ENVIRONMENT, LAND USE AND TRANSPORTATION SYSTEMS

Selected papers

edited by
Agostino Cappelli
Alessandra Libardo
Silvio Nocera

Società italiana
dei docenti di trasporti

Collana Trasporti

FrancoAngeli

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Collana trasporti, diretta da Ennio Cascetta e Giovanni Corona

La collana trasporti ha iniziato le pubblicazioni ormai da oltre venti anni (1982), sotto la responsabilità scientifica di due prestigiosi studiosi della disciplina, i Professori Ilio Adorisio e Pier Paolo Sandonnini, che seppero caratterizzare i primi volumi per l'intelligente scelta degli argomenti ed il rigore del metodo seguito.
La responsabilità scientifica della collana è stata poi assunta nel 1992 dal Prof. Ennio Cascetta, uno degli attuali direttori, e dal Prof. Giorgio Salerno, che cessa la collaborazione e al quale vanno i nostri ringraziamenti per l'opera svolta.
Il settore dei trasporti sta attraversando una fase di notevoli cambiamenti, sia a livello internazionale che, ancor più, nel nostro Paese.
La crescita e, soprattutto, le modifiche strutturali della domanda di trasporto, la maggiore attenzione alla sicurezza e all'ambiente, la congestione sistematica di infrastrutture e servizi di trasporto, la flessione dei finanziamenti pubblici disponibili, l'avvio di un mercato concorrenziale dei servizi, lo sviluppo tecnologico dei veicoli e dei sistemi di controllo, l'evoluzione delle riflessioni sulla città e le sue opportunità localizzative, hanno fatto crescere enormemente la complessità dei sistemi di trasporto e dei problemi connessi alla loro progettazione e alla loro gestione.
In tutti questi anni, la collana con le sue pubblicazioni, ha saputo evidenziare alcune delle principali tematiche affrontandole con metodologie innovative e grande rigore scientifico che hanno portato a dei contributi originali per la disciplina e all'approfondimento delle problematiche.
La presenza nel panorama editoriale italiano di questa collana, sulla quale pubblicano abitualmente la Sidt (Società italiana docenti dei trasporti) e il Progetto finalizzato trasporti del Cnr, ha certamente consentito ai diversi autori di trovare un punto di riferimento ed un momento di incontro, pur se va ovviamente attribuito ai singoli il merito per la qualità, l'intelligenza e la validità degli argomenti.
Per il futuro ci auguriamo che questa iniziativa possa essere ancora di aiuto, e forse di stimolo, a tutti quegli studiosi e operatori che vorranno contribuire ad una migliore conoscenza dei trasporti ed alla soluzione dei tanto numerosi problemi del settore.

I direttori

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Preface

Agostino Nuzzolo[*]

In 2011 the city of Venice hosted the annual conference of the Italian Society of Transportation Scholars (SIDT)[1]. The two-days conference was organized by the IUAV University to debate on the "Sustainability of transportation systems".

During the first day the conference deepened on institutional and technical speeches related to "Sustainability and Technological Innovation of Transportation Systems", following the well-established SIDT conference format in which SIDT encourages discussion with managers of public administrative offices, institution delegates, local authorities and academics starting from opening contributions of people from different cultural backgrounds and with different points of view.

The second day of the conference was dedicated to the SIDT scientific seminar 2011 which was mainly attended by transport researchers debating on the conference theme.

This book contains a selection of the papers presented during the Scientific Seminar focusing on mathematical models and techniques to investigate several aspects of transportation systems.

This is the third book of SIDT proceedings produced in English in order to disseminate SIDT activities to the international community.

Selected papers are a part of the research activities of SIDT members contributing to the community debate on transport systems and related topics, such as technological innovation, land-use, economics, environment and energy for a sustainable development.

I wish to thank the editors, the scientific committee, the reviewers and all those involved for their valuable contribution and for the time they spent for the success of the conference and of this book.

[*] SIDT President, "Tor Vergata" University of Rome.

[1] SIDT gathers all the Italian University Professors and Researchers who study and teach topics of transportation systems.

Introduction

Agostino Cappelli[*]*, Alessandra Libardo*[*]*, Silvio Nocera*[*]

This volume includes a selection of the papers presented during the 2011 Annual Conference of the Italian Society of Transportation Scholars (SIDT). It took place at the IUAV University of Venice, on October 6th and 7th, 2011.

