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Internalizing Congestion and Emissions Externality on Road Networks with Tradable Credits

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Abstract

Congestion and emissions are two problems in traffic. In general, they have conflict with each other. Tradable credits scheme is proved an effective method in Environmental Science. Now more and more scholars introduce it into traffic. Because it possesses the advantages that other methods do not have in alleviating congestion and reducing emissions. In this paper we indicate there always exists a tradable credits scheme that induces a traffic flow distribution with minimum emissions. We proved a given target feasible link flow pattern can be decentralized into user equilibrium by a tradable credits scheme, and sought tradable credits schemes for Pareto-efficient control and management of both traffic congestion and emissions on road networks. There are two models which could describe the Pareto-efficient problem between alleviating congestion and reducing emissions, i.e., bi-level congestion pricing model and weighting problem model. When the emission function is an increasing function, any Pareto-efficient flow pattern can be supported as an user equilibrium by the tradable credit scheme. If the emission function is a non-monotonic function, we divided the network into two cases: loops-free network and loops network which satisfies Gallager's sense. In a loop-free road network, any feasible link flow pattern can be decentralized into user equilibrium by a tradable scheme. In loops network, Pareto-efficient solution may not be decentralized to user equilibrium by tradable credits scheme. However, if the loops network doesn't satisfy Gallager's sense, any feasible Pareto-efficient link flow pattern can be decentralized into user equilibrium by a nonnegative toll scheme/tradable credits scheme. On the contrary, it wouldn't.

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Keyword: Tradable credits; Congestion and emissions; Pareto-efficient; Loops-free; User equilibrium

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1. Introduction

Traffic congestion and emissions are two global problems we have to face in big cities. Due to congestion, more time is wasted on road; Due to emissions, more and more people have to endure severe air pollution. There is a closed connection between traffic congestion and emissions. Traffic emissions in congested conditions are substantially higher than under conditions of freely traffic flow. However, in general, alleviating congestion conflicts with reducing emissions (Nagurney, 2000; Yin and Lawphongpanich, 2006).

In order to alleviate traffic congestion and control emissions, and achieve the sustainability of transportation, for several decades, road pricing has been considered as an effective management instrument. Pigou (1920) firstly proposed the idea of road pricing. Similarly, a road user should pay a charge corresponding to both his own emissions and the increased emissions brought to other users (Jahansson, 1997). Afterward, immense amounts of research on road pricing have been further developed. For recent reviews to congestion pricing, we can see, Yang and Huang (2005), Tsekeris and Voss (2009). However, road pricing has its limitations. The most obvious defect is unfairness. Wu et al. (2012) used an example in which its network located in Seattle regional by Gini coefficient demonstrated the inequity of road pricing. The result showed that none of road pricing policies is progressive (benefiting low-income travelers more than high-income ones).

Given the deficiency about road pricing in alleviating congestion and emissions, tradable credits come up. The theory of pollution permit markets was firstly imposed by Coase (1960) on external costs. The Kyoto Protocol (1997) identified and recommended the system of emission permits as an economic tool to be implemented. In traffic, tradable credits are mainly used for two aspects: emissions and congestion. In transportation pollution, Nagurney (2000), Nagurney and Zhang (2001) put apply the emission permit systems to transportation network. Julie (2012) dealt with the feasibility of a tradable emission permit system (TEPs) for urban motorists to develop a new microeconomic theoretical model which reduces urban pollution. In the part of traffic congestion, it was not until 2011, Yang and Wang comprehensively explore the system of tradable travel credits in a general network. Now it has been extended to heterogeneous users (Wang and Yang et al., 2012), transaction costs (Nie, 2012), income effects (Wu et al., 2012), mixed equilibrium behaviors (He et al., 2013), price and flow dynamics (Ye et al., 2013).

To our knowledge, tradable travel credits system scarcely ever was applied to alleviating traffic congestion and emissions simultaneously. In this paper, we get the minimum emissions and decentralize general flow patterns with tradable credits. We internalized congestion and emission externalities with tradable credits simultaneous and investigated the existence of tradable credits scheme which decentralizes a given Pareto system optimum link flow pattern.

The rest of the paper is organized as follows: Notations and preliminaries are provided in section 2. In section 3, we implemented credits charging to achieve minimum emissions. Tradable credits scheme realized internalizing congestion and emission externality simultaneous and analyzed the Pareto system optimization with credits in section 4. Section 5 presents numerical examples and finally Section 6 concludes the paper.

2. Notation and preliminaries

2.1. The construction of network

Consider a general network *G=(N,A)* with a set of *N* nodes and a set of *A* directed links. Let v_a, $t_a(v_a)$ and $e_a(v_a)$ be the total link flow, travel time and emissions on link $a \in A$, where $t_a(\cdot)$ is a differentiable, non-negative, strictly increasing and convex function. Let $\boldsymbol{W}$ denotes the set of O–D pairs, and R_w the set of all routes between an O–D pair $w \in \boldsymbol{W}$. The travel demand for each O–D pair $w \in \boldsymbol{W}$ is denoted by d_w, $d_w > 0$. Let $f_{r,w}$ denotes the traffic flow on route $r \in R_w$ between an O–D pair $w \in \boldsymbol{W}$. $\boldsymbol{f}$ is a path flow vector $\boldsymbol{f} = (f_{r,w}, r \in R_w, w \in \boldsymbol{W})$. Ω_f denotes the set of feasible path flow patterns defined by (Meng and Yang, 2002)

$$\Omega_f = \left\{ f \middle| f_{r,w} \geq 0, \sum_{r \in R_W} f_{r,w} = d_w, w \in \boldsymbol{W} \right\} \tag{1}$$