复旦管理学杰出贡献奖获奖者代表成果集

2015

中国管理研究与实践

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高自友 杨善林 杨晓光 著

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内 容 提 要

复旦管理学奖励基金会由复旦校友、原中共中央政治局常委、国务院副总理李岚清同志发起，成立于2005年9月。宗旨是奖励我国在管理学领域做出杰出贡献的工作者，倡导管理学理论符合中国国情，并密切与实践相结合，推动我国管理学长远发展，促进我国管理学人才的成长，提高我国管理学在国际上的学术地位和影响力。

复旦管理学奖励基金会设有“复旦管理学杰出贡献奖”，自2006年起，每年依次在管理学的三个子领域“管理科学与工程”“工商管理”和“公共管理”进行评奖。2015年复旦管理学杰出贡献奖的评奖领域是管理科学与工程，产生了高自友、杨善林和杨晓光三位获奖人。

本书汇集了2015年复旦管理学杰出贡献奖高自友、杨善林、杨晓光三位获奖者的代表性学术成果，这些成果代表着目前我国管理学研究的领先水平，在创新性、学术性、实用性三个方面达到了一流标准，对广大管理学研究者有很强的借鉴意义和理论价值。

本书适用于高等院校管理学领域的研究者，也可作为政府经济管理部门工作人员、从事企业管理工作的基层管理者的参考用书。

序　言　一

李岚清

最近20多年来，管理学在我国日益受到人们的重视，这和我国的改革开放、经济社会快速发展有关，也和我国步入社会主义市场经济有关。其实，新中国建立以来，在经济和社会领域内都存在大量的涉及管理学的问题。我长期在大型企业、对外经济贸易部门和从事经济方面的领导工作中也都深切感受到这一点。但由于种种原因，管理学在相当长的时期内未能得到应有的重视。

管理学真正成为一门独立的科学，走进中国人的专业视野，全面进入中国的科学研究和高等教育体系，也就是最近20多年的事情。改革开放以来，中国的经济发展突飞猛进，科学技术日新月异，经济发展和社会进步越来越离不开管理科学的支撑。社会管理、环境管理、公共管理、企业管理等各个方面都对管理学提出了新的要求。经济社会领域改革的不断深入，在参与国际竞争中要取得持续的优势，这些都迫切需要进一步加强管理科学的研究，提高管理水平。可以说，需要管理学解决的问题越来越多，管理渗透到社会、经济生活的各个方面。当前，中国管理科学正迸发出空前的生机和活力，同时也面临着空前的机遇和挑战。

管理学是一门应用性、实践性很强的学科，作为一门科学，它的一些理论和方法在世界范围内具有共性。管理要获得成功，必须植根于一个国家的社会组织和民族文化之中。要真正解决好中国的管理问题，要让中国人对世界范围内涉及自己的管理问题有话语权和平等的参与权，最终还是要依靠中国人自己。管理科学是一个国家软实力的重要组成部分，我们要不断地构建有中国特色的管理科学理论，要具备并不断提高解决各类实际管理问题的能力，要培养出大批有很高学养和丰富经验的管理者，要花大力气建设高质量的管理教育体系，最关键的是要有一支高水平的管理学队伍。

复旦管理学奖励基金会的宗旨在于奖励在中国管理学领域作出贡献的学者和实践工作者，推动管理学的理论和实践相结合，形成中国特色的管理科学体系，最终推动中国管理学的长远发展，促进中国管理学人才的成长，提高中国管理学的国际学术影响力。

复旦管理学杰出贡献奖到今天已经是第5个年头了，12位在管理科学与工程、工商管理和公共管理等领域有杰出贡献的学者获得了这一奖项。这次，基金会把历届获奖人的代表性成果收录成册、公开发行，一方面是希望促进管理学研究成果在全社会的共享；另一方面也希望能够激励更多的中国管理学工作者潜心研究、勇于实践，产生高水准的学术成果，推动中国的管理创新和发展。