The Conference brought together researchers and transportation professionals in a friendly atmosphere, which propelled a fruitful discussion about the relationships between transportation planning, environment and land use modelling. A pool of acknowledged international experts of the matter opened the conference, providing the audience the basic problems, the latest developments and strategies in the matter. The conference has then focussed on the contributions of the scientific community. A selection of the most relevant studies has been included in this volume, which is divided into two main blocks, each of them formed by eleven papers.

The first block deals with the topic "Transit, Transportation and Territory".

In the first paper "*Feeder bus network design problem: a new solving procedure and real size applications*", the colleagues Francesco Ciaffi, Ernesto Cipriani, Stefano Gori and Marco Petrelli pointed on the improvement of the integration between main urban transit services, like rail and bus networks, analyzing Feeder Bus Network Design Problem (FBNDP).

The work "*Determinants of schedule-based transit performances in the city of Bologna*" by Stefano Angelini, Silvia Bertoni, Antonio Danesi, Marco Donzelli and Federico Rupi deals with a literature review on the main factors affecting the reliability of transit system and its relative indexes.

The third paper of the block ("*Biarticulated Rapid Transit, Why not? - Innovation for metropolitan areas: study cases Curitiba and Bogotá*", by IUAV territorial expert Marcello Mamoli) analyzes the results of the implementation of rapid transit systems in the cities of Curitiba and Bogotá.

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Some of the colleagues of the University of Bologna Nazanin R. Dehkordi, Anton Pashkevich, Federico Rupi and Joerg Schweizer author the fourth paper of this block: "*Could PRT trigger a modal-shift to public transport? Results from stated preference street surveys, conducted in central European cities*". Their main findings are that Personal Rapid Transit seems to have the potential for attracting a good number of the potential users.

Laura Eboli and Gabriella Mazzulla of University of Calabria present the applicative study "*The heterogeneous perception of transit service quality*". The study gives a useful contribution to the scientific literature of the sector because of the scarceness of studies in which the heterogeneity of transit users' perceptions is considered in the service quality.

Stefano Carrese and Simone La Spada include the paper "*A fuzzy approach to Public transport quality of service based on AVM data collection: the real case of Rome Bus System*": Automatic Vehicle Monitoring (AVM) data through a fuzzy approach are used to determine the optimal allocation of resources for a given company during bus transport operations for hitting a certain target in terms of service quality.

The seventh paper of the block ("*How transportation system changes affect the regional development and vice versa: a study case*", by Laura Eboli, Carmen Forciniti, Gabriella Mazzulla, and Giuseppe Pungillo) applies spatial analysis techniques and GIS to study the relationships between land-use and transportation system, giving a new road in the urban area Cosenza-Rende as a case study.

The University of Calabria also contributes the paper "*Spatial analysis techniques for examining the acces-sibility of an urban region*" by Laura Eboli, Carmen Forciniti, and Gabriella Mazzulla: a Geographically Weighted Regression (GWR) model was elaborated to estimate the relationships between daily trips made by people resident in an urban area and some explanatory variables linked to population characteristics and accessibility indicators.

The paper "*The Use of Scenario Analysis as a tool for long-term transport planning: a review*" by Elisa Fornasiero, Alessandra Libardo, and Silvio Nocera reviews the potential of Scenario Analysis for long-term transport forecasting.

Air transportation is the subject of the paper "*Airport mergers and acquisitions: the case of Italy*" by Nicola Gualandi, Luca Mantecchini, and Filippo Paganelli: the authors show here that multi-airports management companies may take advantage from the centralization of some business activities (i.e. planning, commercial activities, human resources, administration, etc.), thus realizing significant cost savings.

Last paper of the block is "*Tourist Coach Mobility Plans: current practices and operational criteria*", by Antonio Musso and Cristiana Piccioni, which reviews thoroughly tourist coach management practices by analyzing several concrete European case studies.

The second block focuses on "Externality, Environment and Technological Advances in Transportation".

Pollution is the argument of the first paper of this block, "*A dynamic meso-simulation model to estimate pollutant emissions in a wide network*" by Stefano Gori, Simone La Spada, Livia Mannini, and Marialisa Nigro, who present a dynamic mesoscopic approach to obtain reliable values of pollutant emissions in a wide network.

Federica Crocco, Sergio d'Elia, and Domenico W.E. Mongelli discuss the problem of noise pollution in the paper "*Development of a road traffic noise prediction model in an urban area*", presenting a noise prediction model for urban and suburban areas, developed and calibrated on a testing network in the province of Cosenza.

