off as needed; and (c) the reverse operations of the through traffic in the internal link in a DDI design may cause serious driving errors, especially the wrong-way violations, which may result in an increase in crashes.

One assumption underlying the above operational models is that the geometric layout, including the number of lanes on different directions in the internal link as well as lane markings at intersection approach lanes, is given as an exogenous input and will not change throughout the operation process. However, when an intersection is oversaturated with high traffic demand, the conventional signal control models may not be sufficient to avoid long delays at the signalized diamond interchanges. Furthermore, due to spatial and environmental limitations, it is becoming increasingly difficult to improve diamond interchange operations through geometric improvements.

A further examination of current SDI operation reveals that the large and unbalanced left-turning traffic volume coupled with limited spacing and turning lanes on the internal link contributes most to its failure. Realizing this problem, this research develops a new way to significantly improve the operation of the SDI using dynamic reversible lanes (DRL) in the internal link. The basic concept is to set all the left-turn lanes in the internal link as reversible by using overhead reversible lane control signs. These lanes have the flexibility to be used by different directions during different periods of a signal cycle depending on left-turn volumes and patterns. Such a design would enable a dynamic and integrated utilization of the internal link space and signal green times, resulting a substantial increase of the internal link capacity without the need of major construction.

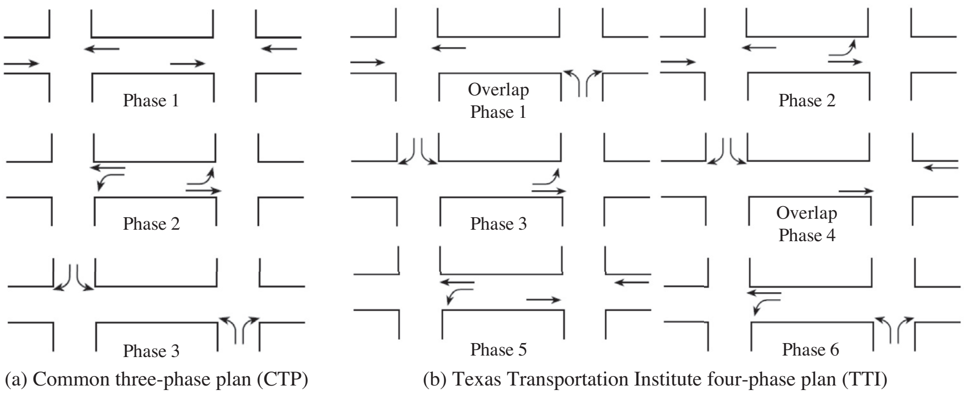

Fig. 1. Common signalization schemes for diamond interchanges (TRB, 2000).

Download English Version:

https://daneshyari.com/en/article/524998

Download Persian Version:

https://daneshyari.com/article/524998

Daneshyari.com