衷心祝愿中国管理学的明天更加美好！

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序 言 二

成思危

管理学是一门应用性、实践性很强的学科，既有科学的规律可循，又有艺术的运用之妙。改革开放以来，我国管理学扎根于中国特色社会主义的实践沃土，积极回答了改革开放对理论和实践提出的新课题，适应了我国经济建设的迫切需要，并在多学科相互融合中不断发展，初步形成了比较适合我国国情的管理学科体系。

从管理科学与工程方面来看，我国的总体研究水平取得了显著提高。在分析预测方法、不确定性决策理论、群体决策理论、供应链管理、管理复杂性研究等领域，还产生了一批在国际上有影响力的优秀成果。从工商管理方面来看，改革开放的实践为中国特色工商管理模式的形成提供了成长沃土。我国学者在股份制公司的组织与运作、公司治理制度的建立与评价、企业战略制定与实施、企业信息管理与电子商务、非公有制企业管理等众多领域进行了深入探索，在建立符合国情的现代企业制度、提高企业管理水平等方面作出了重要贡献。在发挥市场资源配置方面的基础性作用的同时，也需要政府通过适当有效的宏观管理加以引导和调控，解决发展中产生的矛盾，维护有序的市场秩序，促进社会公平，保护生态环境，改善社会保障，实现可持续发展的和谐社会，公共管理研究为国家宏观政策制定提供了重要的理论支持。

为了推动我国管理学长远发展，促进我国管理学人才的成长，提高我国管理学在国际上的学术地位和影响力，复旦管理学奖励基金会自 2006 年起开始奖励我国在管理学学术领域作出杰出贡献的工作者，倡导管理学理论符合中国国情，并密切与实践相结合。获奖人都是活跃在当今管理学学术领域的最优秀学者，获奖人的产生经过了学界的广泛推选，经过了严格的评议过程，始终坚持“创新性、学术性和实用性”的基本评判标准，具有较高的程序公正性和实质公正性。复旦管理学杰出贡献奖是完全由学术界独立完成推选的学术奖项，现在，复旦管理学杰出贡献奖逐渐被更多的人了解，产生了一定知名度，在管理学界具有了越来越大的影响力，评选出的获奖人和他们的成果代表着目前我国管理学研究的先进水平。今后，我们将持续帮助获奖人出版他们的研究成果，促进学术交流，推动理论繁荣。

“创立中国特色的管理理论、建立中国自己的管理学派”不是一朝一夕可以完成的任务。复旦管理学奖励基金会将通过对中国管理学界的长期支持，努力促成这项事业的成功。基金会目前还只是做了一点基础性的工作。我相信通过 10 年、20 年的努力，通过一代又一代管理学者的辛勤工作，通过有选择地学习和吸收国外经验，有批判地继承中国传统的管理哲学和管理思想，一定能够达到这个目标。

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一、高自友学术代表成果汇集篇

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一、高自友学术代表成果汇集篇

高自友

高自友，男，1963年出生，1993年获中国科学院应用数学研究所博士学位。现任北京交通大学交通运输学院教授、系统科学研究所所长，长江学者特聘教授，国家重大基础研究计划“973”项目首席科学家。兼任国家自然科学基金委管理学部副主任，中国系统工程学会副理事长，中国管理科学与工程学会副理事长，俄罗斯自然科学院外籍院士。

高自友教授长期从事城市交通管理理论及其在工程管理中的应用研究，其研究成果主要体现在：(1) 在城市道路交通管理方面，从道路交通流、路网交通流和交通承载力三个维度建立了用以研究城市交通流时空分布规律的数学模型，设计了可有效求解城市交通离散网络设计问题的支撑函数法，被国际同行视为当今国际上求解D-NDP问题的四个有效方法之一；(2) 在城市轨道交通管理方面，系统研究了城市轨道交通列车运输组织优化理论与运行控制方法，提出了移动闭塞条件下的列车控制优化策略，构建了基于出行需求与系统节能的城市轨道交通调度控制一体化理论模型，并研究了衔接道路与城轨的交通枢纽优化设计问题；(3) 提出了基于复杂网络及交通出行者行为科学的相关理论，构建了应用复杂网络理论与方法来研究交通运输系统复杂性的基本框架。

