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TRANSPORTATION
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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

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

MLake
WHK Lam
JP Lebacque
L Leclercq
MLemessi
J-B Lesort
W-H Lin
HKLo
MMaheat
MAuch
JCMunoz
ANagurney
GF Newell
MM Nowakowska
A Poschinger
CJQuain
RRaiucu
ARosa
MSarvi
JDSchmoeker
MLTam
MTamaishi
ETaniguchi
KTanimoto
M A P Taylor
CO Tong
RJ Troutbeck
HVan Lint

Department of Civil Engineering, Queensland University of Technology, Brisbane, Australia
Department of Civil Engineering, Hong Kong Polytechnic University, Hong Kong
Centre d’Enseignement et de Recherche en Mathématique, Ecole Nationale des Ponts-et-Chaussées, Marne-la-Vallée, France
Laboratoire d’Ingénierie Circulation-Transport, Institut National de Recherche sur les Transports et leur Sécurité, Lyon, France
Department of Hydraulics, Transport and Roads, University of Rome La Sapienza, Italy
Laboratoire d’Ingénierie Circulation-Transport, Institut National de Recherche sur les Transports et leur Sécurité, Lyon, France
Department of Civil Engineering, University of Arizona, Tucson, USA
Department of Civil Engineering, Hong Kong University of Science & Technology, Hong Kong
School of the Built Environment and Transport Research Institute, Napier University, Edinburgh, UK
Institute of Transportation Studies, University of California, Berkeley, USA
Institute of Transportation Studies, University of California, Berkeley, USA
Department of Finance & Operations Management, University of Massachusetts, Amherst, USA
Institute of Transportation Studies, University of California, Berkeley, USA
Laboratory of Computer Science, Kielce University of Technology, Poland
Poschinger Mobilitätstechnologie, Wolframshausen, Germany
Department of Civil Engineering, University of Calgary, Canada
Transport Systems Centre, University of South Australia, Adelaide, Australia
School of the Built Environment and Transport Research Institute, Napier University, Edinburgh, UK
Institute of Industrial Science, University of Tokyo, Japan
Transport Operations Research Group, University of Newcastle, UK
Department of Civil & Structural Engineering, Hong Kong Polytechnic University, Hong Kong
Ministry of Land, Infrastructure and Transport, Yokohama, Japan
Department of Civil Engineering, Kyoto University, Japan
Department of Social Systems Engineering, Tottori University, Japan
Transport Systems Centre, University of South Australia, Adelaide, Australia
Department of Civil & Structural Engineering, University of Hong Kong, Hong Kong
Department of Civil Engineering, Queensland University of Technology, Brisbane, Australia
Faculty of Civil Engineering & Geosciences, Delft University of Technology, The Netherlands
<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>U Vandebona</td>
<td>School of Civil Engineering, University of New South Wales, Sydney, Australia</td>
</tr>
<tr>
<td>S C Wirasinghe</td>
<td>Faculty of Engineering, University of Calgary, Canada</td>
</tr>
<tr>
<td>K I Wong</td>
<td>Department of Civil &amp; Structural Engineering, University of Hong Kong, Hong Kong</td>
</tr>
<tr>
<td>S C Wong</td>
<td>Department of Civil &amp; Structural Engineering, University of Hong Kong, Hong Kong</td>
</tr>
<tr>
<td>N Wu</td>
<td>Institute for Transportation &amp; Traffic Engineering, Ruhr University, Bochum, Germany</td>
</tr>
<tr>
<td>H Yang</td>
<td>Department of Civil Engineering, Hong Kong University of Science &amp; Technology, Hong Kong</td>
</tr>
<tr>
<td>T Yamada</td>
<td>Department of Civil Engineering, Hiroshima University, Japan</td>
</tr>
<tr>
<td>Y Yin</td>
<td>Department of Civil Engineering, University of Tokyo, Japan</td>
</tr>
<tr>
<td>D Zhang</td>
<td>Department of Marketing &amp; Management, State University of New York at Oswego, USA</td>
</tr>
<tr>
<td>M Zhang</td>
<td>Department of Civil &amp; Environmental Engineering, University of California, Davis, USA</td>
</tr>
<tr>
<td>X Zhang</td>
<td>Department of Civil Engineering, Hong Kong University of Science &amp; Technology, Hong Kong</td>
</tr>
</tbody>
</table>
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

An example formulation of the MDVSP is as follows:

\[
\text{objective function: } \min_y \sum_{i=1}^{n+1} \sum_{j=1}^{n+1} c_{ij} y_{ij} \tag{1}
\]

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 \( y_{ij} = \begin{cases} 1, & \text{ending is connecting to start} \\ 0, & \text{otherwise} \end{cases} \).

For \( i = n + 1 \) then \( y_{n+1,j} = 1 \) 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

\[
c_{ij} = \begin{cases} K & ; \ i = n + 1; j = 1,2,\ldots,n \\ O & ; \ i = 1,2,\ldots,n; j = n + 1 \\ L_{ij} + E_{ij} & ; \ i,j = 1,2,\ldots,n \end{cases} \tag{2}
\]

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.