A risk-averse user equilibrium model for area traffic control road networks

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1. Introduction

For an urban traffic signal-controlled road network, most of traffic delay and queues are directly reliant on correct and continuous operations of effective signal settings at junctions. The loss of capacity of area traffic control road network due to disruptions in signal setting failure could not only result in the most negative consequences in traffic congestion but also increase substantial travel delay to all road users. The purpose of this paper is to propose an effective model for evaluating the performance reliability of signal-controlled road network under uncertainty in which the traffic streams could be severely affected due to failures of signal control group operations. The vulnerability of a signal-controlled road network is also discussed in this paper where the critical signal control groups can be effectively identified in which the sum of expected traffic queues and delays incurred by all affected traffic streams are substantial. The critical signal-controlled junctions can therefore be identified, when failed to perform its normal functions, could give rise to the maximum travel delay to road users.

The road network reliability has the subject of considerable international research interest in recent years ([1-10]). Du and Nicholson [3] are the first ones who presented an integrated equilibrium model for a degradable transportation system (DTS). The reliability of a degradable transportation system can be defined as the probability that the reduced flow of the system is less than a certain acceptable level of service. Considering the reliability performance of road networks, Bell and Iida [2] recommended a probability measure for evaluating the performance of a road network. Most of work in the reliability of transportation road network mainly focused on building various measures of performance reliability of road networks accounting for behavioral changes of road network travelers in response to occurrence of incidents. The performance on the component level of a road network is either measured on the basis of census data or statistics collected at the component level for which the probability distribution of the performance of interest can be estimated. The travel time allowing for building safety margin into the measure of reliability performance can be conventionally regarded as a common and effective measure for assessing road network performance when the probability of performance of interest at the component level is obtainable. However, there are some situations where the statistical distribution of link travel times will not be reliably derived due to adequacy of data on link travel time. Also, some link travel time distribution will change over time and it becomes doubtful about the stability and correctness of the estimation of link travel time.

In the presence of uncertainty about the state of prevailing network performance, the road network user will intend to take strategic responses toward risk. Bell [7] and Bell and Cassir [8] applied a game-theoretic approach to measuring the performance of interest of the road network and proposed a risk-averse traffic assignment for general road networks. Considering a signal-controlled road network, the reliability of the network is heavily reliant on the robust operation of signal control groups. For traffic streams controlled by the same signal group, the aspects of signal greens are switched simultaneously ([11]) and considerable traffic delay and queues could be caused if this signal group breaks down. At the best knowledge of the author, there exists little research about the issues of road network reliability when signal-controlled junctions are accounted for. Lam et al. [12] presented a risk-averse user equilibrium model for route choice in signal-controlled networks where travel time and accident risk rate are evaluated by simple functions. No explicit consideration is allowed for signal co-ordinations in that paper and platoon dispersions on the adjacent streets are not taken into account.

In this paper, a signal-controlled road network for steady state of traffic flow is considered where link average delay at downstream junction is evaluated using TRANSYT model. Approximate mathematical expressions for traffic queues and average delays under normal conditions can be conveniently obtainable from [13] when cumulative queues are considered explicitly in the uniform part of performance index which is defined in TRANSYT. For a signal-controlled road network under the risk of signal control group failure, a very high abnormal cost might be incurred by travelers provided that the states of road networks are not commonly known to travelers. The travelers are thus supposed to be badly informed about the state of the network and travelers take extremely pessimistic prospective for the uncertainty of network performance. In the signal-controlled road networks, every traffic stream has two states of performance measure: the normal state and the abnormal state. For the normal state it is supposed that the corresponding signal control group operates under normal condition and the performance measure of traffic streams controlled by this group can be evaluated using results obtained in [13]. For abnormal state it is supposed that the corresponding signal control group breaks down and substantial traffic queues and delays for traffic streams controlled by this group could be incurred by travelers. As regards the performance measures for signal-controlled road networks, in this paper, we consider expected performance measures for traffic delays and queues when signal delay incurs on the corresponding signal-controlled links for both normal and abnormal conditions.

The risk-averse user equilibrium traffic assignment can be formulated as two mathematical optimization problems in determining the expected minimum cost network flows and the expected maximum network loss for road network users and virtual attacker. In this paper we formulate such a risk-averse traffic assignment in a signal-controlled road network as a variational equality problem. An adjusted projection method with contractive properties is being developed. Numerical calculations at various area traffic control road networks are being conducted and comparisons are being made with other conventional approach such as MSA.

Keywords: network reliability; network vulnerability; risk-averse traffic assignment;

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