基于上述研究法成果，高自友教授带领团队开发出的北京市交通拥堵评价系统，已在北京市交通运行管理中成功应用；开发出的北京市地面公交调度指挥系统实现了北京市部分公交系统的日常公交调度运营作业，取得了重大社会效益。

高自友教授已获得了国家自然科学奖二等奖、教育部自然科学奖一等奖、第四届钱学森城市学金奖、全国优秀教师等多项荣誉与奖励。

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A reserve capacity model of optimal signal control with user-equilibrium route choice

Gao Ziyou①, Song Yifan②

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Abstract: In this paper, we combine the concept of reserve capacity with the continuous equilibrium network design problem. An integrated method is used to maximize the reserve capacity of a road network. On the one hand we try to find the maximum possible increase in traffic demand by setting traffic signals at individual intersections. On the other hand, we increase the road capacity in order to increase the whole capacity of a road network. A bilevel programming model and heuristic solution algorithm based on sensitivity analysis are proposed to model the reserve capacity problem of optimal signal control with user-equilibrium route choice. The applications of the model and its algorithm are illustrated with two numerical examples.

Keywords: reserve capacity; continuous equilibrium network design; bilevel programming model; sensitivity analysis; user equilibrium; signal-control

1 Introduction

Conventionally, the concept of reserve capacity has been applied to individual signal-controlled intersections, and is measured by the greatest common multiplier of existing flows that can be accommodated subject to the approach of capacity constraints, cycle time, minimum green constraints and others.

Up to now, many works have been done on reserve capacity. Webster and Cobbe (1966) calculated the reserve capacity of a simple signal-controlled intersection. Allsop (1972) generalized the definition of reserve capacity of a whole intersection. Yagar (1974, 1985) extended the linear programming method which was formulated by Allsop (1972) for

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the calculation of reserve capacity to the varying saturation flows from one stage to the next. Heydecker and Dudgeon (1987) also used a similar method to give the group-based signal timing calculation.

In 1996, Wong applied the concept of reserve capacity to priority junctions and roundabouts. Recently, Wong and Yang (1997) extended the concept of reserve capacity to a general signal-controlled road network. Analogous to individual intersections, Wong and Yang (1997) measured the reserve capacity for a signal-controlled network by how large a common multiplier can be applied to current O-D matrix subject to the flow on each link not exceeding a prescribed degree of saturation, cycle time, minimum green constraints and others.

In this paper, we combine the concept of reserve capacity with the continuous equilibrium network design problem. An integrated method is used to maximize the reserve capacity of a road network. On the one hand, we try to find the maximum possible increase in traffic demand by setting traffic signals at individual intersections. On the other hand, we increase the road capacity in order to increase the whole capacity of a road network. A bilevel programming model and heuristic solution algorithm based on sensitivity analysis are proposed to model the reserve capacity problem of optimal signal control with user-equilibrium route choice. The upper-level problem we addressed is to try to find the maximum possible increase in traffic demand by both setting traffic signals and increasing the road capacity, the lower-level problem which is a standard user-equilibrium problem accounts for the user's route choice behavior.

This paper has been organized as follows: In the next section, some basic notations are defined. The definition of reserve capacity of a signal-controlled road network are defined in Section 3. The reserve capacity model of optimal signal control with user-equilibrium route choice and its solution algorithm are presented in Sections 4 and 5. In Section 6, two numerical examples are given. Finally, conclusions are drawn in Section 7.