In the paper "*Dynamic evaluation of road congestion by using on board technologies for buses*", Domenico Gattuso, Gian Carla Cassone, Demetrio Filocamo, Antonio Galletta, and Flavio Marangon propose a methodology to evaluate the level of service on road links by taking into account information recorded by means of special sensors installed in buses. They test and validate the procedure through a pilot experience carried out in the Sicilian city of Messina.

The objective of Adriano Alessandrini, Alessio Cattivera, and Fernando Ortenzi in the work "*An Ecoindex to measure the driving style and its influence on vehicle fuel consumption and CO_2 emissions*" is to define an index ("Ecoindex"), to quantify the driver influence on car fuel consumption and carbon dioxide emissions.

In the paper "*Eco-rationality and the "false friends" of urban sustainable mobility*", Armando Cartenì and Ennio Cascetta investigate the theme of rational decisions in transport policies, concretely testing the environmental effects of some transport policies widely accepted as sustainable on a concrete application for the city of Naples.

Container transport is the subject of the paper "*The container deep sea and transshipment services in Italian ports: an overview*" by Alessandro Farina, Marino Lupi, and Antonio Pratelli: particularly, the authors analyze deep sea container services departing from the two gateway regions of North Adriatic and North Tyrrhenian region, and from the Italian hub ports.

The paper "*A system of models for simulating shop restocking focuses on choices for restocking retailers and food-and-drink outlets*" by Antonio Comi aimes at identifying the main variables affecting the strategy, the transport service and distributor types for restocking, such as the characteristics of shop (e.g. number of employees) and deliveries (e.g. frequency, time, freight type, quantity).

Traffic counters for bike flows are the subject of the paper "*Bike flows and performance of bike facilities: implementation of a procedure for bike traffic counting in the city of Bologna*", by Silvia Bertoni and Federico Rupi: in particular, the paper illustrate the main characteristics of traffic counters, discussing their advantages and shortfalls, and where they should be located in order to minimize vehicular and pedestrian interferences when counting bike flows.

The paper "*Performance evaluation of urban traffic management and ITS: The Rome case study*" by Antonios Tsakarestos, Silvio Nocera, Ioannis Kaparias and

Niv Eden faces the problem of the evaluation of Intelligent Transportation Systems (ITS) through Key Performance Indicators (KPI). It gives an overview of the definition process for the KPI, explains their function and gives an example for the calculation of the KPI based on real-life data provided by the city of Rome.

ITS world is also the subject of the paper "*Typical speed profiles on motorways from floating vehicle data*" by Alessandra Pascale, Francesco P. Deflorio, Monica Nicoli, Bruno Dalla Chiara, and Matteo Pedroli focused on the processing of Floating car data (FCD), particularly on the analysis of daily speed patterns for the construction of an efficient, reliable and accurate historical database.

Last but not least, the book contains an evaluation methodology based on measurements of several sets of indicators for four different Automated Transport Systems: Personal Rapid Transit (PRT), CyberCars (CC), High Tech Buses (HTB), Dual-Mode Vehicles (DMV), presented in the paper "*Evaluation of Automated Transport Systems*" by Adriano Alessandrini, Francesco Filippi, and Daniele Stam.

The editors would like to express their gratitude to those who have contributed to the publication of this book. In particular, we would like to thank the participants to the Seminar, the Scientific Committee of SIDT, and the reviewers of the papers.

Particularly, we have appreciated the care and the precious help of Marilena Laquale from the Publisher Team. A special thank is also due to Elena Spolaore for the valuable support in the final editing of this book.

Feeder bus network design problem: a new solving procedure and real size applications

Francesco Ciaffi[*], *Ernesto Cipriani*[*], *Stefano Gori*[*], *Marco Petrelli*[*]

1. Introduction

It is widely recognized that the remarkable increase in traffic congestion, air pollution, energy consumption and road accidents is produced by the large increase of individual car traffic. On the other side, shifting transport demand towards the public transport enhances urban sustainability making a better use of land, air and energy sources than individual transport mode. Based on such issues, this paper presents a methodology for solving the "Feeder Bus Network Design Problem" ("FBNDP") whose solution seems very useful to improve integration between main urban transit services, like rail and bus networks. FBNDP represents one of those new policies developed in last decade for managing and planning urban transit networks since it allows to design those specific bus lines suitable to cover residential areas collecting transit demand and feeding main transit system in specific transfer points.

