1. A COMBINED TRIP DISTRIBUTION AND ASSIGNMENT MODEL FOR MULTIPLE USER CLASSES

1. LAM, WHK; HUANG, HJ
2. TRANSPORT RES B-METH

> This paper presents a combined trip distribution and assignment model with multiple user classes, in which the trip productions at origins and trip attractions at destinations for each mode are available. In this model, the entropy-type (or gravity-type) trip distribution submodel is incorporated with the user equilibrium assignment problem for multiclass-user transportation networks. The original unsymmetrical link cost functions can be converted to symmetric forms by a 'normalization' procedure, and hence an equivalent convex mathematical programming model is formulated. Two different algorithms based on the Frank-Wolfe's and Evans', respectively are developed and their computational results on test networks are reported. This model is appropriate to be used on congested and multi-modal road networks in which the link travel time is similar for all traffic.

2. Geographic information system design for network equilibrium-based travel demand models

1. Miller, HJ; Storm, JD
2. TRANSPORT RES C-EMER

> Travel demand analyses are useful for transportation planning and policy development in a study area. However, travel demand modeling faces two obstacles. First, standard practice solves the four travel components (trip generation, trip distribution, modal split and network assignment) in a sequential manner. This can result in inconsistencies and non-convergence. Second, the data required are often complex and difficult to manage. Recent advances in formal methods for network equilibrium-based travel demand modeling and computational platforms for spatial data handling can overcome these obstacles. In this paper we report on the development of a prototype geographic information system (GIS) design to support network equilibrium-based travel demand models. The GIS design has several key features, including: (i) realistic representation of the multimodal transportation network, (ii) increased likelihood of database integrity after updates, (iii) effective user interfaces, and (iv) efficient implementation of network equilibrium solution algorithms. Copyright (C) 1996 Elsevier Science Ltd

3. Bilevel programming applied to optimising urban transportation

1. Clegg, J; Smith, M; Xiang, YL; Yarrow, R
2. TRANSPORT RES B-METH

> This paper outlines a multi-modal, elastic, equilibrium transportation model in which signal green-times and prices charged to traverse a route (public transport fares, parking charges or road-use charges) are explicitly included. An algorithm is specified which, for a fairly general objective function, continually moves current traffic flows, green-times and prices within the model toward locally optimal values while taking account of users' responses. The directions of movement of current traffic flows, green-times and prices are determined by solving linear approximations to the actual problem. The results of applying a simplified form of the algorithm to a small network model with five routes and two signal-controlled junctions are given. It is proved that under realistic conditions the sequence of (traffic flows, green-times, prices) triples generated by the algorithm does indeed approach those

> triples which possess a reasonable local optimality property. However the optimal control problem discussed here is non-convex and just a Karush-Kuhn-Tucker point is the answer sought. (C) 2000 Elsevier Science Ltd. All rights reserved.

4. Multi-modal and demand-responsive passenger transport systems: a modelling framework with embedded control systems

1. Horn, MET
2. TRANSPORT RES A-POL

> The LITRES-2 modelling system provides a framework for investigating the performance of urban passenger transport systems, with particular attention to demand-responsive transport modes and. traveller information technologies. The modes covered include conventional timetabled services (buses, trains etc.), taxis (both single- and multiple-hire), and other demand-responsive services. Tables of estimated aggregate demand are disaggregated so as to produce a stream of fully-articulated travel-requests. Individual requests are resolved as single- or multiple-leg journeys, through the use of request-broking and journey-planning modules that seek to minimise travellers' generalised costs. Journey-legs allocated to demand-responsive modes are handled by a fleet-scheduling module which includes provision for instantaneous as well as advance-notice bookings, and for contingent situations such as breakdowns and passenger no-shows. The fleet-scheduling and journey-planning modules are designed as embedded control systems and are intended for use in real-time as well as modelling applications. The paper describes the main analytical and procedural components of LITRES-2, and assesses some methodological issues arising from experience in recent planning studies. The system appears to be well suited for use in modelling situations where the critical issues are concerned with the supply rather than demand side of transportation activity. Crown Copyright (C) 2001 Published by Elsevier Science Ltd. All rights reserved.

5. Network pricing optimization in multi-user and multimodal context with elastic demand

1. Bellei, G; Gentile, G; Papola, N
2. TRANSPORT RES B-METH

> Network Pricing Optimization (NPO) is formulated first as a Network Design Problem (NDP) where the design variables are tolls, the objective function is the Social Surplus and the equilibrium constraint is any current multi-user multimodal stochastic traffic assignment model with elastic demand up to trip generation and asymmetric arc cost function Jacobian. NPO is then formulated also as an Efficient Allocation Problem (EAP), where an optimal flow pattern, the System Optimum (SO), is sought and tolls are consistently determined. Necessary and sufficient conditions for the solutions to both problems are stated, showing the validity of the marginal pricing principle in the context considered. (C) 2002 Elsevier Science Ltd. All rights reserved.

6. Multimodal transit services with heterogeneous travelers

1. Lo, HK; Wan, QKH; Yip, CW
2. TRANSPORT RES REC

> Public transit systems play a pivotal role in serving the transportation needs of many major cities. In Hong Kong, for example, more than 90% of the 11 million daily trips are provided by public transit services. The planning and design of these services, therefore, are important welfare considerations.

> The situation is particularly intriguing if these services are to be provided by the private sector whose primary objective is not to ensure welfare gains or an efficient utilization of the road space but to maximize profit. Analyses are of significant interest and potential application to many transit-oriented cities. In metropolitan areas in which multi- or intermodal trips are common, modeling the multimodal route-choice characteristics of heterogeneous travelers and the strategic interactions among the many private firms are important issues. In this study, mode-choice models were integrated in a network of competing transit operators. A novel network structure, designated as the state-augmented multimodal (SAM) network, was developed via a state augmentation approach. With this SAM network, the effect of fare competition and regulations on social welfare as well as on profitability of the companies could be examined. A case study of the ground transportation system connecting the Hong Kong International Airport with the city's downtown was conducted.

7. Parking capacity and pricing in park'n ride trips: A continuous equilibrium network design problem

1. Garcia, R; Marin, A
2. ANN OPER RES

> In this paper we consider the problem of designing parking facilities for park'n ride trips. We present a new continuous equilibrium network design problem to decide the capacity and fare of these parking lots at a tactical level. We assume that the parking facilities have already been located and other topological decisions have already been taken. The modeling approach proposed is mathematical programming with equilibrium constraints. In the outer optimization problem, a central Authority evaluates the performance of the transport network for each network design decision. In the inner problem a multimodal traffic assignment with combined modes, formulated as a variational inequality problem, generates the share demand for modes of transportation, and for parking facilities as a function of the design variables of the parking lots. The objective is to make optimal parking investment and pricing decisions in order to minimize the total travel cost in a subnetwork of the multimodal transportation system. We present a new development in model formulation based on the use of generalized parking link cost as a design variable. The bilevel model is solved by a simulated annealing algorithm applied to the continuous and non-negative design decision variables. Numerical tests are reported in order to illustrate the use of the model, and the ability of the approach to solve applications of moderate size.

8. A new general equilibrium model

1. Xiang, YL; Smith, MJ; Logie, M
2. APPL OPTIMIZAT

> In this paper we present a new general equilibrium model appropriate for multi-modal networks. A solution of the model gives the equilibrium distribution of travellers and vehicles over a transportation network. The model is expressed in terms of inverse cost-flow functions; and delays are explicitly modelled. The paper outlines an equilibration algorithm and convergence results for a small network are provided. The equilibrium model has been designed in such a way that optimisation procedures may naturally be added to the equilibration algorithm.

9. Modeling transfer and non-linear fare structure in multi-modal network

1. Lo, HK; Yip, CW; Wan, KH

2. TRANSPORT RES B-METH

> In metropolitan areas where multi-modal trips are common, modeling transfers is an important issue. The existing approach of connecting multi-modal networks, without attending to the number or kinds of transfers, cannot fully describe actual behavior. In addition, the common practice of non-linear transit fare structures imposes certain modeling difficulties on the assignment approach. In this study, we develop a formulation to overcome these two difficulties, namely the number and kinds of transfers are explicitly considered and non-linear fare structures accommodated. Through a state augmentation technique, we transform a multi-modal network to one we call state-augmented multi-modal (SAM) network. Once formulated, the SAM network behaves like a simple network and can be combined with traffic assignment or network analysis procedures. A numerical example is provided to illustrate this approach.

10. An extended model and procedural framework for planning multi-modal passenger journeys

1. Horn, MET
2. TRANSPORT RES B-METH

> This paper is concerned with the planning of multiple-leg journeys using public transport services, typically (but not necessarily) in an intra-urban context. The repertoire of transport services may include walking, fixed-route public transport, and demand-responsive modes such as taxis. A journey-planning problem is defined by a request to travel at minimal generalised cost from a given origin to a given destination, subject to timing constraints. The paper presents a comprehensive cost-minimising formulation for such problems, allowing for the possibility of non-linear generalised-cost functions. An optimisation procedure is outlined for problems involving an early-departure style of travel. The new procedure is based on Dijkstra's label-setting shortest-path algorithm, and can be inverted to meet the needs of a late-arrival style of travel. An adaptation to a dilatory or sightseeing style of travel is also possible, but may be problematic with respect to computational performance.

11. Modeling competitive multi-modal transit services: a nested logit approach

1. Lo, HK; Yip, CW; Wan, QK
2. TRANSPORT RES C-EMER

> In metropolitan areas where multi-modal trips are common, modeling the combined-mode choices of travelers, and the strategic interactions between the private service operators are important issues. This study developed a novel network approach, designated as state-augmented multi-modal (SAM) network, to explicitly consider transfer behaviors and non-linear fare structures. To overcome the independence of irrelevant alternatives (IIA) assumption associated with the standard logit approach, we integrated the SAM network with the nested logit (NL) approach. Specifically, we developed a three-level NL choice model to deal with the complex and inter-related decisions in a multi-modal network: the first level focuses on combined-mode choice, the second on transfer location choice, and the third on route choice. Using this NL SAM network as a platform, we examined the effect of fare competition on company profitability as well as on overall network congestion. A case study of the ground transportation system connecting the Hong Kong International Airport to the downtown area is provided to illustrate the approach.

12. A GIS-based decision support system for planning urban transportation policies

1. Arampatzis, G; Kiranoudis, CT; Scaloubacas, P; Assimacopoulos, D
2. EUR J OPER RES

> A decision support system (DSS) integrated in a geographical information system (GIS) for the analysis and evaluation of different transport policies is presented. The objective of the tool is to assist transport administrators enhance the efficiency of the transportation supply while improving environmental and energy indicators. The DDS works on three levels. The first performs the transport network analysis, the second assesses the energy consumption and pollutant emissions and the third evaluates the several policies selected. Road traffic is simulated using a deterministic, multi-modal traffic assignment model with capacity constraints. The model allows the estimation of traffic flow patterns within each link of the road network starting from the knowledge of the network characteristics and traffic demand. Energy consumption and pollutant emission calculations are based on the methodology developed by the CORINAIR working group. The evaluation of each policy scenario is based on a number of traffic, environmental and energy indicators. A multi-criteria analysis, where decision is based upon judging over appropriate weighted criteria, is adopted. Models are integrated in a GIS environment, which serves as the repository of the data as well as the user interface of the tool. The use of the tool is demonstrated through characteristic case studies on the Greater Athens Area in Greece. Two policy measures, one concerning the extension of the region where half of the private cars are prohibited from entering to the Municipality of Athens and the other the reduction of parking places in the same region by 50% are evaluated.

13. Network equilibrium with combined modes: models and solution algorithms

1. Garcia, R; Marin, A
2. TRANSPORT RES B-METH

> In this paper we propose a new model for the equilibrium multi-modal assignment problem with combined modes (MAPCM) for the case of asymmetric costs. MAPCM is stated on a generic passenger assignment equilibrium model, on a generalized traffic assignment model, and on a nested logit distribution as demand model which explicitly takes into account the choice of mode of transport and transfer node among modal networks. This model is formulated as a variational inequality problem in the space of the hyperpath flows and then solved by the disaggregate simplicial decomposition (DSD) algorithm. Illustrations of the model and of the numerical approach are reported on two test networks with asymmetric cost functions.

14. Estimation of origin-destination matrices for a multimodal public transit network

1. Wong, KI; Wong, SC; Tong, CO; Lam, WHK; Lo, HK; Yang, H; Lo, HP
2. J ADV TRANSPORT

> This paper presents a procedure for the estimation of origin-destination (O-D) matrices for a multimodal public transit network. The system consists of a number of favored public transit modes that are obtained from a modal split process in a traditional four-step transportation model. The demand of each favored mode is assigned to the multimodal network, which is comprised of a set of connected links of different public transit modes. An entropy maximization procedure is proposed to simultaneously estimate the O-D demand matrices of all favored modes, which are consistent with target data sets such as the boarding counts and line segment flows that are observed directly in the

> network. A case study of the Hong Kong multimodal transit network is used to demonstrate the effectiveness of the proposed methodology.

15. Implementation and estimation of a combined model of interregional, multimodal commodity shipments and transportation network flows

1. Ham, H; Kim, TJ; Boyce, D
2. TRANSPORT RES B-METH

> A combined model of interregional, multimodal commodity shipments, incorporating regional input-output relationships, and the associated transportation network flows is formulated as an alternative to the traditional four-step travel forecasting procedure of trip generation, distribution, mode choice, and assignment. The paper describes the formulation of the model, its solution using US interregional commodity shipment data, estimation of key parameters, and evaluation of the performance of the model with the observed data. The model was implemented to predict interregional commodity shipments by roads and railways among regions of the US when these networks were disrupted by earthquakes or other natural events.

16. Network modeling approach to transit network design

1. Duff-Riddell, WR; Bester, CJ
2. J URBAN PLAN DEV

> Using the Emme/2 Winnipeg demonstration data bank as an example, a practical method is described for developing and defining a multimodal transit network by using standard transport network modeling software. This method. the stand-alone first phase of a three-phase transit-system design process, makes use of conventional, auto assignment techniques. The optimum transit network is found by including demand penalties as a component of the generalized cost of travel on each link.

17. Passenger route guidance system for multi-modal transit networks

1. Lo, HK; Yip, CW; Mak, B
2. J ADV TRANSPORT

> In many public transport oriented cities in the world, especially Asian cities, the public transport system has been developed extensively, to the extent that it has become increasingly difficult to navigate. Although inter-modal transfers are common and often necessary, a complete set of the routes across transport modes is generally not presented in a form that is accessible to travelers, as each operator would only publish its own routes. Moreover, the common nonlinear fare tables together with inter-modal fare discounts pose challenges to travelers in deciding their best routes. This study develops a multi-modal passenger route guidance system, called eFinder, to aid travelers with their combined mode-route choices. We discuss the architecture and features of this system in this study. This system forms a platform for disseminating public transit information and should complement further development and use of the public transport network by enabling travelers to make informed choices.

18. Advanced pricing and rationing policies for large scale multimodal networks

1. Gentile, G; Papola, N; Persia, L
2. TRANSPORT RES A-POL

> The applying of simplified schemes, such as cordon pricing, as second-best solution to the toll network design problem is investigated here in the context of multiclass traffic assignment on multimodal networks. To this end a suitable equilibrium model has been developed, together with an efficient algorithm capable of simulating large scale networks in quite reasonable computer time. This model implements the theoretical framework proposed in a previous work on the toll optimization problem, where the validity of marginal cost pricing for the context at hand is stated. Application of the model to the real case of Rome shows us, not only that on multimodal networks a relevant share (up to 20%) of the maximum improvements in terms of social welfare achievable with marginal cost pricing can in fact be obtained through cordon pricing, but also that in practical terms rationing is a valid alternative to pricing, thus getting around some of the relevant questions (theoretical, technical, social) the latter raises. As a result we propose a practical method to analyze advanced pricing and rationing policies differentiated for user categories, which enables us to compare alternative operative solutions with an upper bound on social welfare based on a solid theoretical background.

19. MULTI-LAYER NETWORK APPROACH FOR MODELING GENERAL COMBINED-MODE TRIPS

1. Wu, Z. X.; Ye, H. S.; Sun, M.; Lam, William H. K.
2. nan

> This paper describes a multi-layer approach for modeling general combined-mode trips. The model formulation is based on an extended network framework. termed a multi-layer network. Two major problems arising from the specification of a multi-modal network equilibrium model are addressed, i.e. route (or path) enumeration and travel choice in a network with multiple transport modes. It is shown that the multi-layer network approach can facilitate the generation of feasible routes in a multi-modal setting. A feasible route in the multi-layer network is characterized by a combined mode, which indicates the feature of the used modes or mode combinations along the route. All feasible routes between each origin-destination (OD) pair are grouped, according to the combined modes of routes, into four subsets: auto, transit, auto-transit, and pure walking. The travel choice model is given by a nested logit model where the upper level is focused on combined-mode choice while the lower level on route choice. The multi-modal network equilibrium problem is mathematically formulated as a variational inequality (VI) problem. In addition, interactions among various motorized modes sharing the same road space, as well as nonlinear transit fare structures are taken into account in the multi-modal network equilibrium problem.