2 Basic notation

The notations used in this paper are given as follows:

I the set of all origin nodes

J the set of all destination nodes

i an origin node, $i \in I$

j a destination node, $j \in J$

A the set of links in the network

N the set of intersections in the network

R the set of signal-controlled intersections in the network, $R \subset N$

r a signal-controlled intersection, $r \in R$

A_r	the set of links entering the signal-controlled intersection $r \in R$
$\overline{A}$	the set of all signal-controlled links in the network, $\overline{A} = \{A_r, r \in R\}$
$\mathbf{q}$	the current O - D matrix
$\boldsymbol{\lambda}$	a vector of all signal timing variable (upper-level decision variables)
$\boldsymbol{\mu}$	a vector of the O - D matrix multiplier (upper-level decision variables), suppose that the current O - D matrix is $\mathbf{q}$, the multiplied O - D matrix is $\boldsymbol{\mu}\mathbf{q}$
K	the set of paths from origin node i to destination node j
q_{ij}	the O - D flow from origin node i to destination node j
h_k^{ij}	flow on path k from origin node i to destination node j
y_a	capacity increase on link $a \in A$
$\mathbf{y}$	a vector of capacity increase (upper-level decision variables)
$f_a(\mathbf{y}, \boldsymbol{\mu}, \boldsymbol{\lambda})$	flow on link $a \in A$, it is a function of upper-level decision variables $\mathbf{y}$, $\boldsymbol{\mu}$, $\boldsymbol{\lambda}$
$\mathbf{f}$	a vector of all link flows (lower-level decision variables)
δ_{ak}^{ij}	takes a value of 1 if link a is on path k from origin node r to destination node s, and 0 otherwise;
$c_a[f_a(\mathbf{y}, \boldsymbol{\mu}, \boldsymbol{\lambda}), y_a, \lambda_a]$	travel cost function on link $a \in A$
$s_a(y_a, \boldsymbol{\lambda})$	capacity of signal-controlled link $a \in \overline{A}$
$G_a(y_a)$	investment function of link $a \in A$
θ	coefficient converting construction cost to demand flow

3 Definition of reserve capacity of a signal-controlled road network

In this paper, we further extend the concept of reserve capacity which was defined by Wong and Yang (1997) in two aspects. First, Wong and Yang (1997) reckoned that all demand multipliers between each O - D pair are the same after setting traffic signals at individual intersections (i. e. , the O - D demand multiplier is denoted by variable $\boldsymbol{\mu}$). But actually the situation between each O - D pair is quite different (e. g. population, income, path numbers for user to select, intersection numbers in a path, etc.). However, because the high level of congestion only occurred in some links/intersections, we think that all demand multipliers between each O - D pair are not the same after setting traffic signals at individual intersections, i. e. , O - D demand multipliers should be denoted by a vector $\boldsymbol{\mu}$. Thus the reserve capacity is denoted by $(\boldsymbol{\mu}-1)\mathbf{q}$. Second, the concept of reserve capacity in a general signal-controlled road network is a general concept which is that the reserve capacity is maximized by an integrated method that includes both setting traffic signals at individual intersections and increasing road capacity.

Usually, network planners hope that the reserve capacity of road network can reach a prescribed value in the process of transportation planning, but this maximum reserve capacity cannot be reached simply by setting traffic signals. Thus, increasing link capacity must be considered simultaneously.

For fixed and given $\mathbf{q}$, link flow f is a function of the demand multiplier vector $\boldsymbol{\mu}$, signal timing variables, vector $\boldsymbol{\lambda}$, and link capacity increase vector $\mathbf{y}$. In order to ensure that queues and delays at network intersections under equilibrium conditions to be accepted by network users, flows on any signal-controlled links must be constrained so as not to exceed a prescribed maximum acceptable value, i. e. , capacity constraints are given as follows:

$$f_a(\mathbf{y}, \boldsymbol{\mu}, \boldsymbol{\lambda}) \leqslant p_a s_a(y_a, \boldsymbol{\lambda}), \; a \in \overline{A} \tag{1}$$

where p_a is the maximum acceptable degree of saturation for link $a \in \overline{A}$. Furthermore, the signal timing variables at signal-controlled intersections should satisfy some linear constraints which include cycle time, clearance time, minimum and maximum green times. Signal timing variable constraints are given as follows:

$$\mathbf{G}_r \boldsymbol{\lambda}_r \geqslant \mathbf{b}_r, \; r \in R, \tag{2}$$

where $\boldsymbol{\lambda}_r$ is a vector of timing variables at signal-controlled intersections, matrices $\mathbf{G}_r$ and $\mathbf{b}_r$ depend on the specific timing for signal-controlled intersection. For a detailed description, see Allsop (1989).

