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Optimizing congestion and emissions via tradable credit charge and reward scheme without initial credit allocations

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HIGHLIGHTS

- Propose the first-best emissions tradable credit charge and reward scheme to manage emissions.
- Optimize congestion and emissions via the revenue-neutral tradable credit charge and reward scheme.
- Numerical example is adopted to test the proposed scheme.

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ABSTRACT

This paper investigates the revenue-neutral tradable credit charge and reward scheme without initial credit allocations that can reassign network traffic flow patterns to optimize congestion and emissions. First, we prove the existence of the proposed schemes and further decentralize the minimum emission flow pattern to user equilibrium. Moreover, we design the solving method of the proposed credit scheme for minimum emission problem. Second, we investigate the revenue-neutral tradable credit charge and reward scheme without initial credit allocations for bi-objectives to obtain the Pareto system optimum flow patterns of congestion and emissions; and present the corresponding solutions are located in the polyhedron constituted by some inequalities and equalities system. Last, numerical example based on a simple traffic network is adopted to obtain the proposed credit schemes and verify they are revenue-neutral.

1. Introduction

In urban transportation networks, congestion as an inefficient traffic pattern frequently occurs due to the contradiction of traffic network supply that cannot meet travel demand [1]. Traffic administrative sector or policy makers develop and implement many measures, such as, road tolls, signal control, to mitigate traffic congestion (e.g., Refs. [2–5]). With the increase of vehicles, air pollution caused by vehicle emissions seriously affected people's daily life [6,7]. Congestion pricing as a valid economic instrument has been advocated by economists because it can alter travelers' route choice behaviors and further ease traffic congestion and reduce vehicle emissions. However, it is difficult to implement because it does involve the social inequity and spatial inequity issues [8].

To avoid the inequity of the conventional congestion pricing and further explore more reasonable tolls strategies, Yang and Wang [9] introduced the tradable credit scheme to alleviate congestion. The implementation process of such a scheme is divided into three steps: initial credit allocations, credit charges and credit transactions. Different from the traditional congestion tolls scheme, it does not involve financial transfer from travelers' group to government. Subsequently,

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transportation researchers have widely focused on the tradable credit schemes. Wang et al. [10] investigated tradable credit scheme for heterogeneous travelers with discrete value of time (VOT). They formulated appropriate tradable credit schemes and proved these schemes can decentralize system optimal and Pareto-improving system optimal traffic flow patterns to user equilibria. Zhu et al. [11] continued to study the multiclass traffic network equilibrium problem under a given tradable credit scheme with VOT distribution. The user equilibrium and market equilibrium problem is formulated into an infinite variational inequality system; and a given network flow pattern can be decentralized into user equilibrium. Wang et al. [12] further developed a new congestion reduction method, trial and error method for optimal tradable credit schemes on general traffic network. After each trial of tradable credit scheme, the distribution of credit scheme and total credits are updated. The updating strategy is spired by the method of successive averages and its convergence is proved. The thinking of tradable credit scheme was also applied to manage peak-period bottleneck congestion for homogeneous and heterogeneous commuters; Xiao et al. [13] proved the existence of an optimal tradable credit scheme, which can completely eliminate the bottleneck queue. Nie [14] examined the effects of transaction costs on two kinds of markets, an auction market and a negotiated market for tradable credits. Their research indicated that the auction market can achieve the desired equilibrium allocation of credits under the appropriate conditions; transaction costs in the negotiated market could divert the system from the desired equilibrium. Moreover, the initial distribution of credits may affect the equilibrium state.

However, these tradable credit schemes contain the distribution of initial credits, a complex process, which does involve how to identify the eligible travelers and how to assign credits to the eligible travelers. In order to avoid these difficulties, Nie [15] proposed the tradable credit scheme without determining the initial assignment of credits in a bottleneck model. For one thing, the scheme avoids the phase of initial credit distribution. For another, the scheme defined a peak-hour window and charged credits for some travelers experiencing peak-hour window, and rewarded credits for other travelers either traveling outside of peak-hour window or adjusting to alternatives. Liu and Huang [16] extended the tradable credit scheme without initial credit allocations to general traffic network and obtained a credit charge and reward mechanics under system optimum and Pareto-improving system optimum conditions.

The tradable credit schemes above only concentrated on traffic congestion. Transportation managers need to trade-off the relationship between congestion and emissions. Yin and Lawphongpanich [17] adopted a counter-example to illustrate the travel time optimum pricing schemes do not achieve minimum emissions. Then they proposed a non-negative first-best emissions pricing strategy and also investigated the Pareto system optimum pricing problem for congestion and emissions. Chen and Yang [18] proposed a toll cum rebate scheme to manage congestion and emissions and proved the bi-objective SO can be decentralized into UE by a revenue-neutral toll cum rebate scheme. These pricing or pricing cum subsidies strategies still involve the unfairness issue caused by fiscal transfer from drivers to government. Aziz and Ukkusuri [19] designed the tradable emissions credit scheme for managing the bi-objectives of congestion and emissions. Due to some limitations of the initial credit allocations [15,16], for example, (1) how to identify and select the eligible travelers for receiving initial credit allocations; (2) what is the standard for the distribution of initial credit allocations, e.g., travelers' income level, vehicle type, distance between home and work locations; (3) the participation of government does involve the extra consumption of human and financial resources. Thus, it is difficult to optimize congestion and emissions under the tradable credit scheme with initial credit allocations.

In this paper, we study the revenue-neutral tradable credit charge and reward scheme without initial credit allocations to optimize congestion and emissions. First, we present the first-best revenue-neutral emissions toll and rebate scheme and further transfer it to the revenue-neutral tradable credit charge and reward scheme. The proposed credit scheme can decentralize the minimum emission flow pattern to user equilibrium. Moreover, we design the solving method of the proposed credit scheme for minimum emission problem. Second, the revenue-neutral tradable credit charge and reward scheme for bi-objectives were investigated to obtain the Pareto system optimum flow patterns of congestion and emissions; and the corresponding solutions were presented, which are located in the polyhedron constituted by some inequalities and equalities system. Last, a three parallel link connecting one OD pair traffic network is adopted to solve the proposed credit schemes and verify whether they are revenue-neutral.

The remainder of this paper is organized as follows. In Section 2, related symbols, assumptions, and definitions are given and the minimum emission problem under tradable credit charge and reward scheme is investigated. Section 3 dedicatedly discusses the Pareto system optimum problem for bi-objectives, traffic congestion and vehicle emissions under tradable credit charge and reward scheme; and further adopts numerical example to test the proposed tradable credit schemes. Last, Section 4 provides concluding remarks.

2. Optimizing emissions under tradable credit charge and reward scheme without initial allocations

2.1. Optimizing emissions under revenue-neutral toll and rebate scheme

Consider a transportation network represented by a full-connected directed graph $G[N, A]$, where N and A denote the set of nodes and links, respectively. In this paper, we adopt some main notations listed as follows.

$|N|$: Number of nodes
$|A|$: Number of links
W: Set of origin–destination (OD) pairs