The structure of this paper is based on the procedure framework which represents the different steps of the work: firstly it is shown a wide review of other works about feeder bus networks design; next chapters, instead, deal with the problem formulation and his mathematical pattern and, most importantly, the solving procedure framework, based on two different phases. In the first one a heuristic procedure, solving a travelling salesman problem and a k-shortest path algorithm, generates two sets of feasible and complementary routes; in the second phase, instead, a genetic algorithm is proposed for finding a sub-optimal set of routes and associated frequencies.

Finally is shown the application of the model to two different real-life size networks: the city of Winnipeg, in order to test the procedure quality, and the urban area of Rome, so as to compare its effectiveness with the performances of the existing transit networks. Each one of these listed steps was completed taking into

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account all the typical FBNDP goals; the sub-optimal set of lines, routes and frequencies was designed aiming at the balance between service coverage areas and service effectiveness and efficiency, and looking for the improvement of the integration between rail and bus networks in urban area of Rome.

2. State of the art

The transit network design is a complex non convex problem (Newell 1979, Baaj and Mahmassani 1991). It is usually formulated as a non linear optimization problem with both discrete and continuous variables and constraints. The best and most efficient solution methods are based on heuristic procedures but their applications are mainly limited to test cases or real-life networks of small size. A global review about route design, frequency setting, timetabling of transit lines, and their combination is proposed by Baaj and Mahmassani (1995), Desaulniers and Hickman (2007), Guihaire and Hao (2008), Kepaptsoglou and Karlaftis (2009).

Therefore over the last years, the evolution of operational research and computer technology has produced great and renewed attention for the transit network design problem; new approaches based on metaheuristic techniques (Genetic Algorithm –GA–, Simulated Annealing or Tabu Search) have been frequently applied to solve optimization problems. Due to the discrete nature of several variables of the transit network design problem as well as the nonlinearity and the non-convexity of its objective function, probabilistic optimization techniques such as GAs seem to be appropriate.

Despite of this renewed attention for transit network design, still today there are few researches about feeder bus subject. Among the most remarkable there's the one of Chien and Yang (2000), dealing with an alternative methodology for solving feeder bus route design problem in a typical urban irregularly shaped service area, based on a model for finding just the optimal bus route location and its operating headway. All this research starts from the assumption that demand is uniformly distributed within each zone of the service area but differs among zones and that it is no sensitive to service quality. An algorithm allows to design not the entire feeder bus network but a single bus service optimal route, based on a many-to-one travel pattern, aiming to the maximization of service coverage and demand collection in the service area, having a line-haul distance of 10 km from the transfer station to be fed.

Differently from Chien and Yang research, the work proposed by Jerby and Ceder (2006) aims not only to the definition of a methodology for a single feeder bus route design but to an entire feeder bus network planning. Their research is threefold: a) create a method for estimating potential demand for a shuttle bus service, b) elaborate a model focusing on optimal route automatic design and,

finally, c) define a heuristic algorithm designed to take into account road networks of all sizes. All the work is based on a modular approach allowing the entire problem to be partitioned in a chain of sub-problems; first four stages are to estimate the potential demand, creating a base network of a defined service area using inputs and constraints like average travel speeds, maximum travel time and walking distances after the scan of urban entire network and the discard of all the links not used by transit service. Fifth and sixth steps show the model formulation proposed for this particular feeder route design problem, based on a decision variable aiming at maximizing potential demand and minimizing walking distances. Last two stages of the threefold research are about the heuristic algorithm framework, introduced to define circular routes in urban context, both starting and finishing in the same node with a total travel time lower than a fixed constraint.

Another research about FBNDP is the methodology, based on metaheuristic techniques, proposed by Shrivastava e O'Mahony (2006), and its application to real life case of DART, the rapid transit system of Dublin. In this paper, most appealing innovation is represented by the application of a Genetic Algorithm (GA) in order to obtain the sub-optimal set of feeder bus lines and simultaneously the associated frequencies leading to a schedule coordination with main transit system (DART). Hence we can consider at the same time this solving procedure useful for both routing problems and scheduling problems.

Differently from this research, our paper adopts a design approach similar to the one proposed by Fusco et al. (2002). Specifically, methodology proposed in the present work is based on a route generation procedure specific for feeder bus network in order to design a basin of different and complementary lines; then, a genetic algorithm combines the candidate lines in order to find a sub-optimal network of feeder services.

3. Problem Formulation

The feeder bus network design is formulated as an optimization problem consisting in the minimization of all resources and costs related to the public transport system with fixed demand. The optimization problem is subject to route choice model on transit network and a set of feasibility constraints on route length and line frequency.