In the practice of traffic signal control, network planners often prescribe a minimum O－D demand multiplier in order to ensure that all demand multipliers are not lower than this minimum value, that is:

$$\mu_{ij} \geqslant \mu_0 \quad \forall i \in I, j \in J, \tag{3}$$

where μ_0 is the minimum O－D demand multiplier prescribed by the network planner.

4 Formulation of the problem

In general, network design problems are concerned with two groups: network planners and network users. On the one hand the behavior of network users follows the user-equilibrium principle of Wardrop, on the other hand network planners try to maximize reserve capacity minus expenditures for improvements. Alternatively, the reserve capacity would be maximized subject to a budget constraint. The model has the following forms:

4.1 Model 1

(P1) (U1)

$$\max z = \sum_{i \in I, j \in J} \mu_{ij} q_{ij} - \theta \sum_{a \in A} G_a(y_a) \tag{4}$$

$$\text{s.t.} \quad y_a \geqslant 0 \quad \forall a \in A, \tag{5}$$

$$f_a(\mathbf{y}, \boldsymbol{\mu}, \boldsymbol{\lambda}) \leqslant p_a s_a(y_a, \boldsymbol{\lambda}), \; a \in \overline{A}, \tag{6}$$

$$\mathbf{G}_r \boldsymbol{\lambda}_r \geqslant \mathbf{b}_r, \; r \in R, \tag{7}$$

$$\mu_{ij} \geqslant \mu_0 \quad \forall i \in I, j \in J, \tag{8}$$

where $f_a(\mathbf{y}, \boldsymbol{\mu}, \boldsymbol{\lambda})$ solves:

(L1)

$$\min \sum_{a \in A} \int_0^{f_a(\mathbf{y}, \boldsymbol{\mu}, \boldsymbol{\lambda})} c_a(x, y_a, \lambda_a) \mathrm{d}x \tag{9}$$

$$\text{s. t.} \quad \sum_{k \in K} h_k^{ij} = \mu_{ij} q_{ij} \quad \forall i \in I, j \in J, \tag{10}$$

$$f_a = \sum_{i \in I} \sum_{j \in J} \sum_{k \in K} h_k^{ij} \delta_{ak}^{ij} \quad \forall a \in A, \tag{11}$$

$$h_k^{ij} \geqslant 0 \quad \forall i \in I, j \in J, k \in K \tag{12}$$

In this model, the network planners at the upper-level are assumed to make decisions about signal setting at the intersection and investments for the link in order to maximize the reserve capacity minus expenditures for improvements. The users at the lower-level are assumed to follow the user-equilibrium principle of Wardrop under the given facilities.

4.2 Model 2

(P2) (U2)

$$\max z = \sum_{i \in I, j \in J} \mu_{ij} q_{ij} \tag{13}$$

$$\text{s. t.} \quad G_a(y_a) \leqslant B \tag{14}$$

$$y_a \geqslant 0 \quad \forall a \in A \tag{15}$$

$$f_a(\mathbf{y}, \boldsymbol{\mu}, \boldsymbol{\lambda}) \leqslant p_a s_a(y_a, \lambda), \ a \in \overline{A}, \tag{16}$$

$$\mathbf{G}_r \lambda_r \geqslant \mathbf{b}_r, \ r \in R, \tag{17}$$

$$\mu_{ij} \geqslant \mu_0 \quad \forall i \in I, j \in J \tag{18}$$

where $f_a(\mathbf{y}, \boldsymbol{\mu}, \boldsymbol{\lambda})$ solves:

(L2) which is the same as (L1)

where B is the total available budget for link improvements. In this model, the link improvement choice of the upper-level decision maker is explicitly limited by the total budget.