20. A demand model with departure time choice for within-day dynamic traffic assignment

1. Bellei, Giuseppe; Gentile, Guido; Meschini, Lorenzo; Papola, Natale
2. EUR J OPER RES

> A within-clay dynamic demand model is formulated, embodying, in addition to the classic generation, distribution and modal split stages, an actual demand model taking into account departure time choice. The work focuses on this last stage, represented through an extension of the discrete choice framework to a continuous choice set. The dynamic multimodal supply and equilibrium model based on implicit path enumeration, which have been developed in previous work are outlined here, to define within-day dynamic elastic demand stochastic multimodal equilibrium as a fixed point problem on users flows and transit line frequencies. A MSA algorithm capable, in the case of Logit route choice models, of supplying equilibrium flows and frequencies on real dimension networks, is presented, as

> well as the specific procedures implementing the departure time choice and actual demand models. Finally, the results obtained on a test network are presented and conclusions are drawn. (c) 2005 Elsevier B.V. All rights reserved.

21. A study on network design problems for multi-modal networks by probit-based stochastic user equilibrium

1. Uchida, Kenetsu; Sumalee, Agachai; Watling, David; Connors, Richard
2. NETW SPAT ECON

> This paper develops a multi-modal transport network model considering various travel modes including railway, bus, auto, and walking. Travellers are assumed to choose their multi-modal routes so as to minimise their perceived disutilities of travel following the Probit Stochastic User Equilibrium (SUE) condition. Factors influencing the disutility of a multi-modal route include actual travel times, discomfort on transit systems, expected waiting times, fares, and constants specific to transport modes. The paper then deals with the multi-modal network design problem (NDP). The paper employs the method of sensitivity analysis to define linear approximation functions between the Probit SUE link flows and the design parameters, which are then used as constraints in the sub-problem of the NDP instead of the original SUE condition. Based on this reformulated NDP, an efficient algorithm for solving the problem is proposed in the paper. Two instances of this general NDP formulation are then presented in the paper: the optimal frequency design problem for public transport services (FDP), and the anti-freezing admixture dispersion problem (AADP).

22. Congestion pricing for multi-modal transportation systems

1. Hamdouch, Younes; Florian, Michael; Hearn, Donald W.; Lawphongpanich, Siriphong
2. TRANSPORT RES B-METH

> In this paper, we extend the toll pricing framework previously developed for vehicular traffic networks to ones with the potential to include many modes of transportation such as walking, driving, and using public conveyance (e.g., buses, subways, and trains). To determine tolls, we construct a user equilibrium and system optimal model. In both models, we assume that users adopt strategies or hyperpaths to travel between each origin-destination pair and the demand between each pair is fixed. However, the choice between driving and using public transportation is determined by a binomial logit function. As in the case of vehicular traffic networks, the set of valid tolls can be obtained from the solution to the system problem and the equilibrium conditions for the user problem. Then, secondary objective functions similar to those for traffic networks can be used to select a toll vector for, e.g., implementation. We provide a numerical example to illustrate our approach. (c) 2006 Elsevier Ltd. All rights reserved.

23. Application of constrained enumeration approach to Multimodal choice set generation

1. Hoogendoorn-Lanser, Sascha; Bovy, Piet; van Nes, Rob
2. TRANSPORT RES REC

> Collected data often include only information about chosen routes. To gain insight into travelers' route choice behavior or to predict route shares, one must know the set of alternatives from which travelers have chosen their routes. An alternative approach to choice set generation in mixed multimodal networks is presented. This new algorithm-a run-based, constrained enumeration method that uses

> branch-and-bound techniques-is suitable for both estimation and prediction. One key characteristic of the algorithm is a set of constraints that reflects observed travel behavior. The proposed algorithm for choice set generation can be applied to a complete multimodal network at once. However, by exploiting knowledge about the structure of multimodal trips, the separate application of the algorithm to partial networks and consecutive concatenation of subroutes into complete door-to-door routes substantially reduce computation times without resulting in incomplete choice sets. This algorithm for choice set generation has been calibrated for and successfully applied to a real-size, mixed multimodal transport network in the Netherlands. A comparison of generated choice sets with reported chosen and known alternatives indicated that the algorithm can generate these alternatives, with high coverage levels as a result. This result clearly indicates that this constrained enumeration approach meets the requirements for choice set generation and thus offers interesting perspectives for route choice analysis and the prediction of route shares. Furthermore, the separate application of the algorithm to partial networks and the consecutive concatenation of subroutes into complete door-to-door trips substantially do not result in incomplete choice sets.

24. Transit competitiveness in polycentric metropolitan regions

1. Casello, Jeffrey M.
2. TRANSPORT RES A-POL

> This paper analyzes the potential to, and impacts of, increasing transit modal split in a polycentric metropolitan area the Philadelphia, Pennsylvania region. Potential transit riders are preselected as those travelers whose trips begin and end in areas with transit-supportive land uses, defined as activity centers, areas of high-density employment and trip attraction. A multimodal traffic assignment model is developed and solved to quantify the generalized cost of travel by transit services and private automobile under (user) equilibrium conditions. The model predicts transit modal split by identifying the origin-destination pairs for which transit offers lower generalized cost. For those origin-destination pairs for which transit does not offer the lowest generalized cost, I compute a transit competitiveness measure, the ratio of transit generalized cost to auto generalized cost. The model is first formulated and solved for existing transit service and regional pricing schemes. Next, various transit incentives (travel time or fare reductions, increased service) and auto disincentives (higher out of pocket expenses) are proposed and their impacts on individual travel choices and system performance are quantified. The results suggest that a coordinated policy of improved transit service and some auto disincentives is necessary to achieve greater modal split and improved system efficiency in the region. Further, the research finds that two levels of coordinated transit service, between and within activity centers, are necessary to realize the greatest improvements in system performance.

25. Modeling park-and-ride services in a multimodal transport network with elastic demand

1. Li, Zhi-Chun; Lam, William H. K.; Wong, S. C.; Zhu, Dao-Ll; Huang, Hai-Jun
2. TRANSPORT RES REC

> With the rapid development of metro systems in large Asian cities, such as Hong Kong and Shanghai, China, local authorities are developing park-and-ride (P&R) schemes to encourage commuters to reach the cities' central areas by transferring from private cars to metro at stations with P&R facilities. A network equilibrium formulation can be used to model P&R services in a multimodal transportation network with elastic demand. It is assumed that commuters can complete their journeys by three

> options: auto mode, walk-metro mode, and P&R mode. The proposed model simultaneously considered commuters' travel choices on travel mode, route-path, and transfer point, as well as their parking choice behavior. The effects of elastic travel demand, together with passengers' discomfort in metro vehicles, were explicitly incorporated. The resultant problem can be formulated as an equivalent variational inequality problem. Numerical results showed that the introduction of P&R schemes could bring a positive, neutral, or even negative social welfare increment, and its efficiency depends greatly on. the parking charging level and the number of parking spaces supplied at. the P&R site and in the urban central area, as well as the metro dispatching frequency and fare.

26. A multiclass simultaneous transportation equilibrium model

1. Hasan, Mohamad K.; Dashti, Hussain M.
2. NETW SPAT ECON

> Single class travel forecasting models assume that all travelers are similar in their travel-decision characteristics, such as their money-value of the time and their sensitivity to travel times in choosing their origin, destination and mode of travel, etc. To obtain more realistic models, travelers are often divided into classes, either by socio-economic attributes (e.g., income level, car availability, etc.) or by the purpose (e.g., home-based-work, non-home-based-work, home-based-shopping, etc.) of their travel, assuming that travel-decision characteristics are the same within each class, but differ among classes. However, the development of this concept of multiple classes increases the mathematical complexity of travel forecasting models. All the existing multiclass combined models consider the trip generation step of transportation planning process is exogenous to the combined prediction process. In this paper we enhance the Simultaneous Transportation Equilibrium Model (STEM) that developed by Safwat and Magnanti in 1988, and explicitly combined trip generation step, to be a multiclass model in terms of socio-economic group, trip purpose, pure and combined transportation modes, as well as departure time, all interacting over a physically unique multimodal network. The developed Multiclass Simultaneous Transportation Equilibrium Model (MSTEM) is formulated as a Variational Inequality problem and a diagonalization algorithm is proposed to solve it.

27. A Simulation-Based Dynamic Intermodal Network Equilibrium Algorithm

1. Chang, Elaine; Ziliaskopoulos, Athanasios
2. nan

> This paper introduces a Variational Inequality (VI) formulation for the time-dependent combined mode split and traffic assignment problem. Travel costs are represented by generalized cost functions and mode choices are deterministically obtained based on assignment to intermodal least cost paths without accounting for possible randomness in travelers' choices. The intermodal user equilibrium (IUE) is estimated using an inner approximation (IA) algorithm that results in a nonlinear program with linear constraints. The algorithm converges assuming continuous and monotonic path travel cost functions. The paths on multimodal networks are computed with an intermodal optimum path algorithm; a cell transmission-based simulator, enhanced to account for both automobile and transit vehicles, is used to estimate the path travel costs. A heuristic search approach is proposed and implemented in the VISTA simulation-based framework. Computational results are presented on example networks to test convergence and equilibrium.

28. Multimodal, multiclass stochastic dynamic traffic assignment for evaluating information provision strategies

1. Lee, Seungiae
2. J ADV TRANSPORT

A multimodal, multiclass stochastic dynamic traffic assignment model was developed to evaluate pre-trip and enroute travel information provision strategies. Three different information strategies were examined: user optimum [UO], system optimum [SO] and mixed optimum [MO]. These information provision strategies were analyzed based on the levels of traffic congestion and market penetration rate for the information equipment. Only two modes, bus and car, were used for evaluating and calculating the modal split ratio. Several scenarios were analyzed using day-to-day and within day dynamic models. From the results analyzed, it was found that when a traffic manager provides information for drivers using the UO strategy and drivers follow the provided information absolutely, the total travel time may increases over the case with no information. Such worsening occurs when drivers switch their routes and face traffic congestion on the alternative route. This phenomenon is the 'Braess Paradox'.

29. Dynamic micro-assignment modeling approach for integrated multimodal urban corridor management

1. Zhou, Xuesong; Mahmassani, Hani S.; Zhang, Kuilin
2. TRANSPORT RES C-EMER

Development and analysis of demand management strategies for integrated multimodal urban corridor management requires application of a new generation of demand modeling and network analysis tools. This paper describes the development of a dynamic trip micro-assignment and (meso) simulation system that incorporates individual tripmaker choices of travel mode, departure time and route in multimodal urban transportation networks (with different travel modes such as drive alone, shared ride, bus rapid transit and metro rail). These travel choice dimensions arc integrated in a stochastic utility maximization framework that considers multiple user decision criteria such as travel time, travel cost, schedule delay, as well as travel time reliability. A variational inequality model is first proposed to describe the general stochastic dynamic traffic user equilibrium problem. For a typical case that assumes the logit-based alternative choice model, this paper develops an equivalent gap function-based optimization formulation and a heuristic iterative solution procedure. Based on a multidimensional network representation, an efficient time-dependent least cost path algorithm is embedded to generate an intermodal route choice set that recognizes time-dependent mode transfer costs and feasible mode transfer sequences. A two-stage estimation procedure that can systematically utilize historical static demand information, time-dependent link counts, as well as empirically calibrated stochastic departure time choice models is proposed to infer commuters' preferred arrival time distribution, which is important in modeling departure time choice dynamics. A case study based on a large-scale multimodal transportation network (adapted from the Baltimore-Washington corridor) is presented to illustrate the capabilities of the methodology and provide insight into the potential benefit of integrated multimodal corridor management. (C) 2007 Published by Elsevier Ltd.

30. Integrated Analysis of Toll Lanes and Bus Priority Lanes

1. Kim, Dongwook; Schonfeld, Paul

2. TRANSPORT RES REC

> Although toll lanes may generate net benefits, their political acceptability is problematic, especially for vertical equity among income classes. A strategy is presented for gaining acceptability for a toll lane in a congested corridor through a lane allocation approach, which integrates toll and bus lanes along the corridor. A bimodal equilibrium concept is illustrated for the lane allocation scheme for bus and toll lanes. A travel demand model is designed to determine traveler reactions to such lane allocation. With link cost functions specialized by several link groups, the demand model uses the multiclass, multicriteria network equilibrium model in the multimodal network with elastic demand. To address simultaneously the political and economic issues arising from toll and bus lanes in a network, a multiobjective decision-making model supports the lane allocation model. An equity measure based on travel time variations among user groups is incorporated in the decision model and an internal toll-funding scheme is developed to consider revenue allocation. The toll funding can increase available financial resources and may serve most users whose travel is affected by the toll lane. An example analysis indicates that an effective integration strategy of toll and bus lanes and a toll-funding scheme can enhance public acceptability of toll lanes and produces synergistic benefits.

31. Markovian traffic equilibrium

1. Baillon, J. -B.; Cominetti, R.
2. MATH PROGRAM

> We analyze an equilibrium model for traffic networks based on stochastic dynamic programming. In this model passengers move towards their destinations by a sequential process of arc selection based on a discrete choice model at every intermediate node in their trip. Route selection is the outcome of this sequential process while network flows correspond to the invariant measures of the underlying Markov chains. The approach may handle different discrete choice models at every node, including the possibility of mixing deterministic and stochastic distribution rules. It can also be used over a multi-modal network in order to model the simultaneous selection of mode and route, as well as to treat the case of elastic demands. We establish the existence of a unique equilibrium, which is characterized as the solution of an unconstrained strictly convex minimization problem of low dimension. We report some numerical experiences comparing the performance of the method of successive averages (MSA) and Newton's method on one small and one large network, providing a formal convergence proof for MSA.

32. COMBINED MODAL SPLIT AND ASSIGNMENT MODEL FOR THE MULTIMODAL TRANSPORTATION NETWORK OF THE ECONOMIC CIRCLE IN CHINA

1. Li, Shuang; Deng, Wei; Lv, Yisheng
2. TRANSPORT-VILNIUS

> Economic circles have been formed and developing in China. An economic circle consists of more than one closely adjoining central cities and their influence zones. It is always the major engine for the development of one country's economy and even for the world economy. A combined modal split and assignment model with deterministic travel demand is proposed for modelling passengers' choices of intercity bus and train which are two main competing modes in the multimodal transportation network of the economic circle. The generalized travel cost model of highway and railway are used incorporating travel time, ticket fare and passenger's discomfort. On the highway network, the

> interactions of private vehicles and intercity buses are asymmetric. Thus, a variational inequality formulation is proposed to describe the combined model. The streamlined diagonalization algorithm is presented to solve the combined model. The multimodal transportation network based on Yangtze River Delta economic circle is presented to illustrate the proposed method. The results show the efficiency of the proposed model.

33. Multimodal Mesoscopic Approach in Modeling Pedestrian Evacuation

1. Di Gangi, Massimo; Velona, Pietro
2. TRANSPORT RES REC

> A recently funded research project in Italy concerned reduction In risk exposure in urban areas through the definition and the implementation of evacuation procedures. One of the research aims was to specify and calibrate a system of models that could simulate the transportation system when a population must evacuate because of approaching disaster. Various activities were conducted to calibrate a set of cost functions to be implemented within a dynamic network loading procedure to simulate pedestrian outflow related to the evacuation of a building. How flow models are calibrated on the basis of data collected during experimentation at a test site is shown, and the results of their implementation within a multimodal dynamic loading model used to simulate evacuation procedures are described. A comparison between experimental data and simulation results shows that the use of appropriate simulation models can realistically reproduce user behavior and then shows how such models can be used as a support for creating effective evacuation plans. The experimentation involved evacuation of a primary school in an Italian town, but the method applied can be adapted easily to any public building with homogenous characteristics.

34. Multi-class Multi-modal Network Equilibrium with Regular Choice Behaviors: A General Fixed Point Approach

1. Xu, Meng; Gao, Ziyou
2. nan

> In this paper, we propose a new model for the multi-class multi-modal network equilibrium problem, which is a route utility based model, and transfer flows for combined modes are considered specially. The model is formulated as a general fixed point problem. The choice behaviors are assumed regular, which include the common features of deterministic and of continuous with continuous first derivatives additive probabilistic choice models. Users of different classes permit different choice behaviors (including routes, modes, and interchanges), as well as different sets of available routes, modes, and interchanges. Different choice models are explicitly considered; in addition, travel demand of the network can be dealt without using its inverse-unlike the mathematical programming, variational inequality, or complementarity formulations. Existence and uniqueness of the model are analyzed, which extend those conclusions in existed literature.

35. Optimization of a Bus and Rail Transit System with Feeder Bus Services under Different Market Regimes

1. Li, Zhi-Chun; Lam, William H. K.; Wong, S. C.
2. nan

This paper proposes analytical models for optimizing a bus and rail transit system with feeder bus services under different market regimes. The market regimes concerned include: monopoly (with profit maximization), social optimum (with social welfare maximization), and oligopoly. In the proposed models, transit operator aims to optimize the frequencies and fares of the bus, rail and feeder bus services, while accounting for the responses from transit passengers (in terms of travel mode choice as well as demand elasticity) to the level of transit services and fares. A solution algorithm is developed to solve the proposed models. Numerical results show that a single implementation of the feeder bus service scheme may not be most cost-effective. A joint implementation of the feeder bus service scheme and other schemes, such as transfer coordination between transit modes and integrated fare scheme, can significantly improve the performance of the multimodal transit system in terms of total social welfare.

36. An activity-based approach for scheduling multimodal transit services

1. Li, Zhi-Chun; Lam, William H. K.; Wong, S. C.; Sumalee, A.
2. TRANSPORTATION

This paper proposes a new activity-based transit assignment model for investigating the scheduling (or timetabling) problem of transit services in multi-modal transit networks. The proposed model can be used to generate the short-term and long-term timetables of multimodal transit lines for transit operations and service planning purposes. The interaction between transit timetables and passenger activity-travel scheduling behaviors is captured by the proposed model, as the activity and travel choices of transit passengers are considered explicitly in terms of departure time choice, activity/trip chain choices, activity duration choice, transit line and mode choices. A heuristic solution algorithm which combines the Hooke-Jeeves method and an iterative supply-demand equilibrium approach is developed to solve the proposed model. Two numerical examples are presented to illustrate the differences between the activity-based approach and the traditional trip-based method, together with comparison on the effects of optimal timetables with even and uneven headways. It is shown that the passenger travel scheduling pattern derived from the activity-based approach is significantly different from that obtained by the trip-based method, and that a demand-sensitive (with uneven headway) timetable is more efficient than an even-headway timetable.

37. Multiobjective Optimization for Multimodal Evacuation

1. Abdelgawad, Hossam; Abdulhai, Baher; Wahba, Mohamed
2. TRANSPORT RES REC

This paper proposes a multimodal optimization framework that combines vehicular traffic and mass transit for emergency evacuation. The multiobjective approach optimizes the multimodal evacuation framework by investigating three objectives: minimizing in-vehicle travel time, minimizing at-origiin waiting time, and minimizing fleet cost in the case of mass transit evacuation. For auto evacuees, an optimal spatiotemporal evacuation (OSTE) formulation is presented for generating optimal demand scheduling, destination choice, and route choice simultaneously. OSTE implements dynamic traffic assignment techniques coupled with genetic optimization to achieve the objective functions. For transit vehicles, a multiple-depot, time-constrained, pickup and delivery vehicle routing problem (MDTCPD-VRP) is formulated to model the use of public transit shuttle buses during evacuation. MDTCPD-VRP implements constraint programming and local search techniques to achieve the objective function and satisfy constraints. The OSTE and MDTCPD-VRP platforms are integrated in one framework to replicate

> the impact of congestion caused by traffic on transit vehicle travel times. This paper presents a prototype implementation of the conceptual framework for a hypothetical medium-size network in downtown Toronto, Ontario, Canada. The results show that including the waiting time and the in-vehicle travel time in the objective function reduced the network clearance time for auto-evacuees by 40% compared with including only the in-vehicle travel time. For mass transit, when considering fleet cost, an increase of 13% in network clearance time for transit evacuees was observed with a decrease of 12% in fleet size. Mass transit was shown to provide latent transportation capacity that is needed in evacuation situations.

38. Comparison of Agent-Based Transit Assignment Procedure with Conventional Approaches Toronto, Canada, Transit Network and Microsimulation Learning-Based Approach to Transit Assignment

1. Wang, Joshua; Wahba, Mohamed; Miller, Eric J.
2. TRANSP RES RECORD

> The public transportation system, a key part of a multimodal transportation network, has been widely viewed as an efficient way to reduce road congestion and pollution. Public transportation planners use transit assignment models to forecast travel demand and service performance. As technologies evolve and smart transit systems become more prevalent, it is important that assignment models adapt to new policies, such as traveler information provision. This paper investigates three transit assignment tools that represent three approaches to modeling transit trip distribution over a network of fixed routes. These tools are the EMME/2 Transit Assignment Module (Module 535), commonly used by planners; Toronto, Canada, Transit Commission's transit assignment tool, MADITUC; and the newly developed Microsimulation Learning-based Approach to Transit Assignment (MILATRAS). These approaches range from aggregate, strategy-based frameworks to fully disaggregate microscopic platforms. MILATRAS presents a stochastic process approach (i.e., nonequilibrium based) for modeling within-day and day-to-day variations in the transit assignment process in which aggregate travel patterns can be extracted from individual choices. Although MILATRAS presents a different standpoint for analysis in comparison with equilibrium-based models, it still gives the steady state run loads. MILATRAS performs comparatively well with EMME/2 and MADITUC. In addition, MILATRAS presents a policy-sensitive platform for modeling the effects of smart transit system policies and technologies on passengers' travel behavior (i.e., trip choices) and transit service performance.

39. Congestion Pricing for Schedule-Based Transit Networks

1. Hamdouch, Younes; Lawphongpanich, Siriphong
2. TRANSPORT SCI

> In this paper, we develop models for adjusting or setting fares on a transit system to encourage passengers to choose travel strategies that lead to the least travel delay for the entire system. In our problem setting, these fares vary with time of day. Similar to the one used to reduce congestion on vehicular traffic networks, our goal is to adjust or set fares so that a user equilibrium solution under the new fares yields the least delay or is system optimal. On the other hand, pricing frameworks for traffic networks such as marginal cost pricing do not readily apply because the travel delay in transit systems involves factors different from those in vehicular traffic and cannot be expressed in closed functional forms. The models herein are schedule based and account for loading priorities and individual vehicle capacities explicitly. Differences among the proposed models are illustrated with a small network.

40. Pareto-improving congestion pricing on multimodal transportation networks

1. Wu, Di; Yin, Yafeng; Lawphongpanich, Siriphong
2. EUR J OPER RES

> This paper determines a Pareto-improving pricing scheme for alleviating congestion in a multimodal transportation network that includes, e.g., transit services, high-occupancy/toll and general-purpose lanes. In this setting, a pricing scheme refers to a strategy for tolling roads and highways as well as adjusting fares on various transit lines. In addition, such a scheme is Pareto-improving if it maximizes the social benefit without increasing travel-related expense of stakeholders that include individual road users, transit passengers, transit operators, transportation authorities, etc. The user equilibrium and system optimum problem in the multimodal transportation network are discussed along with a model for determining Pareto-improving tolls. The latter is formulated as a mathematical program with complementarity constraints. Two numerical examples are presented to illustrate results from various models.

41. Modeling Evacuation of a Transport System: Application of a Multimodal Mesoscopic Dynamic Traffic Assignment Model

1. Di Gangi, Massimo
2. IEEE T INTELL TRANSP

> In this paper, the analysis of a transportation system under emergency conditions due to hazardous events is considered. To assess the effects on the analyzed transport network, an extension to a mesoscopic dynamic traffic assignment (DTA) model was developed to determine quantitative indicators for estimating the exposure component of the total risk incurred by the transport networks in an area. In particular, a new version that is able to allow for multimodal networks and to consider network reliability was introduced. To give a practical example of the proposed model, it has been applied to two real networks, studying evacuation in the hypothesis that in the event of a calamity the population in the area follows the instructions proposed by the municipal civil protection plan. The work shows how adequate quantitative methodologies based on a dynamic approach can be a useful tool to support the process of evacuation planning at several scales.

42. Large-scale application of MILATRAS: case study of the Toronto transit network

1. Wahba, Mohamed; Shalaby, Amer
2. TRANSPORTATION

> This paper documents the efforts to operationalize the conceptual framework of MIcrosimulation Learning-based Approach to TRansit Assignment (MILATRAS) and its component models of departure time and path choices. It presents a large-scale real-world application, namely the multi-modal transit network of Toronto which is operated by the Toronto Transit Commission (TTC). This large-scale network is represented by over 500 branches with more than 10,000 stops. About 332,000 passenger-agents are modelled to represent the demand for the TTC in the AM peak period. A learning-based departure time and path choice model was adopted using the concept of mental models for the modelling of the transit assignment problem. The choice model parameters were calibrated such that the entropy of the simulated route loads was optimized with reference to the observed route loads, and validated with individual choices. A Parallel Genetic Algorithm engine was used for the parameter calibration process. The modelled route loads, based on the calibrated parameters, greatly

> approximate the distribution underlying the observed loads. 75% of the exact sequence of transfer point choices were correctly predicted by the off-stop/on-stop choice mechanism. The model predictability of the exact sequence of route transfers was about 60%. In this application, transit passengers were assumed to plan their transit trip based on their experience with the transportation network; with no prior (or perfect) knowledge of service performance.

43. Select Zone Analysis for Traffic Impact Studies

1. Mamun, Md. Shahid; Xu, Hongli; Yin, Yafeng
2. TRANSPORT RES REC

> Select zone analysis examines the spatial impacts of a new development and requires knowledge of the distribution of path flows or of the distribution of origin destination (O-D) specific link flows. Because these two flow distributions may not be uniquely determined from assignment of deterministic user equilibriums, the choice of a particular flow distribution as the basis for select zone analysis remains an open question. This paper both suggests the use of the mean of all the solutions for path or O-D specific user equilibriums as that basis and proves its stability. A sampling procedure is proposed to estimate the basis. Numerical examples are provided to demonstrate the proposed concept and compare it with the entropy maximization approach.

44. Stochastic multi-modal transport network under demand uncertainties and adverse weather condition

1. Sumalee, Agachai; Uchida, Kenetsu; Lam, William H. K.
2. TRANSPORT RES C-EMER

> This paper proposes a multi-modal transport network assignment model considering uncertainties in both demand and supply sides of the network. These uncertainties are due to adverse weather conditions with different degrees of impacts on different modes. The paper provides the derivations of mean and variance-covariance of the stochastic passenger flows and dis-utility terms involved in the route/mode choice model under the common-line framework. The risk-averse travelers are assumed to consider both the mean and variance of the random perceived travel time on each multi-modal path in their path choice decisions. The model also considers travelers' perception errors by using a Probit stochastic user equilibrium framework which is formulated as fixed point problem. A heuristic solution algorithm is proposed to solve the fixed point problem. Numerical examples are presented to illustrate the applications of the proposed model.

45. MODELING SPATIAL EQUILIBRIUM TRAVEL PATTERN WITH MULTIMODAL CHOICES - A LINEAR COMPLEMENTARITY SYSTEM APPROACH

1. Wang, David Z. W.
2. nan

> This paper studies the modeling of spatial equilibrium travel pattern with multimodal choices in a model city with a competitive railway/highway system. Commuters choose either the railway or highway for traveling from their home to city center. Flow dependent travel time on highway and crowding cost of rail transit services are considered. A linear complementarity system is proposed to characterize the commuters' modal choices and spatial equilibrium pattern of trip assignment in the

> city with given continuous distribution of home locations. The formulated linear complementarity problem is recast into a mixed integer linear programming problem to be solved.

46. Impact analysis of cordon-based congestion pricing on mode-split for a bimodal transportation network

1. Meng, Qiang; Liu, Zhiyuan
2. TRANSPORT RES C-EMER

> This paper investigates the impact of cordon-based congestion pricing scheme on the mode-split of a bimodal transportation network with auto and rail travel modes. For any given toll-charge pattern, its impact on the mode-split can be estimated by solving a combined mode-split and traffic-assignment problem. Using a binary logit model for the mode-split, the combined problem is converted into a traffic-assignment problem with elastic demand. Probit-based stochastic user equilibrium (SUE) principle is adopted for this traffic-assignment problem, and a continuously distributed value of time (VOT) is assumed to convert the toll charges and transit fares into time-units. This combined mode-split and traffic-assignment problem is then formulated as a fixed-point model, which can be solved by a convergent Cost Averaging method. The combined mode-split and traffic-assignment problem is then used to analyze a multimodal toll design problem for cordon-based congestion pricing scheme, with the aim of increasing the mode-share of public transport system to a targeted level. Taking the fixed-point model as a constraint, the multimodal toll design problem is thus formulated as a mathematical programming with equilibrium constraints (MPEC) model. A genetic algorithm (GA) is employed to solve this MPEC model, which is then numerical validated by a network example.

47. Hierarchical network-based equilibrium model and algorithm for a mixed-traffic urban transport system

1. Si, Bingfeng; Zhong, Ming; Gao, Liang; Gao, Ziyou
2. TRANSPORT PLAN TECHN

> Many equilibrium models and algorithms based on homogeneous motorized traffic have been devised to model urban transport systems in developed countries, but they are inadequate when it comes to represent mixed-traffic urban transport systems, including automobiles, transit, bicycles, and pedestrians, in developing countries such as China or India. In these cases, traffic flow on a road segment is an aggregated result of travellers' combined mode/route choices and corresponding interactions. Therefore, a special assignment model and algorithm are needed for modeling these distinct behaviors. In this article, the structure of a mixed-traffic urban transport system is analyzed and then expanded and represented using a hierarchical network model based on graph theory. Based on the analysis of travelers' combined mode/route choices, generalized travel cost functions and link impedance functions for different modes are formulated, where the interferences between different modes on the same road segments are taken into account. Due to the 'asymmetric' nature of these functions, a variational inequality model is proposed to represent the equilibrium assignment problem in a mixed-traffic urban transport system. The corresponding solution algorithm is also presented. Finally, a numerical example is provided to illustrate the practicality of the proposed model and algorithm.

48. Welfare Effects of Congestion Pricing and Transit Services in Multiclass Multimodal Networks

1. Liu, Yang; Nie, Yu (Marco)
2. TRANSPORT RES REC

> This paper analyzes the welfare effects of congestion pricing with the use of a general bimodal network with heterogeneous users. Transit service is modeled as a cheaper (because of its lower operating cost) and undesirable (because of the relatively long travel time) alternative to the highway network and is added to an origin destination pair as an exclusive link. The analysis characterizes the critical users those who suffer the greatest loss from pricing as those who experience the least change in travel time after pricing. Accordingly, the paper shows that critical users could be rich, poor, or middle class, depending on their origin and destination. This finding highlights the spatial heterogeneity of distributional effects. Furthermore, numerical experiments indicate that (a) those with a low value of time tend to benefit more from greater coverage of transit services than those with intermediate values of time; (b) in the presence of poor transit coverage, users with access to transit may share a disproportionally greater burden for the congestion relief generated by an optimum toll for the system; and (c) the optimum toll for the system generally leads to a welfare gap between the rich and the poor larger than those of toll schemes that have proportionally lower magnitudes and achieve smaller efficiency improvements.

49. Intermodal Path Algorithm for Time-Dependent Auto Network and Scheduled Transit Service

1. Khani, Alireza; Lee, Sanggu; Hickman, Mark; Noh, Hyunsoo; Nassir, Neema
2. TRANSPORT RES REC

> A simple but efficient algorithm is proposed for finding the optimal path in an intermodal urban transportation network. The network is a general transportation network with multiple modes (auto, bus, rail, walk, etc.) divided into the two major categories of private and public, with proper transfer constraints. The goal was to find the optimal path according to the generalized cost, including private-side travel cost, public-side travel cost, and transfer cost. A detailed network model of transfers between modes was used to improve the accounting of travel times during these transfers. The intermodal path algorithm was a sequential application of specific cases of transit and auto shortest paths and resulted in the optimal intermodal path, with the optimal park-and-ride location for transferring from private to public modes. The computational complexity of the algorithm was shown to be a significant improvement over existing algorithms. The algorithm was applied to a real network within a dynamic traffic and transit assignment procedure and integrated with a sequential activity choice model.

50. Hyperpaths in Network Based on Transit Schedules

1. Noh, Hyunsoo; Hickman, Mark; Khani, Alireza
2. TRANSPORT RES REC

> The concept of a hyperpath was introduced for handling passenger strategies in route choice behavior for public transit, especially in a frequency-based transit service environment. This model for handling route choice behavior has been widely used for planning transit services, and hyperpaths are now applied in areas beyond public transit. A hyperpath representing more specific passenger behaviors on

> a network based on transit schedules is proposed. A link-based time-expanded (LBTE) network for transit schedules is introduced; in the network each link represents a scheduled vehicle trip (or trip segment) with departure time and travel time (or arrival time) between two consecutive stops. The proposed LBTE network reduces the effort to build a network based on transit schedules because the network is expanded with scheduled links. A link-based representation of a hypergraph with existing hyperpath model properties that is directly integrated with the LBTE network is also proposed. Transit passenger behavior was incorporated for transfers in the link-based hyperpath. The efficiency of the proposed hyperpath model was demonstrated. The proposed models were applied on a test network and a real transit network represented by the general specification of Google's transit feed.

51. Dynamic System Optimal Routing in Multimodal Transit Network

1. Ma, Tai-Yu; Lebacque, Jean-Patrick
2. TRANSPORT RES REC

> The system optimal routing problem has been widely studied for road networks, though less considered for public transit systems. Traditional shortest path-based multimodal itinerary guidance systems may deteriorate the system performance when the assigned lines become congested. The dynamic system optimal routing model for multimodal transit system is formulated for that issue. The transit system is represented by a multilevel graph to explicitly simulate passenger flow and transit system operations. A solution algorithm based on the cross entropy method is proposed, and its performance is compared with the method of successive averages in static and dynamic cases. A numerical study of a simple multimodal transit network provides the basis for comparing system optimal routing and user optimal routing under different congestion levels.

52. A reliability-based traffic assignment model for multi-modal transport network under demand uncertainty

1. Fu, Xiao; Lam, William H. K.; Chen, Bi Yu
2. J ADV TRANSPORT

> In densely populated and congested urban areas, the travel times in congested multi-modal transport networks are generally varied and stochastic in practice. These stochastic travel times may be raised from day-to-day demand fluctuations and would affect travelers' route and mode choice behaviors according to their different expectations of on-time arrival. In view of these, this paper presents a reliability-based user equilibrium traffic assignment model for congested multi-modal transport networks under demand uncertainty. The stochastic bus frequency due to the unstable travel time of bus route is explicitly considered. By the proposed model, travelers' route and mode choice behaviors are intensively explored. In addition, a stochastic state-augmented multi-modal transport network is adopted in this paper to effectively model probable transfers and non-linear fare structures. A numerical example is given to illustrate the merits of the proposed model. Copyright (c) 2012 John Wiley & Sons, Ltd.

53. Modelling impacts of adverse weather conditions on activity-travel pattern scheduling in multi-modal transit networks

1. Fu, Xiao; Lam, William H. K.; Meng, Qiang
2. TRANSPORTMETRICA B

> In general, adverse weather has significant influence on individuals' activity/travel choice behaviour and such influence is obviously greater in cities which suffer frequent rainy periods. Thus, the impacts of weather conditions should be taken into account in long-term transit service planning. In this paper, an activity-based network equilibrium model for scheduling daily activity-travel patterns (DATPs) in multi-modal transit networks under adverse weather conditions (with different rainfall intensities) is developed. The interdependency of individuals' activity/travel choices and weather conditions are comprehensively investigated. In the proposed model, the DATP choice problem under adverse weather conditions is transformed into an equivalent static transit assignment problem by constructing a novel super-network platform. A rule-based algorithm is proposed to automatically generate the super-network taking into account the rain effects implicitly. The effects of adverse weather on different transit modes and different activities are explicitly modelled. An efficient solution algorithm without prior enumeration of DATPs is proposed for solving the DATP scheduling problem in multi-modal transit networks. Numerical examples are presented to illustrate application of the proposed model and the solution algorithm.

54. A network equilibrium approach for modelling activity-travel pattern scheduling problems in multi-modal transit networks with uncertainty

1. Fu, Xiao; Lam, William H. K.
2. TRANSPORTATION

> An understanding of the interaction between individuals' activities and travel choice behaviour plays an important role in long-term transit service planning. In this paper, an activity-based network equilibrium model for scheduling daily activity-travel patterns (DATPs) in multi-modal transit networks under uncertainty is presented. In the proposed model, the DATP choice problem is transformed into a static traffic assignment problem by constructing a new super-network platform. With the use of the new super-network platform, individuals' activity and travel choices such as time and space coordination, activity location, activity sequence and duration, and route/mode choices, can be simultaneously considered. In order to capture the stochastic characteristics of different activities, activity utilities are assumed in this study to be time-dependent and stochastic in relation to the activity types. A concept of DATP budget utility is proposed for modelling the uncertainty of activity utility. An efficient solution algorithm without prior enumeration of DATPs is developed for solving the DATP scheduling problem in multi-modal transit networks. Numerical examples are used to illustrate the application of the proposed model and the solution algorithm.

55. Social Welfare Maximization of Multimodal Transportation Theory, Metamodel, and Application to Tianjin Ecocity, China

1. Chen, Xiqun (Michael); Yin, Mogeng; Song, Mingzhu; Zhang, Lei; Li, Meng
2. TRANSPORT RES REC

> Multimodal urban transportation systems exhibit complex interactions between components, including users, multimodal transportation facilities, supply side agencies, and operators. Although these interactions are obvious, rigorous quantitative methods for optimizing control variables across modes of transportation on real-world networks are deficient. A social welfare maximization model was established for joint optimization of bus fare, rail transit fare, and congestion tolls for private cars. The authors determined the optimality conditions and the second-order partial derivatives for this optimization problem. Because of the complexity of the multimodal urban transportation system, the

objective function of social welfare has no closed form and is extremely expensive to evaluate. The authors therefore proposed a simulation-based framework for evaluation of the objective function and optimization of three decision variables across multiple travel modes. Several metamodels (i.e., mathematical functions that approximate the true shape of an unknown, nonlinear, and complex objective function) were adopted to approximate the highly nonlinear input-output mappings in the urban system. This is the first study to develop a simulation-based method for joint optimization of transit and road network operations. The case study applied the simulation-based optimization framework to the Sino-Singapore ecocity in Tianjin, China, by using VISSUM as the urban systems simulator. An ecocity is defined by the authors as a thriving city that is socially harmonious, environmentally friendly, resource-efficient, and a model for sustainable development. Results show that metamodels can accurately approximate the real objective function and produce good suboptimal and near-optimal solutions. The optimal combination of transit fares and congestion tolls significantly outperform those under two baseline scenarios. The optimal solutions also suggest that extreme transit fares (too high or too low) or congestion tolls are contrary to welfare-maximizing objectives. The proposed method can be applied for joint optimization of other multimodal planning and operational strategies, such as investment and operational decisions across various modes of transportation.

56. Modeling Transit and Intermodal Tours in a Dynamic Multimodal Network

1. Khani, Alireza; Bustillos, Brenda; Noh, Hyunsoo; Chiu, Yi-Chang; Hickman, Mark
2. TRANSPORT RES REC

A fixed-point formulation and a simulation-based solution method were developed for modeling intermodal passenger tours in a dynamic transportation network. The model proposed in this paper is a combined model of a dynamic traffic assignment, a schedule-based transit assignment, and a park-and-ride choice model, which assigns intermodal demand (i.e., passengers with drive-to-transit mode) to the optimal park-and-ride station. The proposed model accounts for all segments of passenger tours in the passengers' daily travel, incorporates the constraint on returning to the same park-and-ride location in a tour, and models individual passengers at a disaggregate level. The model has been applied in an integrated travel demand model in Sacramento, California, and feedback to the activity-based demand model is provided through separate time-dependent skim tables for auto, transit, and intermodal trips.

57. A dynamic evacuation model for pedestrian-vehicle mixed-flow networks

1. Zhang, Xin; Chang, Gang-len
2. TRANSPORT RES C-EMER

In urban emergency evacuation, a potentially large number of evacuees may depend either on transit or other modes, or need to walk a long distance, to access their passenger cars. In the process of approaching the designated pick-up points or parking areas for evacuation, the massive number of pedestrians may cause tremendous burden to vehicles in the roadway network. Responsible agencies often need to contend with congestion incurred by massive vehicles emanating from parking garages, evacuation buses generated from bus stops, and the conflicts between evacuees and vehicles at intersections. Hence, an effective plan for such evacuation needs to concurrently address both the multi-modal traffic route assignment and the optimization of network signal controls for mixed traffic flows. This paper presents an integrated model to produce the optimal distribution of vehicle and pedestrian flows, and the responsive network signal plan for massive mixed pedestrian-vehicle flows

> within the evacuation zone. The proposed model features its effectiveness in accounting for multiple types of evacuation vehicles, the interdependent relations between pedestrian and vehicle flows via some conversion locations, and the inevitable conflicts between intersection turning vehicle and pedestrian flows. An illustrating example concerning an evacuation around the M&T stadium area has been presented, and the results indicate the promising properties of our proposed model, especially on reflecting the complex interactions between vehicle and pedestrian flows and the favorable use of high-occupancy vehicles for evacuation operations.

58. Continuum modeling of park-and-ride services considering travel time reliability and heterogeneous commuters - A linear complementarity system approach

1. Du, Bo; Wang, David Z. W.
2. TRANSPORT RES E-LOG

> This paper studies the modeling of multimodal choice in a highway/railway system with continuum park-and-ride services along a corridor. Commuter heterogeneity and travel time uncertainty with correlation are considered, while both auto and rail transit are subject to congestion effects. Eventually, the equilibrium multimodal choice is modeled into a linear complementarity system and appropriate solution method is proposed to obtain the spatial equilibrium pattern along the corridor. Computational experiments are conducted to demonstrate the benefits of the proposed formulation and potential applications, such as optimization of park-and-ride facilities, development of land use policies to integrate urban development and transportation planning.

59. Accounting for travel time variability in the optimal pricing of cars and buses

1. Tirachini, Alejandro; Hensher, David A.; Bliemer, Michiel C. J.
2. TRANSPORTATION

> A number of studies have shown that in addition to travel time and cost as the common influences on mode, route and departure time choices, travel time variability plays an increasingly important role, especially in the presence of traffic congestion on roads and crowding on public transport. The dominant focus of modelling and implementation of optimal pricing that incorporates trip time variability has been in the context of road pricing for cars. The main objective of this paper is to introduce a non-trivial extension to the existing literature on optimal pricing in a multimodal setting, building in the role of travel time variability as a source of disutility for car and bus users. We estimate the effect of variability in travel time and bus headway on optimal prices (i.e., tolls for cars and fares for buses) and optimal bus capacity (i.e., frequencies and size) accounting for crowding on buses, under a social welfare maximisation framework. Travel time variability is included by adopting the well-known mean-variance model, using an empirical relationship between the mean and standard deviation of travel times. We illustrate our model with an application to a highly congested corridor with cars, buses and walking as travel alternatives in Sydney, Australia. There are three main findings that have immediate policy implications: (i) including travel time variability results in higher optimal car tolls and substantial increases in toll revenue, while optimal bus fares remain almost unchanged; (ii) when bus headways are variable, the inclusion of travel time variability as a source of disutility for users yields higher optimal bus frequencies; and (iii) including both travel time variability and crowding discomfort leads to higher optimal bus sizes.

60. A simulation tool for bicycle sharing systems in multimodal networks

1. Romero, Juan P.; Moura, Jose L.; Ibeas, Angel; Alonso, Borja
2. TRANSPORT PLAN TECHN

> This paper presents a methodology for modelling an urban transport system, integrating public bicycles in a multi-modal network. A bike cost function that reproduces the effect of slopes on cycling speeds is proposed. Also, the effect of traffic levels on the attractiveness of cycling routes is taken into account. The model applies the modal split and network assignment phases in a multimodal network with different classes of users. It has been verified over a test network and then validated by applying it to a real case in the city of Santander in Spain. The results obtained make this model a useful decision-making tool to encourage the use of the public bicycle from a sustainable development point of view.

61. Finding Least Cost Hyperpaths in Multimodal Transit Networks Methodology, Algorithm, and Large-Scale Application

1. Verbas, I. Oemer; Mahmassani, Hani S.
2. TRANSPORT RES REC

> This paper presents a least cost hyperpath algorithm that captures the complexities that arise in a transit network because of the number of transfers, the standing and overcrowding penalties, the availability of walking and biking in addition to the transit modes, and the mode specific limitations such as availability of bike parking. The problem was formulated as a mathematical program, and then a hybrid label setting correcting algorithm was proposed as a solution. The multi modal time-and approach-dependent algorithm does not require spatial or temporal expansion of the network; this feature results in good computational performance for large-scale applications. Scenario runs performed on the large-scale Chicago Transit Authority network, in Illinois, validate the accuracy and performance of the algorithm.

62. A stochastic multimodal reliable network design problem under adverse weather conditions

1. Uchida, Kenetsu; Sumalee, Agachai; Ho, H. W.
2. J ADV TRANSPORT

> This paper formulates a network design problem (NDP) for finding the optimal public transport service frequencies and link capacity expansions in a multimodal network with consideration of impacts from adverse weather conditions. The proposed NDP aims to minimize the sum of expected total travel time, operational cost of transit services, and construction cost of link capacity expansions under an acceptable level of variance of total travel time. Auto, transit, bus, and walking modes are considered in the multimodal network model for finding the equilibrium flows and travel times. In the proposed network model, demands are assumed to follow Poisson distribution, and weather-dependent link travel time functions are adopted. A probit-based stochastic user equilibrium, which is based on the perceived expected travel disutility, is used to determine the multimodal route of the travelers. This model also considers the strategic behavior of the public transport travelers in choosing their routes, that is, common-line network. Based on the stochastic multimodal model, the mean and variance of total travel time are analytical estimated for setting up the NDP. A sensitivity-based solution algorithm is proposed for solving the NDP, and two numerical examples are adopted to demonstrate the characteristics of the proposed model. Copyright (c) 2014 John Wiley & Sons, Ltd.

63. A bi-level programming for bus lane network design

1. Yu Bin; Kong Lu; Sun Yao; Yao Baozhen; Gao Ziyou
2. TRANSPORT RES C-EMER

This paper proposes a bi-level programming model to solve the design problem for bus lane distribution in multi-modal transport networks. The upper level model aims at minimizing the average travel time of travelers, as well as minimizing the difference of passengers' comfort among all the bus lines by optimizing bus frequencies. The lower level model is a multi-modal transport network equilibrium model for the joint modal split/traffic assignment problem. The column generation algorithm, the branch-and-bound algorithm and the method of successive averages are comprehensively applied in this paper for the solution of the bi-level model. A simple numerical test and an empirical test based on Dalian economic zone are employed to validate the proposed model. The results show that the bi-level model performs well with regard to the objective of reducing travel time costs for all travelers and balancing transit service level among all bus lines. (C) 2015 Elsevier Ltd. All rights reserved.

64. Integrated Frequency Allocation and User Assignment in Multimodal Transit Networks Methodology and Application to Large-Scale Urban Systems

1. Verbas, I. Oemer; Mahmassani, Hani S.
2. TRANSPORT RES REC

This paper presents an integrated solution method to the frequency. setting problem using optimization and assignment simulation. With a bilevel solution framework, an optimization problem is run at the upper level under the assumption that the total transit demand is fixed. The objective is to maximize wait time savings under the budget, fleet size, vehicle load, and policy headway constraints. At the lower level, an assignment and simulation algorithm is run; the algorithm models the demand response to the new frequency setting and transmits updated ridership and flow values to the upper level. The procedure is repeated until the improvement in the wait time savings converges. The platform is tested on the Chicago Transit Authority network in Illinois for the morning peak. The wait time savings in this experiment are converging and are found to be comparable with the results of a stand-alone frequency-setting algorithm that finds optimal solutions. Results are comparable with the optimal results of a stand-alone platform introduced in another study that modeled the demand response locally by using elasticities as opposed to networkwide modeling using assignment. The integrated platform can be used for medium-term strategic and long-term planning decisions.

65. Multimodal Evacuation Simulation and Scenario Analysis in Dense Urban Area

1. Yuan, Fang; Puchalsky, Christopher M.
2. TRANSPORT RES REC

Simulation is an effective tool for estimating evacuation times, identifying system bottlenecks, and evaluating traffic management strategies under a variety of operational and behavioral assumptions. The development of a multimodal simulation model for modeling evacuation activities in Center City, Philadelphia, Pennsylvania, is presented. The model applied a dynamic sequential assignment method to simulate the movement and interactions of pedestrians, private vehicles, and buses while considering the variation of evacuation demand and network conditions during evacuation operations. The model was used to perform scenario analysis and provide inputs to update current evacuation

> plans. This study shares the experience and findings from the Philadelphia study in modeling multimodal evacuations in dense urban areas.

66. Modelling urban traffic dynamics based upon the variational formulation of kinematic waves

1. Chow, Andy H. F.; Li, Shuai; Szeto, W. Y.; Wang, David Z. W.
2. TRANSPORTMETRICA B

> This paper presents a dynamic traffic modelling framework based on the variational formulation of kinematic waves. We compare the effectiveness of this relatively recent numerical method with the traditional Godunov-based cell transmission method on various aspects including modelling shocks, dispersion of vehicle platoons, moving bottlenecks, and traffic characteristics with respect to real-world observations made in Central London, UK. The results suggest that the variational method is able to produce high-quality estimates both theoretically and empirically. This study opens up a new research direction in the area of urban traffic modelling and optimisation.

67. Rule-Based Mode Choice Model: INSIM Expert System

1. Memon, A. A.; Meng, M.; Wong, Y. D.; Lam, S. H.
2. J TRANSP ENG

> This paper presents an innovative rule-based intelligent network simulation model (INSIM) expert system (IES) which simulates real-time mode choice decision-making process of commuters in the presence of multimodal traveler information. The IES captures interactions among available modes and decides on the commuter's mode based on a commuter's socioeconomic traits and prevailing travel condition. The commuter's mode choice behavior is modeled and represented by cognitive rules in the rule-base of the IES. Two important characteristics of the IES, the reliability and the adaptive learning, are highlighted. Three different models, i.e., (1) pure rule-based model (PRB), (2) discrete choice model (DCM), and (3) probabilistic model (COM) are introduced to formulate the mode choice decisions. Simulation results show that the highest level of accuracy can be achieved by applying the PRB model to generate mode choice decisions. (C) 2014 American Society of Civil Engineers.

68. Bayesian network-based formulation and analysis for toll road utilization supported by traffic information provision

1. Chen, Cong; Zhang, Guohui; Wang, Hua; Yang, Jinfu; Jin, Peter J.; Walton, C. Michael
2. TRANSPORT RES C-EMER

> Congestion pricing has been proposed and investigated as an effective means of optimizing traffic assignment, alleviating congestion, and enhancing traffic operation efficiencies. Meanwhile, advanced traffic information dissemination systems, such as Advanced Traveler Information System (ATIS), have been developed and deployed to provide real-time, accurate, and complete network-wide traffic information to facilitate travelers' trip plans and routing selections. Recent advances in ATIS technologies, especially telecommunication technology, allow dynamic, personalized, and multimodal traffic information to be disseminated and impact travelers' choices of departure times, alternative routes, and travel modes in the context of congestion pricing. However, few studies were conducted to determine the impact of traffic information dissemination on toll road utilizations. In this study, the effects of the provisions of traffic information on toll road usage are investigated and analyzed based

on a stated preference survey conducted in Texas. A Bayesian Network (BN)-based approach is developed to discover travelers' opinions and preferences for toll road utilization supported by network-wide traffic information provisions. The probabilistic interdependencies among various attributes, including routing choice, departure time, traffic information dissemination mode, content, coverage, commuter demographic information, and travel patterns, are identified and their impacts on toll road usage are quantified. The results indicate that the BN model performs reasonably well in travelers' preference classifications for toll road utilization and knowledge extraction. The BN Most Probable Explanation (MPE) measurement, probability inference and variable influence analysis results illustrate travelers using highway advisory radio and internet as their primary mode of receiving traffic information are more likely to comply with routing recommendations and use toll roads. Traffic information regarding congested roads, road hazard warnings, and accident locations is of great interest to travelers, who tend to acquire such information and use toll roads more frequently. Travel time formation for home-based trips can considerably enhance travelers' preferences for toll road usage. Female travelers tend to seek traffic information and utilize toll roads more frequently. As expected, the information provided at both pre-trip and en-route stages can positively influence travelers' preferences for toll road usage. The proposed methodology and research findings advance our previous study and provide insight into travelers' behavioral tendencies concerning toll road utilization in support of traffic information dissemination. (C) 2015 Elsevier Ltd. All rights reserved.

69. Activity-based market equilibrium for capacitated multimodal transport systems

1. Chow, Joseph Y. J.; Djavadian, Shadi
2. TRANSPORT RES C-EMER

Empirical studies have shown that demand for multimodal transport systems is highly correlated with activity schedules of individuals. Nonetheless, existing analytical equilibrium models of multimodal systems have only considered trip-based demand. We propose a new market equilibrium model that is sensitive to traveler activity schedules and system capacities. The model is based on a constrained mixed logit model of activity schedule choice, where each schedule in the choice set is generated with a multimodal extension of the household activity pattern problem. The extension explicitly accounts for both passenger choices of activity participation and multimodal choices like public transit, walking, and vehicle parking. The market equilibrium is achieved with Lagrangian relaxation to determine the optimal dual price of the capacity constraint, and a method of successive averages with column generation finds an efficient choice set of activity schedules to assign flows over the dynamic network load capacities. An example illustrates the model and algorithm, effects similar to Vickrey's morning commute model can be observed as a special case. A case study of the Oakville Go Transit station access last mile problem in the Greater Toronto Area is conducted with 166 survey samples reflecting 3680 individuals. Results suggest that a $10 fixed parking fee at Oakville station would lead to a reduction of access auto share from 54.8% to 49.5%, an increase in access transit share from 20.7% to 25.9%, and a disutility increase of 11% for the of single-activity residents of Oakville. (C) 2015 Elsevier Ltd. All rights reserved.

70. Day-to-day Dynamics & Equilibrium Stability in A Two-Mode Transport System with Responsive bus Operator Strategies

1. Cantarella, Giulio E.; Velona, Pietro; Watling, David P.
2. NETW SPAT ECON

> This paper presents a day-to-day dynamic analysis of mode choice behaviour in a transportation system. Presented results, regarding a simple two-mode system, support the conjecture that multiple equilibria can likely be observed in such systems. This condition may have a great impact on the design of transit operator strategies.

71. Inferring origin-destination pairs and utility-based travel preferences of shared mobility system users in a multi-modal environment

1. Kumar, Anshuman Anjani; Kang, Jee Eun; Kwon, Changhyun; Nikolaev, Alexander
2. TRANSPORT RES B-METH

> This paper presents a methodological framework to identify population-wide traveler type distribution and simultaneously infer individual travelers' Origin-Destination (OD) pairs, based on the individual records of a shared mobility (bike) system use in a multimodal travel environment. Given the information about the travelers' outbound and inbound bike stations under varied price settings, the developed Selective Set Expectation Maximization (SSEM) algorithm infers an underlying distribution of travelers over the given traveler types, or classes, treating each traveler's OD pair as a latent variable; the inferred most likely traveler type for each traveler then informs their most likely OD pair. The experimental results based on simulated data demonstrate high SSEM learning accuracy both on the aggregate and dissagregate levels.

72. Integrated Mode Choice and Dynamic Traveler Assignment in Multimodal Transit Networks Mathematical Formulation, Solution Procedure, and Large-Scale Application

1. Verbas, I. Omer; Mahmassani, Hani S.; Hyland, Michael F.; Halat, Hooram
2. TRANSPORT RES REC

> This paper introduces an integrated mode choice-multimodal transit assignment model and solution procedure intended for large-scale urban applications. The cross-nested logit mode choice model assigns travelers to car, transit, or park-and-ride. The dynamic multimodal transit assignment-simulation model determines minimum hyperpaths and assigns and simulates transit and park-and-ride travelers iteratively until the network approaches a state of equilibrium. After a given number of iterations, the updated transit network travel times are fed into the mode choice model and the model reassigns travelers to transit, car, or park-and-ride. The outer feedback loop between the mode choice model and the transit assignment model continues until the mode probabilities for each traveler do not change between iterations. A unique contribution of the method presented in this paper is that it reaches mode choice convergence with the use of disaggregate agents (travelers) instead of aggregate modal flows at the origin-destination level. The integrated model is successfully implemented on the Chicago Transit Agency's bus and train network in Illinois. Different procedures for reaching convergence are tested; the results suggest that a gap-based formulation is more efficient than the method of successive averages.

73. Simultaneous optimization of fuel surcharges and transit service runs in a multimodal transport network: a time-dependent activity-based approach

1. Li, Z. -C.; Yin, Y.; Lam, W. H. K.; Sumalee, A.
2. TRANSP LETT

This paper addresses the simultaneous optimization problem of fuel surcharges and transit service runs for energy sustainability of multimodal transport network using a time-dependent activity-based approach. To model commuters' choices of trip chain, travel mode, departure time, route, and activity timing and duration over the times of a day, a time-dependent activity and multimodal travel choice equilibrium problem is first addressed and formulated as an equivalent variational inequality (VI) problem. A new model for optimizing the fuel surcharges and transit vehicle runs is proposed to maximize the total social net benefit of the multimodal transport system. The proposed model explicitly considers the interaction between the fuel surcharges and transit service runs and the commuters' activity-travel scheduling behavior. A heuristic solution algorithm is then developed to solve the proposed model. Finally, an illustrative example is given to show the application of the proposed model with various sensitivity tests. Insightful findings are presented with particularly the effects of the fuel surcharges and transit service improvement on the performance of the multimodal transport system in terms of the modal split, fuel consumption, and total social net benefit.

74. Schedule Consistency for Daily Activity Chains in Integrated Activity-Based Dynamic Multimodal Network Assignment

1. Xu, Xiang (alex); Zockaie, Ali; Mahmassani, Hani S.; Halat, Hooram; Verbas, Omer; Hyland, Michael; Vovsha, Peter; Hicks, James
2. TRANSPORT RES REC

The dynamic multimodal network assignment problem at the daily schedule level is addressed by integrating an activity-based model and a dynamic traffic assignment tool through a unified framework. The framework achieves this integration while retaining disaggregated individualized information. The problem is formulated as a fixed-point problem, and equilibrium is achieved by minimizing the gap between the expected travel lime, which is used by the activity-based model to generate the travelers' individual and household activity schedules, and their experienced travel times, simulated by the dynamic traffic assignment tool. The schedule adjustment problem for individuals and households is formulated as a linear optimization problem. Two measures-inconsistent-schedule penalty and number of households with unrealistic schedules-are defined to monitor the status of the equilibrium and convergence gap of the integrated system. To ensure convergence of the applied integration, heuristic strategies for selecting individuals for schedule adjustment and path swap are tested in a subarea network of Chicago, Illinois. Selecting individuals for schedule adjustment based on their inconsistent-schedule penalty reduces both defined measures significantly and leads to the convergence of the planned schedule and the experienced (i.e., simulated) schedule.

75. A real-time algorithm to solve the peer-to-peer ride-matching problem in a flexible ridesharing system

1. Masoud, Neda; Jayakrishnan, R.
2. TRANSPORT RES B-METH

Real-time peer-to-peer ridesharing is a promising mode of transportation that has gained popularity during the recent years thanks to the wide-spread use of smart phones, mobile application development platforms, and online payment systems. An assignment of drivers to riders, known as the ride-matching problem, is a central component of a peer to-peer ridesharing system. In this paper we discuss the features of a flexible ridesharing system and propose an algorithm to optimally solve the ride-matching problem in a flexible ridesharing system in real-time. We generate random instances of

> the problem, and perform sensitivity analysis over some of the important parameters in a ridesharing system. Furthermore, we discuss two novel approaches to increase the performance of a ridesharing system. (C) 2017 Elsevier Ltd. All rights reserved.

76. Integrated planning of park-and-ride facilities and transit service

1. Song, Ziqi; He, Yi; Zhang, Lihui
2. TRANSPORT RES C-EMER

> This paper proposes an integrated planning framework to locate park-and-ride (P&R) facilities and optimize their capacities as well as transit service frequencies simultaneously. P&R users' route choice behavior is explicitly considered, and a link-based multimodal user equilibrium model is established. The optimal location and capacity of P&R facilities and transit service design problem is formulated as a mathematical program with complementarity constraints (MPCC), and a solution algorithm based on the active-set approach is developed to solve the optimal design problem effectively. A numerical example is employed to demonstrate that the optimal design shifts commuters from the automobile mode to transit and P&R modes and, hence improves the net social benefit dramatically. (C) 2016 Elsevier Ltd. All rights reserved.

77. Evidence-Based Transit and Land Use Sketch Planning Using Interactive Accessibility Methods on Combined Schedule and Headway-Based Networks

1. Conway, Matthew Wigginton; Byrd, Andrew; van der Linden, Marco
2. TRANSPORT RES REC

> There is a need for indicators of transportation-land use system quality that are understandable to a wide range of stakeholders and that can provide immediate feedback on the quality of interactively designed scenarios. Location-based accessibility indicators are promising candidates, but indicator values can vary strongly depending on time of day and transfer wait times. Capturing this variation increases complexity, slowing calculations. This paper presents new methods for rapid yet rigorous computation of accessibility metrics, allowing immediate feedback during early-stage transit planning while being rigorous enough for final analyses. The approach is statistical, characterizing the uncertainty and variability in accessibility metrics related to differences in departure time and headway-based scenario specification. The analysis was carried out on a detailed multimodal network model including both public transportation and streets. Land use data were represented at high resolution. These methods were implemented as open-source software running on a commodity cloud infrastructure. Networks were constructed from standard open data sources, and scenarios were built in a map-based web interface. A case study is presented, describing how these methods were applied in a long-term transportation planning process for an urbanized, polycentric Randstad region in the Netherlands.

78. Integrated Airline Scheduling: Considering Competition Effects and the Entry of the High Speed Rail

1. Cadarso, Luis; Vaze, Vikrant; Barnhart, Cynthia; Marin, Angel
2. TRANSPORT SCI

> Airlines and high speed rail are increasingly competing for passengers, especially in Europe and Asia. Competition between them affects the number of captured passengers and, therefore, revenues. We

> consider competition between airlines (legacy and low-cost) and high speed rail. We develop a new approach that generates airline schedules using an integrated mixed integer, nonlinear optimization model that captures the impacts of airlines' decisions on passenger demand. We estimate the demand associated with a given schedule using a nested logit model. We report our computational results on realistic problem instances of the Spanish airline IBERIA and show that the actual airline schedules are found to be reasonably close to the schedules generated by our approach. Next, we use this optimization modeling approach under multimodal competition to evaluate multiple scenarios involving entry of high speed rail into new markets. We account for the possibility of demand stimulation as a result of the new services. We validate our approach using data from markets that had an entry by high speed rail in the past. The out-of-sample validation results show a close match between the predicted and observed solutions. Finally, we use our validated model to predict the impacts of future entry by high speed rail in new markets. Our results provide several interesting and useful insights into the schedule changes, fleet composition changes, and fare changes that will help the airline cope effectively with the entry of high speed rail.

79. A Credit-Based Congestion Management Scheme in General Two-Mode Networks with Multiclass Users

1. Liu, Yang; Nie, Yu (Marco)
2. NETW SPAT ECON

> This paper examines the design of the credit-based congestion management schemes that achieve Pareto-improving outcome in general two-mode networks. It is assumed that transit is a slower but cheaper alternative to driving alone. The distributional welfare effects of congestion pricing on users with the different value of time (VOT) in Liu and Nie (Trans Res Board 2283:34-43, 2012) are used in developing Pareto-improving credit schemes. We show that, similar to the single-mode model, the sufficient and necessary condition for the existence of a discriminatory Pareto-improving credit scheme is the reduction in the total system cost. A sufficient condition for the existence of an anonymous Pareto-improving credit scheme is also derived. A cross-OD subsidization scheme is proposed when the sufficient condition is not satisfied for each origin-destination (O-D) pair. Numerical experiments on the expanded Sioux Falls networks with a log-normal VOT distribution demonstrate that the proposed Pareto-improving scheme can generate positive net revenue in the presence of good transit coverage.

80. Application of smart card data in validating a large-scale multi-modal transit assignment model

1. Tavassoli, Ahmad; Mesbah, Mahmoud; Hickman, Mark
2. PUBLIC TRANSPORT

> The accuracy of transit assignment plays an important role in the successful design and operation of a transit system. The majority of previous studies on validating transit assignment models has used limited survey data or has lacked a large-scale multimodal and high quality dataset. Considering the advantages of smart card [automatic fare collection (AFC)] systems, the aims of this study are to put forward a methodological framework to validate existing transit assignment models and to quantify the performance of these models. Our study combines data from three sources: the General Transit Feed Specification, an AFC system, and a strategic transport model from a large-scale multimodal public transport network, namely the South-East Queensland (SEQ) network in Australia. The AFC

> system in SEQ has provided a very large and highly accurate dataset on passenger boardings and alightings for the three transit modes of bus, rail and ferry. Following a data analysis, an origin-destination trip matrix is estimated for the AM peak period using AFC data as an input to the transit assignment model. Then, the results of the transit assignment model are compared with the actual passengers' route choices over the same period, at different levels of aggregation. The model performance is quantified by each route (and direction), by each segment of each route (and direction), and by each stop. The results indicate that relatively tighter thresholds are required to validate the transit assignment at the segment level than at the stop level. Furthermore, the validation results indicate that the greatest error is realized for the bus mode, while the level of accuracy in the rail mode is the best. The results suggest a segment-level analysis should be used as the most useful level of aggregation for future calibration and validation of transit assignment models.

81. Modelling joint activity-travel pattern scheduling problem in multi-modal transit networks

1. Fu, Xiao; Lam, William H. K.
2. TRANSPORTATION

> Over the past decades, many activity-based travel behaviour models have been proposed based on individuals' independent decision making. The modelling of individuals' joint activity/travel choices, however, has received less attention. In reality, both independent and joint activities/travels form individual's normal daily activity-travel patterns. Travel surveys have indicated that joint activity/travel constitutes an important part in individuals' daily activity-travel patterns. On this basis, explicit modelling of joint activity/travel choices is an essential component for long-term transport planning. In this study, an activity-based network equilibrium model is proposed for scheduling two-individual joint activity-travel patterns (JATPs) in congested multi-modal transit networks. The proposed model can be used to comprehensively investigate individuals' activity choices (e.g. activity start time and duration, activity sequence) and travel choices (e.g. departure time, route and mode) in multi-modal transit networks, including both independent ones and joint ones. The time-dependent JATP choice problem is converted into an equivalent static user equilibrium model by constructing a joint-activity-time-space (JATS) super-network platform. Joint travel benefit is modelled by incorporating a commonality factor in the JATP utility. A solution algorithm without prior JATP enumeration is proposed to solve the JATP scheduling problem on the JATS super-network. Numerical results show that individuals' independent and joint activity/travel choices can be simultaneously investigated by the proposed model. The impacts of joint travel benefit on individuals' independent and joint activity-travel choices are explicitly investigated.

82. Analysis of multimodal two-dimensional urban system equilibrium for cordon toll pricing and bus service design

1. Li, Zhi-Chun; Wang, Ya-Dong
2. TRANSPORT RES B-METH

> This paper presents a multimodal urban system equilibrium model to address cordon toll pricing and bus service design issues in a two-dimensional monocentric city. Commuters are assumed to travel by auto or bus from their home locations to their workplace located in the city center through a ring-radial routing system. Auto users must pay tolls when passing through the cordons installed on the radial major roads. The multimodal two-dimensional urban system equilibrium is first formulated and its properties are analytically explored. A social welfare maximization model that simultaneously

> determines the optimal cordon toll location, toll level, bus service frequency and fare on each radial major road is then proposed. The effects of different tolling schemes (uniform and differential cordon-based, first-best, and no toll) on the multimodal urban system are also examined and compared. (C) 2018 Elsevier Ltd. All rights reserved.

83. Multimodal transit network design in a hub-and-spoke network framework

1. Huang, Di; Liu, Zhiyuan; Fu, Xiao; Blythe, Philip T.
2. TRANSPORTMETRICA A

> This study focuses on the reconfiguration of bus services in an urban area with a newly constructed rail system. A hub-and-spoke network framework is introduced for the multimodal transit system. The rail services are taken as the backbone, and the bus services (main bus lines and feeder bus lines) are reconfigured to better integrate with rail services forming the core of a Mobility as a Service (MaaS). A cluster-based approach is used for selecting hubs from rail stations. Bus stops are taken as non-hub nodes. Main bus lines are designed based on a heuristic line generation approach and feeder bus lines are developed by solving a travelling salesman problem. A bi-level programming model is proposed to determine frequencies of each mode and addressed by the artificial bee colony algorithm. The effectiveness of the proposed methods is illustrated by numerical examples and applied to the Mandl's benchmark compared with existing studies.

84. Hierarchical control of heterogeneous large-scale urban road networks via path assignment and regional route guidance

1. Yildirimoglu, Mehmet; Sirmatel, Isik Ilber; Geroliminis, Nikolas
2. TRANSPORT RES B-METH

> High level of detail renders microscopic traffic models impractical for control purposes and local control schemes cannot coordinate actions over large scale heterogeneously congested urban networks. Developing efficient models and control methods for large-scale urban road networks is, therefore, an important research challenge. Alleviating congestion via manipulation of traffic flows or assignment of vehicles to specific paths has a great potential in achieving efficient network usage. Motivated by this fact, this paper proposes a hierarchical traffic management system. The upper-level route guidance scheme builds a model predictive control (MPC) scheme and optimizes network performance based on actuation via regional split ratios, whereas the lower-level path assignment mechanism develops an integer linear programming (ILP) formulation and recommends subregional paths for vehicles to follow, satisfying the regional split ratios in order to achieve said performance. Simulation results from a 49-subregion or 7-region network shows a great potential of the proposed scheme in achieving coordination and efficient use of network capacity, leading to increased mobility. (C) 2018 Elsevier Ltd. All rights reserved.

85. Remote park-and-ride network equilibrium model and its applications

1. Liu, Zhiyuan; Chen, Xinyuan; Meng, Qiang; Kim, Inhi
2. TRANSPORT RES B-METH

> Existing park-and-ride (P&R) sites are usually located near a train/bus station where construction and operation costs are considerably high. Thus, this paper proposes a new P&R service mode, Remote P&R (RPR), where the car park locates in a suburban area with lower land value. Dedicated express bus

service is used to connect this site and a nearby train station. To quantitatively evaluate the impacts of RPR on the network flows, a combined modal split and traffic assignment model (CMSTA) is developed, where a cross-nested logit (CNL) model is adopted to cope with the mode similarity. The problem is formulated as a convex programming model and solved by the Evans algorithm, and then extended to asymmetric path-based cases, where a variational inequality (VI) model is built and solved by a self-adaptive gradient projection (SAGP) algorithm. Taking the CMSTA as the lower level and multimodal stochastic system optimum (MSSO) as the objective, we further develop a mathematical programming model with equilibrium constraints (MPEC) for the optimal network design of RPR. Based on an origin-based reformulation of the MPEC model, an exact solution method based on the nonlinear valid inequalities (NVI) is applied. Numerical examples demonstrate that the RPR services can significantly influence network users' travel decisions, promote the usage of public transportation and mitigate traffic congestion in the congested area of metropolitan cities. (C) 2018 Elsevier Ltd. All rights reserved.

86. Time-Dependent Intermodal A* Algorithm: Methodology and Implementation on a Large-Scale Network

1. Verbas, Omer; Auld, Joshua; Ley, Hubert; Weimer, Randy; Driscoll, Shon
2. TRANSPORT RES REC

This paper proposes a time-dependent intermodal A* (TDIMA*) algorithm. The algorithm works on a multimodal network with transit, walking, and vehicular network links, and finds paths for the three major modes (transit, walking, driving) and any feasible combination thereof (e.g., park-and-ride). Turn penalties on the vehicular network and progressive transfer penalties on the transit network are considered for improved realism. Moreover, upper bounds to prevent excessive waiting and walking are introduced, as well as an upper bound on driving for the park-and-ride (PNR) mode. The algorithm is validated on the large-scale Chicago Regional network using real-world trips against the Google Directions API and the Regional Transit Authority router.

87. Day-to-day modal choice with a Pareto improvement or zero-sum revenue scheme

1. Guo, Ren-Yong; Szeto, W. Y.
2. TRANSPORT RES B-METH

We investigate the day-to-day modal choice of commuters in a bi-modal transportation system comprising both private transport and public transit. On each day, commuters adjust their modal choice, based on the previous day's perceived travel cost and intraday toll or subsidy of each mode, to minimize their perceived travel cost. Meanwhile, the transportation authority sets the number of bus runs and the tolls or subsidies of two modes on each day, based on the previous day's modal choice of commuters, to simultaneously reduce the daily total actual travel cost of the transportation system and achieve a Pareto improvement or zero-sum revenue target at a stationary state. The evolution process of the modal choice of commuters, associated with the strategy adjustment process of the authority, is formulated as a dynamical system model. We analyze several properties of the dynamical system with respect to its stationary point and evolutionary trajectory. Moreover, we introduce new concepts of Pareto improvement and zero-sum revenue in a day-to-day dynamic setting and propose the two targets' implementations in either a prior or a posterior form. We show that, although commuters have different perceived travel costs for using the same travel mode, the authority need not know the probability distribution of perceived travel costs of commuters to achieve the Pareto improvement

> target. Finally, we give a set of numerical examples to show the properties of the model and the implementation of the toll or subsidy schemes. (C) 2018 Elsevier Ltd. All rights reserved.

88. Beyond a complete failure: the impact of partial capacity degradation on public transport network vulnerability

1. Cats, Oded; Jenelius, Erik
2. TRANSPORTMETRICA B

> Disruptions in public transport networks (PTNs) often lead to partial capacity reductions rather than complete closures. This study aims to move beyond the vulnerability analysis of complete failures by investigating the impacts of a range of capacity reductions on PTN performance. The relation between network performance and the degradation of line or link capacities is investigated by establishing a vulnerability curve and related metrics. The analysis framework is applied to a full-scan analysis of planned temporary line-level capacity reductions and an analysis of unplanned link-level capacity reductions on the most central segments in the multi-modal rapid PTN of Stockholm, Sweden. The impacts of capacity reductions are assessed using a non-equilibrium dynamic public transport operations and assignment model. The nonlinear properties of on-board crowding, denied boarding, network effects and route choice result in non-trivial, generally convex, relations which carry implications on disruption planning and real-time management.

89. Modelling and managing bus service regularity with influence of prevailing traffic

1. Chow, Andy H. F.; Li, Shuai
2. TRANSPORTMETRICA B

> This paper presents a multi-modal framework for modelling and analysing different headway control strategies for improving bus service regularity. The interaction between buses and their surrounding traffic is captured in a multi-modal system through a Hamilton-Jacobi formulation of kinematic wave model. This paper further presents a set of signal-based strategies which regulate bus headway through adjusting signal timing plans. The results reveal that the capability of regulating bus headway disturbances through utilising traffic signals is important for maximising bus service regularity and coordinating the bus dynamics with surrounding traffic. This study generates new insights on managing bus reliability and multi-modal traffic in busy urban networks.

90. Data-driven stochastic transit assignment modeling using an automatic fare collection system

1. Cheon, Seung Hoon; Lee, Changju; Shin, Seongil
2. TRANSPORT RES C-EMER

> In modern urban transit networks, buses and subways are not distinguished as different modes of transportation; this makes it challenging to analyze travel behaviors with multiple modes for the purpose of developing policies and plans. With the introduction of Automatic Fare Collection (AFC) systems, these modes are operated along a complex of links and nodes that constitute a multimodal transit network. Methods for analyzing travel behaviors in mass transit have been developed, but previous approaches fail to adequately reflect travel behaviors and network features (e.g., transfers, mode and route preferences). To overcome such limitations, this research proposes a smart card data-based analytical method with which travel behaviors can be efficiently and accurately examined. AFC

systems provide a tremendous amount of data that contain detailed trip information, and using these data reinforces the reliability of the proposed data driven method. The proposed method of analysis involves four core processes: establishing a scheme for how multiple transit modes can be integrated into one multimodal transit network on the basis of information derived from the AFC system, selecting feasible paths, assigning trips using a stochastic approach, and verifying analytical results by comparing them with findings from trip datasets. This method was used to analyze monthly smart card data collected from the AFC system in 2009 in the greater Seoul area. Multimodal transit networks were constructed from 34,852 bus stops and 539 subway stations using smart card data, and in total, 3,614,875 trips were used in the analysis. The final model for stochastic transit assignment was developed using the proposed method, which was verified by comparing actual and assigned trips. The proposed method exhibits high accuracy (83.93%) and a high R-square value (0.981), which supports the strength of the proposed stochastic transit assignment model. The findings reveal new interesting research directions for exploration, such as developing more disaggregated models (e.g., for specific regions, times, and users), considering detailed transfer features (e.g., transferable boundaries, transfer facilities, and transfer times), confirming the method's applicability by testing it in other cities, and incorporating both multimodal transit and road networks into the proposed model.

91. Development of a Multimodal Microsimulation-Based Evacuation Model

1. Alam, Jahedul; Habib, Muhammad Ahsanul; Venkatadri, Uday
2. TRANSPORT RES REC

This study presents a multimodal evacuation microsimulation modeling framework. The paper first determines optimum marshal point locations and transit routes, then examines network conditions through traffic microsimulation of a mass evacuation of the Halifax Peninsula, Canada. The proposed optimization modeling approach identifies marshal point locations based on transit demand obtained from a Halifax Regional Transport network model. A mixed integer linear programming (MILP) technique is used to formulate the marshal point location and transit route choice problem. The study proposes a novel approach to solving the MILP problem, using the branch and cut algorithm, which demonstrates superiority in computation time and production of quality solutions. The optimization model determines 135 marshal points and 12 transit routes to evacuate approximately 8,400 transit-dependent individuals. Transit demand and marshal point locations are found to be concentrated at the core of the peninsula. The microsimulation modeling takes a dynamic traffic assignment-based approach. The simulation model predicts that it takes 22 h to evacuate all auto users but just 7 h for the transit-dependent population. The study reveals that the transit system has excess capacity to assist evacuees who switch from auto and other modes. Local traffic congestion prolongs the evacuation of a few densely-populated zones in the downtown core of the peninsula. The findings of this research help policy-makers understand the impacts of marshal point locations and transit route choice decisions on multimodal evacuation performance, and provide insights into emergency planning of multimodal evacuations under mode switch and transit-based evacuation scenarios.

92. From Traditional to Automated Mobility on Demand: A Comprehensive Framework for Modeling On-Demand Services in SimMobility

1. Nahmias-Biran, Bat-hen; Oke, Jimi B.; Kumar, Nishant; Basak, Kakali; Araldo, Andrea; Seshadri, Ravi; Akkinepally, Arun; Azevedo, Carlos Lima; Ben-Akiva, Moshe
2. TRANSPORT RES REC

Mobility on demand (MoD) systems have recently emerged as a promising paradigm for sustainable personal urban mobility in cities. In the context of multi-agent simulation technology, the state-of-the-art lacks a platform that captures the dynamics between decentralized driver decision-making and the centralized coordinated decision-making. This work aims to fill this gap by introducing a comprehensive framework that models various facets of MoD, namely heterogeneous MoD driver decision-making and coordinated fleet management within SimMobility, an agent- and activity-based demand model integrated with a dynamic multi-modal network assignment model. To facilitate such a study, we propose an event-based modeling framework. Behavioral models were estimated to characterize the decision-making of drivers using a GPS dataset from a major MoD fleet operator in Singapore. The proposed framework was designed to accommodate behaviors of multiple on-demand services such as traditional MoD, Lyft-like services, and automated MoD (AMoD) services which interact with traffic simulators and a multi-modal transportation network. We demonstrate the benefits of the proposed framework through a large-scale case study in Singapore comparing the fully decentralized traditional MoD with the future AMoD services in a realistic simulation setting. We found that AMoD results in a more efficient service even with increased demand. Parking strategies and fleet sizes will also have an effect on user satisfaction and network performance.

93. The link transmission model with variable fundamental diagrams and initial conditions

1. van der Gun, Jeroen P. T.; Pel, Adam J.; van Arem, Bart
2. TRANSPORTMETRICA B

The link transmission model is a macroscopic network traffic flow simulation tool based on Lighthill-Whitham-Richards theory. While its efficiency and accuracy are superior to the well-known cell transmission model, applications of its current numerical formulations are limited by the inability to apply changes to the fundamental diagrams of links within a simulation and the need to start the simulation with an empty network. We resolve both limitations by developing a methodology for initialising the discrete-time link model with a non-empty initial condition and for computing within-link densities during the simulation, which can then serve as an initial condition for continued simulation with a new fundamental diagram. Since the computation of within-link densities is algebraic, no new numerical errors are introduced. Optional support for multiple commodities, subcritical delays and platoon dispersion, are retained. The resulting model is demonstrated on a motorway corridor network with variable speed limits and dynamic lane management.

94. A multi-modal network equilibrium model with captive mode choice and path size logit route choice

1. Wang, Guangchao; Chen, Anthony; Kitthamkesorn, Songyot; Ryu, Seungkyu; Qi, Hang; Song, Ziqi; Song, Jianguo
2. TRANSPORT RES A-POL

In this paper, we consider captive mode travelers (those who have no other choices but rely on one specific travel mode for daily commuting trips) in a multi-modal network equilibrium (MMNE) problem. Specifically, the dogit model is adopted to account for captive mode travelers in the modal split problem, and the path-size logit (PSL) model is used to capture route overlapping effects in the traffic assignment problem. The dogit-PSL MMNE model is formulated as an equivalent entropybased mathematical programming (MP) problem, which admits solution existence and uniqueness. Three numerical examples are provided. The first example examines the effects of mode captivity and route

> overlapping on network performances and observes that accounting for captive mode travelers would produce different equilibrium states and hence the network performance indicators. The second example applies the dogit-PSL MMNE model for evaluating the exclusive bus lane (EBL) expansion plans, in which a consistent synthetic proportional index is proposed. Numerical results show that considering mode captivity may produce substantial impacts on the odds (up to 50 percent of odds in the given scenarios) of making different EBL line expansion decisions. The third example implements the dogit-PSL MMNE model in the Seoul network to show the applicability of the dogitPSL MMNE model in a real-size multi-modal system.

95. A multi-modal competitive hub location pricing problem with customer loyalty and elastic demand

1. Mahmoodjanloo, Mehdi; Tavakkoli-Moghaddam, Reza; Baboli, Armand; Jamiri, Atefeh
2. COMPUT OPER RES

> This paper develops a multi-modal competitive hub location pricing problem whose target is the design of a transportation system for a company that plans to enter into a market with elastic demand, in which an existing transportation company operates its hub-and-spoke network. The entrant company aims to attract customers in the market by convenient locations for its hubs and proper pricing of its transportation services, while customer loyalty is different in the nodes. Hence, mixed-integer programming based on a multi-nominal logit model is proposed. Thereafter, to solve the single allocation hub-and-spoke model, it is decomposed into a bi-level model. In the new structure, the master problem is associated with hub location and assignment decisions, and the sub-problem is associated with pricing decisions. Moreover, upper and lower bounds are calculated to determine the price of transportation routes. Finally, based on a nested approach, a scatter search algorithm is used to search the solution space of the master problem, and a matheuristic method is designed to solve the pricing problem interactively. The proposed approach is employed to solve a case study in the postal service industry of Iran.

96. Calibrating a transit assignment model using smart card data in a large-scale multi-modal transit network

1. Tavassoli, Ahmad; Mesbah, Mahmoud; Hickman, Mark
2. TRANSPORTATION

> This paper describes a practical automated procedure to calibrate and validate a transit assignment model. An optimization method based on particle swarm algorithm is adopted to minimize a defined error term. This error term which is based on the percentage of root mean square error and the mean absolute percent error encompasses deviation of model outputs from observations considering both segment level as well as the mode level and can be applied to a large scale network. This study is based on the frequency-based assignment model using the concept of optimal strategy while any transit assignment model can be used in the proposed methodological framework. Lastly, the model is validated using another weekday data. The proposed methodology uses automatic fare collection (AFC) data to estimate the origin-destination matrix. This study combines data from three sources: the general transit feed specification, AFC, and a strategic transport model from a large-scale multimodal public transport network. The South-East Queensland (SEQ) network in Australia is used as a case study. The AFC system in SEQ has voluminous and high quality data on passenger boardings and alightings across bus, rail and ferry modes. The results indicate that the proposed procedure can

> successfully develop a multi-modal transit assignment model at a large scale. Higher dispersions are seen for the bus mode, in contrast to rail and ferry modes. Furthermore, a comparison is made between the strategies used by passengers and the generated strategies by the model between each origin and destination to get more insights about the detailed behaviour of the model. Overall, the analysis indicates that the AFC data is a valuable and rich source in calibrating and validating a transit assignment model.

97. Model formulation and calibration procedure for integrated multi-modal activity routing and network assignment models

1. Najmi, Ali; Rey, David; Waller, S. Travis; Rashidi, Taha H.
2. TRANSPORT RES C-EMER

> In this paper, a novel transport planning model system (TPMS) is formulated built on the concepts of network, multi-modality, integrity and instant calibration. In the proposed formulation, activity-travel pattern (ATP) choice elements including the choices of activity, activity sequence, mode, departure time, and parking location, are all unified into a time-dependent ATPs generator. The proposed model accounts for the dynamicity of the network, including time-of-day and congestion effects in a joint structure for transport supply and demand. Moreover, the proposed TPMS explicitly formulates an operating capacitated public transport system. To allow visiting locations multiple times and to alleviate the complexity of the proposed model, a novel multi-visit vehicle routing problem is proposed which does not enumerate the node and link visits. In order to calibrate the model based on the major travel attributes of the travel survey data, a set of splitting ratios are introduced to distribute trips on the network. The model uses the splitting ratios to integrate the ATPs generator and the traffic assignment (TA) model in a unified TPMS structure. The effectiveness of the proposed structure is demonstrated through numerical examples provided.

98. Modeling and managing ridesharing in a multi-modal network with an aggregate traffic representation: A doubly dynamical approach

1. Wei, Bangyang; Saberi, Meead; Zhang, Fangni; Liu, Wei; Waller, S. Travis
2. TRANSPORT RES C-EMER

> This study models a multi-modal network with ridesharing services. The developed model reproduces the scenario where travelers with their own cars may choose to be a solo-driver, a ridesharing driver, a ridesharing rider, or a public transit passenger while travelers without their own cars can only choose to be either a ridesharing rider or a public transit passenger. The developed model can capture the (clock) time-dependent choices of travelers and the evolution of traffic conditions, i.e., the within-day traffic dynamics. In particular, the within-day traffic dynamics in a city region is modeled through an aggregate traffic representation, i.e., the Macroscopic Fundamental Diagram (MFD). This paper further develops a doubly dynamical system that examines how the within-day time-dependent travelers' choices and traffic conditions will evolve from day to day, i.e., the day-to-day dynamics. Based on the doubly dynamical framework, this paper proposes two different congestion pricing schemes that aim to reduce network congestion and improve traffic efficiency. One scheme is to price all vehicles including both solo-driving and ridesharing vehicles (for ridesharing trips, the price is shared by the driver and rider), while the other scheme prices the solo-driving vehicles only in order to encourage ridesharing. The pricing levels (under each scheme) can be determined either through an adaptive adjustment mechanism from period to period driven by observed traffic conditions, or through solving

> a bi-level optimization problem. Numerical studies are conducted to illustrate the models and effectiveness of the pricing schemes. The results indicate that the emerging ridesharing platform may not necessarily reduce traffic congestion, but the proposed congestion pricing schemes can effectively reduce congestion and improve system performance. While pricing solo-driving vehicles only may encourage ridesharing, it can be less effective in reducing the overall congestion when compared to pricing both solo-driving and ridesharing vehicles.

99. Integrated route choice and assignment model for fixed and flexible public transport systems

1. Narayan, Jishnu; Cats, Oded; van Oort, Niels; Hoogendoorn, Serge
2. TRANSPORT RES C-EMER

> The recent technological innovations in various ICT platforms have given rise to innovative mobility solutions. Such systems could potentially address some of the inherent shortcomings of a line/schedule based public transport system. Previous studies either assumed that flexible on-demand services are used as an exclusive door-to-door service or offered as a feeder connection to high-capacity public transport services. However, users may combine line/schedule based public transport systems (Fixed PT) and on-demand services (Flexible PT) so that their travel impedance is minimized. To this end, we propose a multimodal route choice and assignment model that allows users combining Fixed and Flexible PT or use them as individual modes while demand for these services is endogenously determined. The model takes into account the dynamic demand-supply interaction using an iterative learning framework. Flexible public transport can be used to perform any part of the trip, ranging from a first/last mile service to an exclusive direct door-to-door connection. The developed model is implemented in an agent based simulation framework. The model is applied to a network centered around the city of Amsterdam, The Netherlands. Scenarios where Fixed PT and Flexible PT are offered as mutually exclusive modes or can be combined into a single journey, are analysed. Results indicate that Flexible PT is predominantly used for covering <30% of the trip length, indicating that it is mainly used as an access or egress mode to Fixed PT. This results with an overall increase in the share of public transport trips. Also, the average waiting time of Flexible PT users when used in combination with Fixed PT are lower than the scenario where each of them is used as an exclusive mode.

100. A many-to-many assignment game and stable outcome algorithm to evaluate collaborative mobility-as-a-service platforms

1. Pantelidis, Theodoros P.; Chow, Joseph Y. J.; Rasulkhani, Saeid
2. TRANSPORT RES B-METH

> As Mobility as a Service (MaaS) systems become increasingly popular, travel is changing from unimodal trips to personalized services offered by a platform of mobility operators. Evaluation of MaaS platforms depends on modeling both user route decisions as well as operator service and pricing decisions. We adopt a new paradigm for traffic assignment in a MaaS network of multiple operators using the concept of stable matching to allocate costs and determine prices offered by operators corresponding to user route choices and operator service choices without resorting to nonconvex bilevel programming formulations. Unlike our prior work, the proposed model allows travelers to make multimodal, multi-operator trips, resulting in stable cost allocations between competing network operators to provide MaaS for users. An algorithm is proposed to efficiently generate stability

> conditions for the stable outcome model. Extensive computational experiments demonstrate the use of the model to handling pricing responses of MaaS operators in technological and capacity changes, government acquisition, consolidation, and firm entry, using the classic Sioux Falls network. The proposed algorithm replicates the same stability conditions as explicit path enumeration while taking only 17 seconds compared to explicit path enumeration timing out over 2 hours.

101. Joint Frequency-Setting and Pricing Optimization on Multimodal Transit Networks at Scale

1. Bertsimas, Dimitris; Ng, Yee Sian; Yan, Julia
2. TRANSPORT SCI

> Modern public transportation systems are increasingly complex: they are operated on a large scale, must support booming urban populations, and run under tight budget constraints. Additionally, passengers are able to make choices between a variety of commuting options. We develop formulations for minimizing system wait time in multimodal networks, while accounting for operator budget constraints, capacity constraints, and passenger preferences. Furthermore, our algorithms run to near optimality in minutes for city-sized networks. We demonstrate the benefit of setting schedule frequencies and prices jointly through case studies on real data from Boston and Tokyo. To our knowledge, ours is the first paper that addresses joint frequency-setting and pricing optimization for public transit networks and at scale.

102. Shortest hyperpaths in a multimodal hypergraph with real-time information on some transit lines

1. Lopez, David; Lozano, Angelica
2. TRANSPORT RES A-POL

> This paper presents an algorithm to find multimodal shortest hyperpaths in a transport system where transit arrival is random (i.e. random-arrival transit system), while real-time information on vehicle arrivals is only available for some lines and modes. When the algorithm is queried, there is a short horizon where real-time information is accurate, and past this the most reliable information for estimating the arrivals is to use a random distribution specific to the lines. This problem occurs frequently in emerging cities where the transit schedules are not maintained. A Combined Real-Time Hypergraph is constructed to model the multimodal transport system where all the public transport modes have random arrivals and real-time information on arrivals is available for some lines of some modes. In order to model the period of time when some lines have real-time information, the composition of the head nodes of hyperarcs changes over time. The algorithm is tested on a real-life transport system where we change the number of lines with available real-time information to assess the performance of the algorithm in different scenarios. We found that incrementing the number of lines with real-time information does not impact the performance.

103. Calibration of a transit route choice model using revealed population data of smartcard in a multimodal transit network

1. Kim, Ikki; Kim, Hyoung-Chul; Seo, Dong-Jeong; Kim, Jung In
2. TRANSPORTATION

> One of the major objectives of this study is to provide more realistic and accurate results related to transit passenger's route choice behavior by using population data of revealed preference from smartcard transaction records. The smartcard data of the Seoul city provides both boarding and alighting location and time, which can make possible to trace each passenger's actually used path trajectory with close to 100% market penetration of smartcard usage. This study built an abstract transit network with representative nodes by aggregating all near-by bus stops within walkable distance and with abstract paths by aggregating lines for a specific OD pair that run the same trajectory links by same transit modes. This complex and huge-scale transit network allowed to analyze the route choice behavior of transit passengers in a multimodal transit system that could not be found from the data of relatively small-size cities. This study selected OD pairs which had two or more alternative paths in order to analyze choice behavior requiring a plural alternative choice set. The number of the selected OD pairs are 124,393 pairs that are 33.9% of whole OD pairs that has two or more trip records. The calibration result showed that it is good statistically and logically to include the six explanatory variables in the utility function of the multinomial Logit model. Those are in-vehicle travel time, out-of-vehicle travel time, transfer penalty index, travel time reliability measure, and path circuity index.

104. Assessing the impacts of automated mobility-on-demand through agent-based simulation: A study of Singapore

1. Oh, Simon; Seshadri, Ravi; Azevedo, Carlos Lima; Kumar, Nishant; Basak, Kakali; Ben-Akiva, Moshe
2. TRANSPORT RES A-POL

> The advent of autonomous vehicle technologies and the emergence of new ride-sourcing business models has spurred interest in Automated Mobility-on-Demand (AMOD) as a prospective solution to meet the challenges of urbanization. AMOD has the potential of providing a convenient, reliable and affordable mobility service through more competitive cost structures enabled by autonomy (relative to existing services) and more efficient centralized fleet operations. However, the short and medium-term impacts of AMOD are as yet uncertain. On the one hand, it has the potential to alleviate congestion through increased ride-sharing and reduced car-ownership, and by complementing mass-transit. Conversely, AMOD may in fact worsen congestion due to induced demand, the cannibalization of public transit shares, and an increase in Vehicle-Kilometers Traveled (VKT) because of rebalancing and empty trips. This study attempts to systematically examine the impacts of AMOD on transportation in Singapore through agent-based simulation, modeling demand, supply and their interactions explicitly. On the demand side, we utilize an activity-based model system, that draws on data from a smartphone-based stated preferences survey conducted in Singapore. On the supply side, we model the operations of the AMOD fleet (including the assignment of requests to vehicles and rebalancing), which are integrated within a multimodal mesoscopic traffic simulator. Comprehensive simulations are conducted using a model of Singapore for the year 2030 and yield insights into the impacts of AMOD in dense transit-dependent cities from the perspective of the transportation planner, fleet operator, and user. The findings suggest that an unregulated introduction of AMOD can cause significant increases in network congestion and VKT, and have important policy implications that could potentially inform future deployments of AMOD.

105. Complete Estimation Approach for Characterizing Passenger Travel Time Distributions at Rail Transit Stations

1. Zhu, Wei; Fan, Weili; Wei, Jin; Fan, Wei David

2. J TRANSP ENG A-SYST

> Route choice behavior of a rail transit passenger is not directly observable and it may be affected by the route travel time to a large extent. Compared to the on-train time, travel times at stations, including walking time and waiting time, have been receiving less attention and therefore become more difficult to analyze. A common method to analyze the travel time at a rail transit station is to directly assume a distribution function and to further fit the distribution. However, most distribution functions in the prior literature were used without validation and/or conclusive decision on the best fit. In such context, this paper develops a complete approach to estimating both the walking and waiting times at stations (including origin stations, destination stations, and transfer stations) by mining automatic fare collection (AFC) and automatic train supervision (ATS) data, and their distributions are further discussed and characterized in detail. An initial case study of the Beijing subway network shows that it can deduce passengers' walking and waiting times in sequence, and consequently obtain and depict their distributions with high performance.

106. Data Fusion Approach for Evaluating Route Choice Models in Large-Scale Complex Urban Rail Transit Networks

1. Zhu, Wei; Wei, Jin; Fan, Wei (David)
2. J TRANSP ENG A-SYST

> With the increases in both the urban rail transit (URT) network scale and complexity, a route choice model that was previously developed may not function properly anymore and therefore must be constantly evaluated if possible and updated whenever necessary. This paper develops and uses a posterior approach that fuses multisource data from both the automatic fare collection (AFC) and automatic train supervision (ATS) systems to provide accurate and intelligent evaluation of route choice models, especially for large-scale complex URT networks. A method to rebuild passengers' journey one by one is put forward that makes the proposed approach work in a more disaggregate manner. Then, observed travel time (OTT), and simulated travel time (STT), which are deduced by fusing multisource data from AFC and ATS systems, are defined. Instead of using traditional manual-based methods, the evaluation of route choice models is conducted by comparing and testing the distributions of both OTTs and STTs, and two nonparametric statistical techniques (NPSTs) are adopted. Pilot case studies are conducted on the Beijing subway network and the results obtained clearly show that the approach can disaggregately evaluate the route choice model and can also be easily incorporated into an automatic evaluation procedure.

107. Topology Optimization of Road Networks

1. Krylatov, Alexander; Zakharov, Victor; Tuovinen, Tero
2. SPRING TRACT TRANSP

> In this chapter is mainly devoted to the capacity allocation problem as one of the most significant for road network topology optimization. A brief review on problems concerning network design and relevant fields is given in the Sect. 6.1. Capacity allocation control for a general topology network in the form of a mathematical problem is formulated in the Sect. 6.2. The Sect. 6.3 is devoted to solving the capacity allocation problem for a single-commodity linear network of non-interfering routes. The solution is obtained explicitly that allows to make practically substantial conclusions. The Sect. 6.4

> addresses the problem of optimal capacity allocation control under multi-modal traffic flows. The multi-modality influence on optimal control strategy for capacity allocation is also discussed.

108. Responsive bus dispatching strategy in a multi-modal and multi-directional transportation system: A doubly dynamical approach

1. Zhang, Fangni; Liu, Wei
2. TRANSPORT RES C-EMER

> This paper examines the time-dependent bus dispatching problem in a multi-modal context. Traditional studies along this line often optimize the bus frequency or schedule. However, they may fail as the realized bus frequency or schedule is constrained by the time-varying traffic congestion on the road. Adding more buses to service does not necessarily increase the service frequency. Given this, we look into the time-dependent bus dispatching (number of buses in service on road) when taking into account complex multi-modal and multi-directional flow interactions on the road. In particular, the traffic dynamics over clock time is modeled through an aggregate traffic representation with flow interactions between cars and buses, and interactions between traffic in opposite moving directions. Instead of explicitly optimizing the size of dispatched bus fleet, we propose an adaptive fleet size adjustment mechanism where we have a target level of bus loading factor. This adaptive or responsive approach, by taking advantage of the doubly dynamical system proposed in Liu and Geroliminis (2017), adjusts the size of dispatched bus fleet over calendar time and accommodates day-to-day variations of mode choices and traffic patterns. Numerical studies show that the proposed approach can help bus operator to reduce operating cost and improve net benefit while maintaining comparable user costs for passengers. This study offers a new perspective for dynamic bus dispatching strategy and improves our understanding of multi-modal traffic dynamics.

109. Joint design of multimodal transit networks and shared autonomous mobility fleets

1. Pinto, Helen K. R. F.; Hyland, Michael F.; Mahmassani, Hani S.; Verbas, I. Omer
2. TRANSPORT RES C-EMER

> Providing quality transit service to travelers in low-density areas, particularly travelers without personal vehicles, is a constant challenge for transit agencies. The advent of fully-autonomous vehicles (AVs) and their inclusion in mobility service fleets may allow transit agencies to offer better service and/or reduce their own capital and operational costs. This study focuses on the problem of allocating resources between transit patterns and operating (or subsidizing) shared-use AV mobility services (SAMSs) in a large metropolitan area. To address this question, a joint transit network redesign and SAMS fleet size determination problem (JTNR-SFSDP) is introduced, and a bi-level mathematical programming formulation and solution approach are presented. The upper-level problem modifies a transit network frequency setting problem (TNFSP) formulation via incorporating SAMS fleet size as a decision variable and allowing the removal of bus routes. The lower-level problem consists of a dynamic combined mode choice-traveler assignment problem (DCMC-TAP) formulation. The heuristic solution procedure involves solving the upper-level problem using a nonlinear programming solver and solving the lower-level problem using an iterative agent-based assignment-simulation approach. To illustrate the effectiveness of the modeling framework, this study uses traveler demand from Chicago along with the regions existing multimodal transit network. The computational results indicate significant traveler benefits, in terms of improved average traveler wait times, associated with optimizing the joint design of multimodal transit networks and SAMS fleets compared with the initial transit network design.

110. Multi-Modal Combined Route Choice Modeling in the MaaS Age Considering Generalized Path Overlapping Problem

1. Li, Dawei; Yang, Min; Jin, Cheng-Jie; Ren, Gang; Liu, Xianglong; Liu, Haode
2. IEEE T INTELL TRANSP

> In the MaaS (Mobility as a Service) age, the alternatives of route choice for a trip will not be the single mode paths, but the combined routes utilizing more than one travel mode in the multi-modal transportation systems. When modeling the multi-modal combined route choices, alternative routes are correlated not only because of the overlapping of physical links, but also because of the overlapping of travel modes. We define this problem as the generalized path overlapping problem. To address the generalized overlapping problem, a multi-modal logit kernel (MLK) model is proposed to explicitly consider the correlations of unobserved utilities of combined routes. In this model, the unobserved utilities of combined routes are divided to two parts, the link specific parts and the independent route specific parts. The link specific parts are further divided to two parts: physical link specific and the mode specific. The generalized path overlapping problem is captured by the sharing of these two parts of unobserved link utilities. Based on this model, the stochastic user equilibrium on multi-model transport networks is represented as a fixed-point problem. Numerical studies are designed to illustrate the effects of incorporating generalized overlapping problem on disaggregated route choice prediction and aggregated traffic flow assignment. With different settings of physical link and mode specific error terms, the variations of disaggregated route choice predictions and aggregated traffic flows are discussed. It is found that, the generalized overlapping problem can be captured by the proposed model and significantly affect both the individual route choice predictions and aggregated traffic flows at equilibrium.

111. Inferring origin-Destination demand and user preferences in a multi -modal travel environment using automated fare collection

1. Wu, Laiyun; Kang, Jee Eun; Chung, Younshik; Nikolaev, Alexander
2. OMEGA-INT J MANAGE S

> Eliciting individual travelers' Origin-Destination (OD) information is critical for enabling public transit system policy-makers and operators to serve travelers in a calculated way. Accurate estimation of route choice model parameters is also important, in that it can help assess or predict the service levels that such a system can be expected to achieve. The knowledge of both the OD links and route choice logic is especially in demand for emerging mobility services, where providers work to accommodate individu-alized services and also offer incentives to travelers for specific trips. We show that all this information can be distilled from a particular type of data - the Automated Fare Collection (AFC) system data - in a fast, low-cost way. This paper presents a two-step methodological framework to identify individual travelers' true ODs (beyond stop-level ODs), as well as infer their travel preferences. The key to our work is the ability to identify and process the observations of travelers' routing choices between the same ODs under different travel environment conditions. A presented specially-crafted case study validates the pro-posed method in application with a real-world AFC data of Seoul, Korea, confirming the method's high inferential ability, under a basic route choice model.

112. A mixed-equilibrium model of individual and household activity-travel choices in multimodal transportation networks

1. Vo, Khoa D.; Lam, William H. K.; Li, Zhi-Chun
2. TRANSPORT RES C-EMER

This paper develops a novel household-oriented activity-based mixed-equilibrium model for estimating individual and household activity-travel choices in multimodal transportation networks with interactions between private car and public transit modes. In the novel model, household members with heterogeneous errors of perception on the time-dependent utility of different activity types make daily joint/solo activity-travel choices in a mixed-equilibrium manner, which maximizes either perceived household utility or perceived individual utility. A logit-based stochastic choice model is developed to capture the mixed equilibrium with heterogeneous errors of perception and used to predict the choices of alternative joint activity-travel paths (JATPs) on a supernetwork platform. Based on this stochastic JATP choice model, the mixed-equilibrium model is formulated as an equivalent variational inequality (VI) problem and solved using a modified diagonalization method. This converts the time-dependent activity-travel scheduling problem into an equivalent static traffic assignment problem on JATPs. The conditions required for the existence and uniqueness of a solution to the equivalent VI problem in terms of a JATP flow pattern are also identified. Numerical examples are provided to illustrate the model's merits and its applications for examining the effect of the coronavirus disease 2019 (COVID-19) pandemic.

113. Scheduled service network design with resource management for two-tier multimodal city logistics

1. Fontaine, Pirmin; Crainic, Teodor Gabriel; Jabali, Ola; Rei, Walter
2. EUR J OPER RES

We address the tactical-planning problem for an extended two-tiered City Logistics system. This more realistic problem setting, compared to the literature, integrates inbound and outbound demands, different transportation modes combining traditional, road-based, carriers with modes and vehicles of mass transport, such as light and regular rail. Aside from the assignment of customers to consolidation distribution centers and satellites, we manage a number of major resources, such as the multiple satellite capacity measures and the structure, allocation, and size of the heterogeneous fleets. We propose a scheduled service network design formulation for the tactical planning of such extended systems, and develop an efficient Benders decomposition algorithm, which includes a tailored partial decomposition technique for deterministic mixed-integer linear-programming formulations. The results of extensive numerical experiments show the efficiency of the proposed solution method, as well as the benefits of integrating several demand types and multimodal transportation networks into a single formulation.

114. A Two-Phase Gradient Projection Algorithm for Solving the Combined Modal Split and Traffic Assignment Problem with Nested Logit Function

1. Ryu, Seungkyu; Chen, Anthony; Kitthamkesorn, Songyot
2. J ADV TRANSPORT

This study provides a gradient projection (GP) algorithm to solve the combined modal split and traffic assignment (CMSTA) problem. The nested logit (NL) model is used to consider the mode correlation under the user equilibrium (UE) route choice condition. Specifically, a two-phase GP algorithm is developed to handle the hierarchical structure of the NL model in the CMSTA problem. The Seoul

> transportation network in Korea is adopted to demonstrate an applicability in a large-scale multimodal transportation network. The results show that the proposed GP solution algorithm outperforms the method of the successive averages (MSA) algorithm and the classical Evan's algorithm.

115. A new bi-objective model of the urban public transportation hub network design under uncertainty

1. Kaveh, Firoozeh; Tavakkoli-Moghaddam, Reza; Triki, Chefi; Rahimi, Yaser; Jamili, Amin
2. ANN OPER RES

> This paper presents a new bi-objective multi-modal hub location problem with multiple assignment and capacity considerations for the design of an urban public transportation network under uncertainty. Because of the high construction costs of hub links in an urban public transportation network, it is not economic to create a complete hub network. Moreover, the demand is assumed to be dependent on the utility proposed by each hub. Thus, the elasticity of the demand is considered in this paper. The presented model also has the ability to compute the number of each type of transportation vehicles between every two hubs. The objectives of this model are to maximize the benefits of transportation by establishing hub facilities and to minimize the total transportation time. Since exact values of some parameters are not known in advance, a fuzzy multi-objective programming based approach is proposed to optimally solve small-sized problems. For medium and large-sized problems, a meta-heuristic algorithm, namely multi-objective particle swarm optimization is applied and its performance is compared with results from the non-dominated sorting genetic algorithm. Our experimental results demonstrated the validity of our developed model and approaches. Moreover, an intensive sensitivity analyze study is carried out on a real-case application related to the monorail project of the holy city of Qom.

116. Impacts of real-time information levels in public transport: A large-scale case study using an adaptive passenger path choice model

1. Paulsen, Mads; Rasmussen, Thomas Kjaer; Nielsen, Otto Anker
2. TRANSPORT RES A-POL

> Public transport services are often uncertain, causing passengers' travel times and routes to vary from day to day. However, since door-to-door passenger delays depend on both intended and realised routes, they are difficult to calculate, as opposed to vehicle delays which can be derived directly from the widely available Automated Vehicle Location (AVL) data of the public transport system. In this study we use three months of such historical AVL data to calculate corresponding realised routes and passengers delays in a large-scale, multi-modal transport network by formulating and implementing an adaptive passenger path choice model in an agent-based scenario of Metropolitan Copenhagen with 801,719 daily trips. The proposed model allows analysing five different levels of real-time information provision, ranging from no information at all to global real-time information being available everywhere. The results of more than 258 million (positive or negative) passenger delays show that variability of passengers' travel time is considerable and much larger than that of the public transport vehicles. It is also shown that obtaining global real-time information at the beginning of the trip reduces passengers delay dramatically, although still being inferior to receiving such along the trip. Additionally, being able to automatically obtain real-time passenger information while walking and being on-board public transport services is found not to lead to considerable improvements compared

> to acquiring such information manually while waiting at stops, although slight benefits are demonstrated in supplementary models run with pseudo-intelligent vehicle delay forecasting.

117. Maximizing space-time accessibility in multi-modal transit networks: an activity-based approach

1. Fu, Xiao; Lam, William H. K.; Chen, Bi Yu; Liu, Zhiyuan
2. TRANSPORTMETRICA A

> Over the past decades, the impact of transport operating strategy improvements on space-time accessibility, which is an important research area for network design problem, has not been explicitly investigated particularly with the use of activity-based approach. In this paper, a novel activity-based space-time accessibility measure is introduced for considering individuals' accessibility to various activities and travels in a unified super-network framework. A bi-level programming model is proposed for optimizing time-dependent transit line headways and fares in a multi-modal transit network from the activity-based space-time accessibility perspective. In the upper level, transit line headways and fares are optimized by time of day to maximize the network-wide activity-based space-time accessibility. At the lower level, an activity-based network equilibrium model is adapted to provide the resultant activity-travel patterns as reactions to the upper level decision. A simplified network in Hong Kong selected area is used to illustrate the application of the proposed model.

118. Evolution of multimodal final user equilibrium considering public transport network design history

1. Ameli, Mostafa; Lebacque, Jean Patrick; Leclercq, Ludovic
2. TRANSPORTMETRICA B

> Analysing the properties of a network equilibrium can help to have a better view about network state, robustness, and the effect of any variation in the network. This study investigated the impacts of network design history on day-to-day multimodal user equilibrium. In particular, we analyze the long-term evolution of the network, including opening new multimodal options and its impacts on the final network equilibrium. First, the analysis focuses on static network loading with different successive configurations. Then, a more realistic setting is studied by simulation. A large-scale multimodal network with the flexible opening over time of three possible transport facilities shows that the final equilibrium is not unique; more importantly, significant differences can be observed in public transportation occupancy, while user equilibrium is enforced in all situations. Some solutions prove to be better from the collective viewpoint (shorter total travel time), thus giving new insight into public transport planning.

119. The bi-objective multimodal car-sharing problem

1. Enzi, Miriam; Parragh, Sophie N.; Puchinger, Jakob
2. OR SPECTRUM

> The aim of the bi-objective multimodal car-sharing problem (BiO-MMCP) is to determine the optimal mode of transport assignment for trips and to schedule the routes of available cars and users whilst minimizing cost and maximizing user satisfaction. We investigate the BiO-MMCP from a user-centred point of view. As user satisfaction is a crucial aspect in shared mobility systems, we consider user preferences in a second objective. Users may choose and rank their preferred modes of transport for

> different times of the day. In this way, we account for, e.g., different traffic conditions throughout the planning horizon. We study different variants of the problem. In the base problem, the sequence of tasks a user has to fulfil is fixed in advance and travel times as well as preferences are constant over the planning horizon. In variant 2, time-dependent travel times and preferences are introduced. In variant 3, we examine the challenges when allowing additional routing decisions. Variant 4 integrates variants 2 and 3. For this last variant, we develop a branch-andcut algorithm which is embedded in two bi-objective frameworks, namely the epsilon-constraint method and a weighting binary search method. Computational experiments show that the branch-and cut algorithm outperforms the MIP formulation and we discuss changing solutions along the Pareto frontier.

120. Regional Bicycle Network Evaluation and Strategic Planning: A Quantitative Methodological Approach Despite Limited Data Sources for Cycling

1. van Dulmen, Alex; Fellendorf, Martin
2. TRANSPORT RES REC

> In cases where budgets and space are limited, the realization of new bicycle infrastructure is often hard, as an evaluation of the existing network or the benefits of new investments is rarely possible. Travel demand models can offer a tool to support decision makers, but because of limited data availability for cycling, the validity of the demand estimation and trip assignment are often questionable. This paper presents a quantitative method to evaluate a bicycle network and plan strategic improvements, despite limited data sources for cycling. The proposed method is based on a multimodal aggregate travel demand model. Instead of evaluating the effects of network improvements on the modal split as well as link and flow volumes, this method works the other way around. A desired modal share for cycling is set, and the resulting link and flow volumes are the basis for a hypothetical bicycle network that is able to satisfy this demand. The current bicycle network is compared with the hypothetical network, resulting in preferable actions and a ranking based on the importance and potentials to improve the modal share for cycling. Necessary accompanying measures for other transport modes can also be derived using this method. For example, our test case, a city in Austria with 300,000 inhabitants, showed that a shift of short trips in the inner city toward cycling would, without countermeasures, provide capacity for new longer car trips. The proposed method can be applied to existing travel models that already contain a mode choice model.