The optimization problem can be formally defined as follows:

$$\left(\hat{\mathbf{r}},\hat{\mathbf{f}}\right) = \arg\min\ z\left(\mathbf{r},\mathbf{f},\mathbf{q}_{\mathrm{t}}^{*}\right) \qquad (1)$$

subject to hyperpath assignment on transit network and to a set of feasibility

constraints that define both minimum and maximal values for route length and bus frequency, where the following notations have been introduced are:

- z is the objective function;
- $\mathbf{r}$ is the vector of routes;
- $\hat{\mathbf{r}}$ is the vector of optimal routes;
- $\mathbf{f}$ is the vector of lines frequencies;
- $\hat{\mathbf{f}}$ is the vector of optimal frequencies;
- $\mathbf{q}_t^*$ is the equilibrium vector of segment flows on the transit network;
- Λ is the user route choice model function;
- $\mathbf{C}_t$ is the vector of path generalized costs on the transit network.

The objective function z is defined as the sum of operator's costs z1 and users' costs z2 plus an additional penalty related to the level of unsatisfied demand z3:

$$z\left(\mathbf{r},\mathbf{f},\mathbf{q}_t^*\right) = z_1\left(\mathbf{r},\mathbf{f}\right) + z_2\left(\mathbf{r},\mathbf{f},\mathbf{q}_t^*\right) + z_3\left(\mathbf{r},\mathbf{f},\mathbf{q}_t^*\right) \qquad (2)$$

The transit users' costs are a weighted sum of in-vehicle travel time, access time, waiting time and a transfer penalty. Transit operator's costs are computed as a combination of total bus travel distance and total bus travel time. To provide transit services to as many transit users as possible, another additional component is included in the objective function z. This supplementary term represents a penalty that is proportional to the unsatisfied transit demand of the design network. The third term reflects the need to reject the banal solution of minimum cost ("zero users and zero service"). Solutions characterized by large increase of the unsatisfied transit demand are also discarded. Thus objective function formulation, similar to the one proposed by Cipriani et al. (2009) for main transit network design, is developed to properly weight "z1", "z2" and "z3" terms, in order to represent specific needs of feeder bus networks.

The input data are the public transport demand matrix, the characteristics of the road network and the rapid rail transit system, the operating and users' unit costs. Outputs are bus routes and their frequency as well as the total costs and the vector of flows on the public transport network.

4. Solution approach

The proposed solution framework consists of two main stages:

1. a heuristic route generation algorithm (HRGA) that generates a large and rational set of feasible routes, by applying different design criteria and practical rules;

2. a genetic algorithm (GA) that finds the optimal network of routes and their frequencies.

Of course, given the well-known non-convexity of the problem and the heuristic nature of the method, there is no guarantee that the solution found, indicated as $[\hat{\mathbf{r}}, \hat{\mathbf{f}}]$ in equation (1), will be optimal. In other words, the outcome of the heuristic procedure corresponds to a (known) minimum that is local respect to the (unknown) global one.

In the first phase of the solution procedure (Stage 1), a heuristic algorithm generates two different and complementary sets of rational and realistic routes (K-shortest path and TSP type routes). This provides a large set of feasible routes that are nevertheless quite diversified among them, because they are built according to typical feeder bus network design criteria. Therefore balance between effectiveness and efficiency (user or operator point of view) and maximization of service coverage in the area and improvement of integration between rail and bus networks represents the remarks which led us in choosing main elements of HRGA. The "K-shortest path" type routes are composed by many and direct short routes connecting main system stations (transfer points) with any centroids laying in our service area, in order to minimize total travel time for transit users and total operating costs for operators. The TSP-type routes come from the application of "Travelling Salesman Problem algorithm" and connect all centroids to railway or subway stations with a single path; therefore, based on such issues, TSP-type routes are less than K-shortest ones since only few complementary paths fulfil the initial goal of maximization of service coverage and demand collection in the area.

The resulting set of feasible routes is the basin from which the GA select routes to build a network (Stage 2). The design variables are transit routes and the GA is implemented in the MATLAB language while the fitness evaluation requires computing, for each solution generated, the three terms of the objective function by simulating the public transport network with the EMME software (EMME User's manual, 2008).

As the performance of the transit system depends on the service frequencies, which should be optimized depending on the passenger volumes, an iterative assignment and frequency setting procedure, first introduced by Baaj and Mahmassani (1990), is applied.

4.1 Heuristic route generation algorithm

The first component of the solution framework is the HRGA. Two complementary sets of candidate routes are generated by HRGA applying different design criteria and practical rules.

The HRGA is divided into the following five sequential steps: