TRANSPORTATION AND TRAFFIC THEORY IN THE 21st CENTURY

CEDER (ed.)
Transportation and Traffic Theory: Proceedings of the 14th International Symposium on Transportation and Traffic Theory

DAGANZO (ed.)
Fundamentals of Transportation and Traffic Operations

ETTEMA & TIMMERMANS (eds.)
Activity-Based Approaches to Travel Analysis

GÄRLING (ed.)
Theoretical Foundations of Travel Choice Modelling

HENSHER (ed.)
Travel Behaviour Research: The Leading Edge

ORTÚZAR (ed.)
Travel Behaviour Research: Updating the State of Play

STOPHER & LEE-GOSSELIN (eds.)
Understanding Travel Behaviour in An Era of Change

Handbooks in Transport

HENSHER & BUTTON (eds.)
Handbook of Transport Modelling

BREWER et al. (eds.)
Handbook of Logistics and Supply-Chain Management

BUTTON & HENSHER (eds.)
Handbook of Transport Systems and Traffic Control

transport connect

TRANSPORTATION AND TRAFFIC THEORY IN THE 21ST CENTURY

Proceedings of the 15th International Symposium on Transportation and Traffic Theory
Adelaide, Australia, 16-18 July 2002

edited by

MICHAEL A. P. TAYLOR

Transport Systems Centre
University of South Australia

Emerald

United Kingdom – North America – Japan
India – Malaysia – China

Emerald Group Publishing Limited
Howard House, Wagon Lane, Bingley BD16 1WA, UK

Reprints and permission service
Contact: booksandseries@emeraldinsight.com

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN: 978-0-58-547460-1

Preface

It is my pleasure to present the proceedings of the *15th International Symposium on Transportation and Traffic Theory* (ISTTT15), held at the University of South Australia in Adelaide, Australia on 16-18 July 2002. The ISTTT series is the main gathering for the world's transportation and traffic theorists. It deals exclusively with the scientific aspects of transportation and traffic phenomena. Although it embraces a wide range of specific topics from traffic flow theory and travel demand modelling to road safety and logistics and supply chain modelling, the work of the ISTTT is hallmarked in all its topics of interest by intellectual innovation, research excellence and rigour in the analytical treatment of real word transport and traffic problems.

The ISTTT prides itself in the extremely high quality of its proceedings. No more than three dozen papers are selected for presentation, following a rigorous two-stage selection and peer review process, firstly of extended abstracts and then of full papers. The proceedings define the international state of the art of research in transportation and traffic science at the time of the symposium. We are indebted to the authors, whose contributions continue the interest in and standards of the symposium. Due to the large number of abstracts submitted and to their high quality, the selection process was difficult, and some hard decisions had to be made. I wish to thank the authors of all submitted abstracts and papers for their contribution.

The important and time consuming work undertaken by our referees must be acknowledged. The referees had to review up to four papers each of the 59 full papers submitted to the conference. Their task was essential in ensuring the high quality of the symposium, and I wish to thank them all for their hard work and diligence.

Special thanks are due to all of the people directly involved in the conference organisation. Professor Phil Howlett and Dr Mark Hochman provided particular support from the university, and my colleagues in the Transport Systems Centre all made valuable contributions to the organisation. Ms Kylie Bickley deserves especial thanks for her outstanding efforts in planning and administration of the symposium. Professor Avi Ceder, organiser of the 14th ISTTT, gave invaluable advice, and Professors Ezra Hauer and Carlos Daganzo, respectively current Convenor and incoming Convenor of the International Advisory Committee, must be thanked for their encouragement and advice.

Michael A P Taylor
February 2002

International Advisory Committee

E Hauer	University of Toronto, Canada (Convenor)
R E Allsop	University College London, UK
M G H Bell	Imperial College, London, UK
P H L Bovy	Delft University of Technology, The Netherlands
W Brilon	Ruhr-University Bochum, Germany
A Ceder	Technion-Israel Institute of Technology, Haifa, Israel
C F Daganzo	University of California, Berkeley, USA
N H Gartner	University of Massachusetts, Lowell, USA
H Keller	Technical University of Munich, Germany
R Kitamura	Kyoto University, Japan
M Kuwahara	University of Tokyo, Japan
W H K Lam	Hong Kong Polytechnic University, Hong Kong
J-B Lesort	Institut National de Recherche sur les Transports et leur Sécurité, Lyon, France
H S Mahmassani	University of Texas at Austin, USA
V V Silyanov	Moscow State Automobile and Road Technical University, Russia
M A P Taylor	University of South Australia, Adelaide, Australia
M Tracz	Cracow University of Technology, Poland
S C Wirasinghe	University of Calgary, Canada

Honorary members

M Koshi	Nikon University, Tokyo, Japan
W Leutzbach	University of Karlsruhe, Germany
Y Makigami	Ritsumeikan University, Kyoto, Japan
G Retzko	Technical University Darmstadt, Germany
D I Robertson	Universities of London and Nottingham, UK
S Yagar	University of Waterloo, Canada

Contributors

R Akcelik	Akcelik & Associates, Melbourne, Australia
J M S J Bandara	Department of Civil Engineering, University of Moratuwa, Sri Lanka
A Alessandrini	Department of Hydraulics, Transport and Roads, University of Rome La Sapienza, Italy
M G H Bell	Department of Civil & Environmental Engineering, Imperial College, London, UK
M Besley	Akcelik & Associates, Melbourne, Australia
P H L Bovy	Faculty of Civil Engineering & Geosciences, Delft University of Technology, The Netherlands
W Brilon	Institute for Transportation & Traffic Engineering, Ruhr University, Bochum, Germany
M J Cassidy	Institute of Transportation Studies, University of California, Berkeley, USA
A Ceder	Transportation Research Institute, Technion-Israel Institute of Technology, Haifa, Israel
C F Daganzo	Institute of Transportation Studies, University of California, Berkeley, USA
G Davis	Department of Civil Engineering, University of Minnesota, Minneapolis, USA
J Dong	Department of Marketing & Management, State University of New York at Oswego, USA
L J Ferreira	Department of Civil Engineering, Queensland University of Technology, Brisbane, Australia
K Fukuyama	Department of Civil Engineering, Tohoku University, Sendai, Japan
N H Gartner	Department of Civil & Environmental Engineering, University of Massachusetts, Lowell, USA
F Giorgi	Laboratoire d'Ingénierie Circulation-Transport, Institut National de Recherche sur les Transports et leur Sécurité, Lyon, France
D Heidemann	Institute of Applied Research, Heilbronn University of Applied Sciences, Kuenzelsau, Germany
B Heydecker	Centre for Transport Studies, University College London, UK
S Hoogendorn	Faculty of Civil Engineering & Geosciences, Delft University of Technology, The Netherlands
H-J Huang	School of Management, Beijing University of Aeronautics & Astronautics, PRC
H Ieda	Department of Civil Engineering, University of Tokyo, Japan
Y Iida	Department of Transportation Engineering, Kyoto University, Japan
R Kates	Transport Engineering & Planning Unit, Technical University of Munich, Germany
H Keller	Transport Engineering & Planning Unit, Technical University of Munich, Germany
B Kerner	DaimlerChrysler, Stuttgart, Germany
H Kita	Department of Social Systems Engineering, Tottori University, Japan
M Kuwahara	Institute of Industrial Science, University of Tokyo, Japan

M Lake	Department of Civil Engineering, Queensland University of Technology, Brisbane, Australia
W H K Lam	Department of Civil Engineering, Hong Kong Polytechnic University, Hong Kong
J P Lebacque	Centre d'Enseigement et de Recherche en Mathématique, Ecole Nationale des Ponts-et Chaussées, Marne-la-Vallée, France
L Leclerq	Laboratoire d'Ingénierie Circulation-Transport, Institut National de Recherche sur les Transports et leur Sécurité, Lyon, France
M Lemessi	Department of Hydraulics, Transport and Roads, University of Rome La Sapienza, Italy
J-B Lesort	Laboratoire d'Ingénierie Circulation-Transport, Institut National de Recherche sur les Transports et leur Sécurité, Lyon, France
W-H Lin	Department of Civil Engineering, University of Arizona, Tuczon, USA
H K Lo	Department of Civil Engineering, Hong Kong University of Science & Technology, Hong Kong
M Maher	School of the Built Environment and Transport Research Institute, Napier University, Edinburgh, UK
M Mauch	Institute of Transportation Studies, University of California, Berkeley, USA
J C Munoz	Institute of Transportation Studies, University of California, Berkeley, USA
A Nagurney	Department of Finance & Operations Management, University of Massachusetts, Amherst, USA
G F Newell	Institute of Transportation Studies, University of California, Berkeley, USA (posthumous)
M Nowakowska	Laboratory of Computer Science, Kielce University of Technology, Poland
A Poschinger	Poschinger Mobilitätstechnologie, Wolfratshausen, Germany
C J Quain	Department of Civil Engineering, University of Calgary, Canada
R Raicu	Transport Systems Centre, University of South Australia, Adelaide, Australia
A Rosa	School of the Built Environment and Transport Research Institute, Napier University, Edinburgh, UK
M Sarvi	Institute of Industrial Science, University of Tokyo, Japan
J-D Schmoecker	Transport Operations Research Group, University of Newcastle, UK
M L Tam	Department of Civil & Structural Engineering, Hong Kong Polytechnic University, Hong Kong
M Tamaishi	Ministry of Land, Infrastructure and Transport, Yokohama, Japan
E Taniguchi	Department of Civil Engineering, Kyoto University, Japan
K Tanimoto	Department of Social Systems Engineering, Tottori University, Japan
M A P Taylor	Transport Systems Centre, University of South Australia, Adelaide, Australia
C O Tong	Department of Civil & Structural Engineering, University of Hong Kong, Hong Kong
R J Troutbeck	Department of Civil Engineering, Queensland University of Technology, Brisbane, Australia
H Van Lint	Faculty of Civil Engineering & Geosciences, Delft University of Technology, The Netherlands

U Vandebona School of Civil Engineering, University of New South Wales, Sydney, Australia
S C Wirasinghe Faculty of Engineering, University of Calgary, Canada

K I Wong Department of Civil & Structural Engineering, University of Hong Kong, Hong Kong
S C Wong Department of Civil & Structural Engineering, University of Hong Kong, Hong Kong
N Wu Institute for Transportation & Traffic Engineering, Ruhr University, Bochum, Germany
H Yang Department of Civil Engineering, Hong Kong University of Science & Technology, Hong Kong
T Yamada Department of Civil Engineering, Hiroshima University, Japan
Y Yin Department of Civil Engineering, University of Tokyo, Japan
D Zhang Department of Marketing & Management, State University of New York at Oswego, USA
M Zhang Department of Civil & Environmental Engineering, University of California, Davis, USA
X Zhang Department of Civil Engineering, Hong Kong University of Science & Technology, Hong Kong

1

A STEP FUNCTION FOR IMPROVING TRANSIT OPERATIONS PLANNING USING FIXED AND VARIABLE SCHEDULING

Avishai Ceder, Civil Engineering Dept., Transportation Research Institute, Technion-Israel Institute of Technology, Haifa, Israel 32000.

ABSTRACT

This work describes a highly informative graphical technique for the problem of finding the least number of vehicles required to service a given timetable of trips. The technique used is a step function, called a deficit function, which was introduced in the last 20 years as an optimization tool for minimizing the number of vehicles in a fixed trip schedule. However not much attention was given to the possibility of variable trip schedule, within given tolerances, and to the deficit function use for additional elements in the transit operations planning process. The objectives of this work are four fold: **(a)** to develop an improved lower bound to the fixed schedule fleet size problem, **(b)** to use the deficit function for minimizing the fleet size with variable schedules (possible shifts in departure times), **(c)** to allow for the combination of deadheading trip insertions and shifts in departure times in the fleet size minimization problem, and **(d)** to outline example applications of the deficit function use in designing better transit services. In addition this work covers the procedures to create the chains of trips (daily vehicle duty or block) where the number of these chains complies with the minimum fleet size derived. The algorithms developed are accompanied with examples. The approach used in this work provides immediate feedback on the value of shifting departure times, within given tolerances, as well as combining these shifts with the insertion of deadheading trips for reducing the fleet size. The value of embarking on such a technique is to achieve the greatest vehicle saving while complying with passenger demand. This saving is

attained through a procedure incorporating a man/computer interface which would allow the inclusion of practical considerations that experienced transit schedulers may wish to introduce in the schedule.

1. INTRODUCTION

1.1 Objectives

Transit operations planning can be thought of as a multistep process. Due to the complexity of this process each step is normally conducted separately, and sequentially fed into the other. The process steps are: (1) Network route design; (2) Setting timetables; (3) Scheduling vehicles to trips; and (4) Assignment of drivers. In order for this process to be cost-effective and efficient, it should embody a compromise between passenger comfort and cost of service. For example, a good match between vehicle supply and passenger demand occurs when vehicle schedules are constructed so that the observed passenger demand is accommodated while the number of vehicles in use is minimized.

This work describes a highly informative graphical technique for the problem of finding the least number of vehicles required to service a given timetable of trips. The technique used is a step function, called a deficit function, which was introduced in the last 20 years as an optimization tool for minimizing the number of vehicles in a fixed trip schedule. However not much attention was given to the possibility of variable trip schedule, within given tolerances, and to the deficit function use for additional elements in the transit operations planning process. The objectives of this work are four fold: **(a)** to develop an improved lower bound to the fixed schedule fleet size problem, **(b)** to use the deficit function for minimizing the fleet size with variable schedules (possible shifts in departure times), **(c)** to allow for the combination of deadheading trip insertions and shifts in departure times in the fleet size minimization problem, and **(d)** to outline example applications of the deficit function use in designing better transit services.

1.2 Exact solution approaches

The problem of scheduling vehicles in a multi-depot scenario is known as the Multi-Depot Vehicle Scheduling Problem (MDVSP). This problem is complex (NP-hard) and considerable effort is devoted to solve it in an exact way. Review and description of some exact solutions can be found in Desrosiers *et al* (1995), Daduna and Paixao (1995), Löbel (1999), and Mesquita and Paixao (1999).

An example formulation of the MDVSP is as follows:

$$\text{objective function: } \min_{y}\left\{\sum_{i=1}^{n+1}\sum_{j=1}^{n+1} c_{ij}\, y_{ij}\right. \qquad (1)$$

where i is the event of-ending of a trip at time a_i, j is the event of-start of a trip at time b_j,

and $y_{ij} = \left\{\begin{matrix} 1, \text{ ending is connecting to start} \\ 0, \text{ otherwise} \end{matrix}\right\}$.

For $i = n+1$ then $y_{n+1j} = 1$ if a depot supplies a vehicle for the *j*-th trip. For $i = n+1$ then $y_{i,n+1} = 1$ if after the i-th trip end, the vehicle returns to a depot, and $y_{n+1,n+1}$ = No. of vehicles remain unused at a depot.

The cost function c_{ij} takes the form

$$c_{ij} = \left\{\begin{matrix} K & ; \; i = n+1; j = 1,2,\ldots,n \\ O & ; \; i = 1,2,\ldots,n; j = n+1 \\ L_{ij} + E_{ij} & ; \; i,j = 1,2,\ldots,n \end{matrix}\right\} \qquad (2)$$

where: K = the saving incurred by reducing the fleet size by one vehicle,

L_{ij} = direct dead-heading cost from event i to j, and

E_{ij} = cost of idle time of a driver between i and j.

This formulation which appears in a similar form in Gavish *et al* (1978) covers the chaining of vehicles in a sequential order from the depot to the transit routes alternating with idle time and dead-heading trips, and back to the depot. This is a zero-one integer programming problem that can be converted to a large scale assignment problem. In addition, the assignment of vehicles from the depots to the vehicle schedule generated in the above chaining process can be formulated as a "transportation problem" known in every operations research literature.

Löbel (1999) is using a branch-and-cut method for MDVSP with the generation of upper bounds and the use of Lagrangean relaxations and pricing. Mesquita and Paxiao (1999) are comparing in this problem the linear relaxation based on multicommodity network flow approach.