5 Solution algorithm based on sensitivity analysis

In order to solve the problem we must evaluate the changes in equilibrium link flows caused by the changes in link capacity, the signal timing variable and O - D demand multiplier under the condition that all constraint conditions are not being violated. It is difficult to evaluate the changes in equilibrium link flows directly because of the implicit, nonlinear function form of equilibrium link flows. A good idea is to use the linear function to approximate the nonlinear function of equilibrium link flows, which was used by Yang and Yagar (1994). Therefore, we must calculate the derivative of the link flows, with respect to capacity increases, the signal timing variable and O-D demand multiplier. The sensitivity analysis theory for equilibrium network flows, which was originally proposed by Tobin and Friesz (1988) and further extended and applied by Yang and Yagar (1994) and Yang (1997) is used to calculate the derivative of the link flows, with respect to capacity increases, the signal timing variable and O-D demand multiplier. The only thing we must note is denoting the perturbed parameter by a vector, that is $\varepsilon = [\mathbf{y}, \boldsymbol{\mu}, \boldsymbol{\lambda}]^T$.

Let $\mathbf{y}^*$, $\boldsymbol{\mu}^*$ and $\boldsymbol{\lambda}^*$ denote an initial solution to link capacity, the O-D demand multiplier and signal timing variable, respectively, and let $f_a(\mathbf{y}^*, \boldsymbol{\mu}^*, \boldsymbol{\lambda}^*)$ denote the corresponding equilibrium link flows, which are solved from lower-level problem. After calculating the derivative information, $f_a(\mathbf{y}, \boldsymbol{\mu}, \boldsymbol{\lambda})$ whose function form is unknown, the equation can be written as follows:

$$f_a(\mathbf{y}, \boldsymbol{\mu}, \boldsymbol{\lambda}) \approx f_a(\mathbf{y}^*, \boldsymbol{\mu}^*, \boldsymbol{\lambda}^*) + \sum_{a\in A}\left[\frac{\partial f_a(\mathbf{y}^*, \boldsymbol{\mu}^*, \boldsymbol{\lambda}^*)}{\partial y_a}\right](y_a - y_a^*)$$
$$+ \sum_{i\in I,\, j\in J}\left[\frac{\partial f_a(\mathbf{y}^*, \boldsymbol{\mu}^*, \boldsymbol{\lambda}^*)}{\partial \mu_{ij}}\right](\mu_{ij} - \mu_{ij}^*) + \sum_{a\in \bar{A}}\left[\frac{\partial f_a(\mathbf{y}^*, \boldsymbol{\mu}^*, \boldsymbol{\lambda}^*)}{\partial \lambda_a}\right](\lambda_a - \lambda_a^*) \tag{19}$$

When substituting (19) into the upper-level problem, the upper-level problem becomes an ordinary nonlinear programming problem with the variable link capacity increase, signal timing and O-D demand multiplier. This ordinary nonlinear programming problem can be solved by the well-known simple method, thus one can get a new improved point $(\mathbf{y}, \boldsymbol{\mu}, \boldsymbol{\lambda})$ from which a new nonlinear programming problem is again generated and again solved by the same method, and so on. Therefore, the method is in fact a sequence of linear approximations to the original bilevel problem.

The structure of bilevel optimization leads to a problem, that is, complexities are not generally encountered in familiar single-level mathematical programming problems, even a simple bilevel linear programming problem is nonconvex. Ben-Ayed and Blair (1990) showed that the bilevel linear programming problem is an NP-hard problem, and there are no polynomial algorithms for it. Thus, even if there exists an exact algorithm for some class of the bilevel programming problem, it is obvious that this kind of exact algorithm could not be applied to the practice of large-scale road network designs. Therefore, we adopt heuristics SAB algorithm to solve the problem. The solution procedure is the same as that adopted in Wong and Yang's papers. For a detailed description, see Wong and Yang (1997).

6 Numerical analysis

Two examples are presented in order to test the solution algorithm and the main idea

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