Estimation of origin-destination matrices from link traffic counts on congested networks

1. Year: 1992
2. Journal: Transportation Research Part B
3. Authors: Yang, Hai and Sasaki, Tsuna and Iida, Yasunori and Asakura, Yasuo

Conventional methods for estimating origin-destination (O-D) trip matrices from link traffic counts assume that route choice proportions are given constants. In a network with realistic congestion levels, this assumption does not hold. This paper shows how existing methods such as the generalized least squares technique can be integrated with an equilibrium traffic assignment in the form of a convex bilevel optimization problem. The presence of measurement errors and time variations in the observed link flows are explicitly considered. The feasibility of the model is always guaranteed without a requirement for estimating consistent link flows from counts. A solution algorithm is provided and numerical simulation experiments are implemented in investigating the model's properties. Some related problems concerning O-D matrix estimation are also discussed. {\textcopyright} 1992.

The equilibrium-based origin-destination matrix estimation problem

1. Year: 1994
2. Journal: Transportation Research Part B
3. Authors: Yang, Hai and Iida, Yasunori and Sasaki, Tsuna

This paper examines a model due to Nguyen for estimating origin-destination (O-D) matrices from observed traffic flows on each network link. It is shown that the previous bilevel optimization models for choosing an O-D matrix can be transformed into single convex programs. Under the condition that the observed link flow pattern is an equilibrium, Nguyen's model is demonstrated to be equivalent to an underspecified system of linear equations with non-negative variables. By exploiting the properties of the system's feasible region, simpler methods, such as a least squares technique, can be used to obtain an O-D matrix that, when user-optimally assigned to the network, reproduces the observed link flows. {\textcopyright} 1993.

Traffic assignment and traffic control in general freeway-arterial corridor systems

1. Year: 1994
2. Journal: Transportation Research Part B
3. Authors: Yang, Hai and Yagar, Sam

We consider a general traffic corridor consisting of two subsystems of a freeway network and a surface street network. The two systems are coupled by access ramps to provide multiple alternative routes for drivers from their origins to destinations. Each ramp can be metered to influence flow distributions in such a way that some system performance index (e.g. total travel time) is optimized, provided that each driver chooses an individual minimum cost route in response to any given ramp control. In this article we first present a bilevel programming formulation of the traffic assignment and traffic control problem in the traffic corridor system. The lower-level problem represents a traffic equilibrium model involving explicitly ramp queuing, which predicts how drivers will react to any given on-ramp control pattern. The upper-level problem is to determine ramp metering rates that optimize a system performance criterion, taking into account drivers' route choice behavior. We also present a sensitivity analysis for the queuing network equilibrium problem. Explicit expression of the derivatives of

> equilibrium link flows and equilibrium ramp queuing times with respect to ramp metering rates is derived. A heuristic algorithm, using the derivative information from the sensitivity analysis, is developed to solve the proposed bilevel on-ramp traffic control problem. A numerical example is provided to illustrate the bilevel control model and the solution algorithm. {\textcopyright} 1994.

Heuristic algorithms for the bilevel origin-destination matrix estimation problem

1. Year: 1995
2. Journal: Transportation Research Part B
3. Authors: Yang, Hai

> Recently, a bilevel programming approach has been used for estimation of origin-destination (O-D) matrix in congested networks. This approach integrates the conventional generalized least squares estimation model and the standard network equilibrium model into one process. We extend this approach and develop a more general model and efficient heuristic algorithms to handle more realistic situation where link flow interaction cannot be ignored. The extended model is formulated in the form of a bilevel programming problem with variational inequality constraints. The upper-level problem seeks to minimize the sum of error measurements in traffic counts and O-D matrices, while the lower-level problem represents a network equilibrium problem formulated as variational inequalities, which guarantees that the estimated O-D matrix and corresponding link flows satisfy the network equilibrium conditions. Two computational techniques are presented for solving the bilevel O-D matrix estimation model. One is a heuristic iterative algorithm between traffic assignment and O-D matrix estimation and the other one is a sensitivity analysis based heuristic algorithm. Properties of the two algorithms are analyzed theoretically and compared numerically with small network examples. It is concluded that both algorithms can be used as efficient approaches for the bilevel O-D matrix estimation problems. {\textcopyright} 1995.

Traffic restraint, road pricing and network equilibrium

1. Year: 1997
2. Journal: Transportation Research Part B: Methodological
3. Authors: Yang, Hai and Bell, Michael G.H.

> Road pricing is now being advocated as an efficient means of managing traffic demand and of meeting other objectives, such as reducing the environmental impact of road traffic and improving public transport. This paper shows how a network toll pattern could be determined so as to reduce network travel demand to a desirable level. The demand between each origin-destination pair is described as a function of the generalized travel cost. When there is no toll charge, higher values of potential demand might cause congestion and queuing at bottleneck links of the road network. Queuing delay at saturated links may grow to choke off enough potential demand to reduce realized demand to the capacity of the network, thus leading to a queuing equilibrium where travel demand and travel cost match each other. In this paper, we first show how an elastic-demand network equilibrium model with queue could be used to determine this demand supply equilibrium. We then seek a link toll pattern to remove the wasteful queuing delay, and or restrain the realized demand to a desirable level to satisfy environment capacity constraints. We also show that the link toll pattern that could hold the traffic demand to a desirable level is not unique, a bi-level programming method is developed to select the best toll pattern among the feasible solutions based on pre-specified criteria. {\textcopyright} 1997 Elsevier Science Ltd.

Bilevel programming applied to optimising urban transportation

1. Year: 2001
2. Journal: Transportation Research Part B: Methodological
3. Authors: Clegg, Janet and Smith, Mike and Xiang, Yanling and Yarrow, Robert

> 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.

Cone projection versus half-space projection for the bilevel optimisation of transportation networks

1. Year: 2001
2. Journal: Transportation Research Part B: Methodological
3. Authors: Clegg, J. and Smith, M. J.

> This paper describes the half-space projection method and cone-projection methods of optimizing an urban transportation model. The paper then compares these two methods as applied to seek optimal capacity changes within a very simple example network model. The optimization has, in each of the cases, a bilevel character since it is performed on two functions; the equilibrium function E (which must have value zero for equilibrium) and the objective function Z which is minimized subject to the constraint that E is zero. Thus E = 0 (or `small') always has priority.

A bi-level programming approach for trip matrix estimation and traffic control problems with stochastic user equilibrium link flows

1. Year: 2001
2. Journal: Transportation Research Part B: Methodological
3. Authors: Maher, Michael J. and Zhang, Xiaoyan and Vliet, Dirck Van

> This paper deals with two mathematically similar problems in transport network analysis: trip matrix estimation and traffic signal optimization on congested road networks. These two problems are formulated as bi-level programming problems with stochastic user equilibrium assignment as the second-level programming problem. We differentiate two types of solutions in the combined matrix estimation and stochastic user equilibrium assignment problem (or the combined signal optimization and stochastic user equilibrium assignment problem): one is the solution to the bi-level programming problem and the other the mutually consistent solution where the two sub-problems in the combined problem are solved simultaneously. In this paper, we shall concentrate on the bi-level programming approach, although we shall also consider mutually consistent solutions so as to contrast the two types

> of solutions. The purpose of the paper is to present a solution algorithm for the two bi-level programming problems and to test the algorithm on several networks.

An equivalent continuously differentiable model and a locally convergent algorithm for the continuous network design problem

1. Year: 2001
2. Journal: Transportation Research Part B: Methodological
3. Authors: Meng, Q. and Yang, H. and Bell, M. G.H.

> The continuous network design problem (CNDP) is characterized by a bilevel programming model and recognized to be one of the most difficult and challenging problems in transportation. The main difficulty stems from the fact that the bilevel formulation for the CNDP is nonconvex and nondifferentiable, and indeed only some heuristic methods have been so far proposed. In this paper, the bilevel programming model for CNDPs is transferred into a single level optimization problem by virtue of a marginal function tool. By exploring the inherent nature of the CNDP, the marginal function for the lower-level user equilibrium problem is proved to be continuously differentiable and its functional value and derivative in link capacity enhancement can be obtained efficiently by implementing a user equilibrium assignment subroutine. Thus a continuously differentiable but still nonconvex optimization formulation of the CNDP is created and a locally convergent augmented Lagrangian method is applied to solve this equivalent problem. The descent direction in each step of the inner loop of the solution method can be found by doing an all or nothing assignment. These favorable characteristics indicate the potential of the algorithm to solve large CNDPs. Numerical examples are presented to compare the proposed method with some existing algorithms.

Modeling urban taxi services in congested road networks with elastic demand

1. Year: 2001
2. Journal: Transportation Research Part B: Methodological
3. Authors: Wong, K. I. and Wong, S. C. and Yang, Hai

> This paper extends the simple network model of urban taxi services proposed by Yang and Wong (Yang, H., Wong, S.C., 1998. Transportation Research B 32, 235-246). The extensions include incorporation of congestion effects, customer demand elasticity, reformulation of the model and development of a new solution algorithm. Instead of the previous characterization of pure taxi movements in a network by a system of nonlinear equations, a two-level model formulation is proposed for taxi movements in congested road networks. The bi-level problem is a combined network equilibrium model that describes simultaneous movements of vacant and occupied taxis as well as normal traffic in a user-optimal manner for given total customer generation from each origin and total customer attraction to each destination. The upper-level problem is a set of linear and nonlinear equations ensuring that the relation between taxi and customer-waiting times and the relation between customer demand and taxi supply are satisfied. The lower-level problem can be solved by the conventional multi-class combined trip distribution and assignment algorithm, whereas the upper-level problem is solved by a Newtonian algorithm with line search. A numerical example is presented to illustrate the proposed model and algorithm and demonstrate the characteristics of the taxi services in congested road networks. {\textcopyright} 2001 Elsevier Science Ltd. All rights reserved.

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

1. Year: 2002
2. Journal: Transportation Research Part B: Methodological
3. Authors: Ziyou, Gao and Yifan, Song

> In this paper, we combine the concept of reserve capacity with the continuous equilibrium network design problem. An integrated method is used to maximize the reserve capacity of a road network. On the one hand we try to find the maximum possible increase in traffic demand by setting traffic signals at individual intersections. On the other hand, we increase the road capacity in order to increase the whole capacity of a road network. A bilevel programming model and heuristic solution algorithm based on sensitivity analysis are proposed to model the reserve capacity problem of optimal signal control with user-equilibrium route choice. The applications of the model and its algorithm are illustrated with two numerical examples. {\textcopyright} 2002 Elsevier Science Ltd. All rights reserved.

Benefit distribution and equity in road network design

1. Year: 2002
2. Journal: Transportation Research Part B: Methodological
3. Authors: Meng, Qiang and Yang, Hai

> In the classical continuous network design problem, the optimal capacity enhancements are determined by minimizing the total system cost under a budget constraint, while taking into account the route choice behavior of network users. Generally the equilibrium origin-destination travel costs for some origin-destination (O-D) pairs may be increased after implementing these optimal capacity enhancements, leading to positive or negative results for network users. Therefore, the equity issue about the benefit gained from the network design problem is raised. In this paper, we examine the benefit distribution among the network users and the resulting equity associated with the continuous network design problem in terms of the change of equilibrium O-D travel costs. Bilevel programming models that incorporate the equity constraint are proposed for the continuous network design problem. A penalty function approach by embodying a simulated annealing method is used to test the models for a network example. {\textcopyright} 2001 Elsevier Science Ltd. All rights reserved.

TRANSYT derivatives for area traffic control optimisation with network equilibrium flows

1. Year: 2003
2. Journal: Transportation Research Part B: Methodological
3. Authors: Chiou, Suh Wen

> A bi-level mathematical programming technique has previously been proposed, in which an area traffic control problem is dealt with as the upper level problem whilst the users' equilibrium traffic assignment is dealt with as the lower level problem. The performance index of the upper level problem is defined as the sum of a weighted linear combination of the rate of delay and number of stops per unit time for all traffic streams, which is evaluated by the traffic model from TRANSYT. Approximate mathematical expressions for various components of the performance index and the average delay to a vehicle at the downstream junction in the TRANSYT model for both undersaturated and oversaturated links are considered. As a step towards heuristics for finding good solutions to this form of the bi-level problem, in this paper, explicit expressions have been obtained for the partial derivatives of all these quantities with respect to the signal control variables. Numerical calculations have been shown on example test

> network and good agreement of the results with these derivatives determined by numerical differentiation is obtained. {\textcopyright} 2003 Elsevier Science Ltd. All rights reserved.

Estimation of origin-destination trip-tables based on a partial set of traffic link volumes

1. Year: 2003
2. Journal: Transportation Research Part B: Methodological
3. Authors: Sherali, Hanif D. and Narayanan, Arvind and Sivanandan, R.

> Knowledge of motorists' origin-destination (OD) travel information is necessary for a wide range of transportation planning activities. The high cost of manpower and other expenses associated with conventional survey techniques for OD estimation have motivated the development of models that can inexpensively estimate these flows from easily available traffic link volumes. In this paper, we develop an approach for synthesizing these OD flows based on only a partial set of link volume information. This consideration introduces nonlinearities in the cost function of the model because of the dependence of link travel costs on link volumes, and requires the determination of a fixed-point (rather than an optimal) solution to the proposed model. Such a fixed point is determined heuristically by iteratively approximating the nonlinear model using a sequence of linear programs. Computational results on three sample networks from the literature are presented to evaluate the method and to provide insights into its performance relative to some maximum entropy and bilevel programming approaches. {\textcopyright} 2003 Elsevier Ltd. All rights reserved.

Solving the toll design problem with multiple user groups

1. Year: 2004
2. Journal: Transportation Research Part B: Methodological
3. Authors: Chen, Mei and Bernstein, David H.

> Congestion pricing has been regarded as an efficient method to reduce network-wide travel cost. In this study, a methodology for toll design is developed to provide policy-makers with suggestions on both where to charge tolls and how much the tolls should be. As opposed to the traditional approach of marginal social cost pricing, this methodology is capable of dealing with the more realistic case, in which only a small number of links can be tolled. Furthermore, this methodology can accommodate multiple user groups. Specifically, we make several simplifying assumptions which enable us to convert a traditional bilevel formulation of the toll design problem into a single level, standard nonlinear optimization problem. {\textcopyright} 2003 Elsevier Ltd. All rights reserved.

A continuous equilibrium network design model and algorithm for transit systems

1. Year: 2004
2. Journal: Transportation Research Part B: Methodological
3. Authors: Gao, Ziyou and Sun, Huijun and Shan, Lian Long

> In this paper, a bilevel programming model for transit network design problem is presented, in which the upper model is a normal transit network design model, and the lower model is a transit equilibrium assignment model. A heuristic solution algorithm based on sensitivity analysis is designed for the model proposed. Finally, a simple numerical example is given to illustrate the application of the model and algorithm and some conclusions are drawn. {\textcopyright} 2003 Elsevier Ltd. All rights reserved.

Modeling private highways in networks with entry-exit based toll charges

1. Year: 2004
2. Journal: Transportation Research Part B: Methodological
3. Authors: Yang, Hai and Zhang, Xiaoning and Meng, Qiang

> Previous studies on private highways generally involve network equilibrium models with link-specific and hence link-additive toll charges. In reality, toll charges for private highways depend on the entry and exit points, which are not always link-additive. This study formulates and solves the optimal toll design problem of private highways with entry-exit based toll charges using a bi-level programming approach. The lower-level traffic equilibrium problem with entry-exit based toll charges is still formulated as an optimization problem and the Frank-Wolfe algorithm is adapted for finding its solution, where the descent direction-finding sub-problem (all-or-nothing traffic assignment) is solved via a simple network transformation. The proposed method circumvents the difficulty of path enumeration or generation frequently involved in general non-additive traffic assignment problems and, hence, has the potentials to efficiently solve large network problems. Following an exploration of the properties of the lower-level traffic equilibrium sub-problem, the bi-level optimal toll design problem is solved by a recently developed efficient marginal function approach. {\textcopyright} 2003 Elsevier Ltd. All rights reserved.

Genetic algorithm solution for the stochastic equilibrium transportation networks under congestion

1. Year: 2005
2. Journal: Transportation Research Part B: Methodological
3. Authors: Ceylan, Halim and Bell, Michael G.H.

> A bi-level and mutually consistent (MC) programming techniques have previously been proposed, in which an area traffic control problem (ATC) is dealt with as upper-level problem whilst the users' equilibrium traffic assignment is dealt with as lower-level problem. In this study, genetic algorithm (GA) approach has been proposed to solve upper-level problem for a signalized road network under congestion. Stochastic user equilibrium (SUE) traffic assignment is applied at the lower-level. At the upper-level, GA provides a feasible set of signal timings within specified lower and upper bounds on signal timing variables and feeds into lower-level problem. The SUE assignment is solved by way of Path Flow Estimator (PFE) and TRANSYT traffic model is applied at upper-level to obtain network performance index (PI) and hence fitness index. Network performance index is defined as the sum of a weighted linear combination of delay and number of stops per unit time under various levels of traffic loads. For this purpose, the genetic optimizer, referred to as GATRANSPFE, combines the TRANSYT model, used to estimate performance, with the PFE logit assignment tool, used to predict traffic reassignment, is developed. The GATRANSPFE that can solve the ATC and SUE traffic assignment problem has been applied to the signalized road networks under congestion. The effectiveness of the GATRANSPFE over the MC method has been investigated in terms of good values of network performance index and convergence. Comparisons of the performance index resulting from the GATRANSPFE and that of mutually consistent TRANSYT-optimal signal settings and SUE traffic flows are made. {\textcopyright} 2004 Elsevier Ltd. All rights reserved.

Bilevel programming for the continuous transport network design problem

1. Year: 2005
2. Journal: Transportation Research Part B: Methodological
3. Authors: Chiou, Suh Wen

> A Continuous Network Design Problem (CNDP) is to determine the set of link capacity expansions and the corresponding equilibrium flows for which the measures of performance index for the network is optimal. A bilevel programming technique can be used to formulate this equilibrium network design problem. At the upper level problem, the system performance index is defined as the sum of total travel times and investment costs of link capacity expansions. At the lower level problem, the user equilibrium flow is determined by Wardrop's first principle and can be formulated as an equivalent minimization problem. In this paper we exploit a descent approach via the implementation of gradient-based methods to solve CNDP generally where the Karush-Kuhn-Tucker points can be obtained. Four variants of gradient-based methods are presented and numerical comparisons are widely made with the previous on three kinds of test networks. The proposed methods have achieved substantially better results in terms of the robustness to the initials and the computational efficiency in solving equilibrium assignment problems than did others especially when the congested road networks are considered. {\textcopyright} 2004 Elsevier Ltd. All rights reserved.

Solution algorithm for the bi-level discrete network design problem

1. Year: 2005
2. Journal: Transportation Research Part B: Methodological
3. Authors: Gao, Ziyou and Wu, Jianjun and Sun, Huijun

> The discrete network design problem deals with the selection of link additions to an existing road network, with given demand from each origin to each destination. The objective is to make an optimal investment decision in order to minimize the total travel cost in the network, while accounting for the route choice behaviors of network users. Because of the computational difficulties experienced with the solution algorithm of nonlinear bi-level mixed integer programming with a large number of 0-1 variables, the discrete network design problem has been recognized as one of the most difficult yet challenging problems in transport. In this paper, at first a traditional bi-level programming model for the discrete network design problem is introduced, and then a new solution algorithm is proposed by using the support function concept to express the relationship between improvement flows and the new additional links in the existing urban network. Finally, the applications of the new algorithm are illustrated with two numerical examples. Numerical results indicate that the proposed algorithm would be efficient in practice. {\textcopyright} 2004 Published by Elsevier Ltd.

A bi-level model of the relationship between transport and residential location

1. Year: 2006
2. Journal: Transportation Research Part B: Methodological
3. Authors: Chang, Justin Sueun and Mackett, Roger Laurence

> This paper explores a bid-rent network equilibrium model which represents the relationship between transport and residential location. The relationship is examined in terms of the competition of decision-makers for locations. The model discusses difficulties in addressing the characteristics of locations, particularly heterogeneity and indivisibility. A hedonic interpretation is included as a way to resolve these challenges. The model investigates the process in which households make their decisions. This

process is shown as an n-player non-cooperative game, following the Nash equilibrium for this game, which is defined as well. The game is accompanied by the systematic interactions between transport and land-use. A mutual adjustment process represents these interactions. The three components are structured by a bi-level mathematical program. The final formulation is interpreted as an oligopolistic Cournot game of which consequence is an approximation of the n-player non-cooperative game. The functional relationship between the decision variables of the upper and the lower levels of the bi-level program produces endogenously-determined transport impedance and locational attractiveness. The endogenous network performance indices of the model are expected to overcome the lack of a realistic network equilibrium description in the existing models. A path-based heuristic algorithm and a simple numerical example are presented. Finally, some concluding remarks are given. {\textcopyright} 2005 Elsevier Ltd. All rights reserved.

Sensitivity analysis of separable traffic equilibrium equilibria with application to bilevel optimization in network design

1. Year: 2007
2. Journal: Transportation Research Part B: Methodological
3. Authors: Josefsson, Magnus and Patriksson, Michael

We provide a sensitivity analysis of separable traffic equilibrium models with travel cost and demand parameters. We establish that while equilibrium link flows may not always be directionally differentiable (even when the link travel costs are strictly increasing), travel demands and link costs are; this improves the general results of Patriksson [Patriksson, M., 2004. Sensitivity analysis of traffic equilibria. Transportation Science 37, 258-281]. The new results contradict common belief that equilibrium cost and demand sensitivities hinge on that of equilibrium flows. The paper by Tobin and Friesz [Tobin, R.L., Friesz, T.L., 1988. Sensitivity analysis for equilibrium network flow. Transportation Science 22, 242-250] brought the classic non-linear programming subject of sensitivity analysis to transportation science. Theirs is still the most widely used device by which "gradients" of traffic equilibrium solutions are calculated, for use in bilevel transportation planning applications such as network design, origin-destination (OD) matrix estimation and problems where link tolls are imposed on the users in order to reach a traffic management objective. However, it is not widely understood that the regularity conditions proposed by them are stronger than necessary. Also, users of their method sometimes misunderstand its limitations and are not aware of the computational advantages offered by more recent methods. In fact, a more often applicable formula was proposed already by Qiu and Magnanti [Qiu, Y., Magnanti, T.L., 1989. Sensitivity analysis for variational inequalities defined on polyhedral sets. Mathematics of Operations Research 14, 410-432], and Bell and Iida [Bell, M.G.H., Iida, Y., 1997. Transportation Network Analysis. John Wiley & Sons, Chichester, UK] describe one of the cases in practice in which the formula by Tobin and Friesz would not be able to generate sensitivity information, because one of their regularity conditions fails to hold. This paper provides an overview of this formula, and illustrates by means of examples that there are several cases where it is not applicable. Our findings are illustrated with small numerical examples, as are our own analysis. The findings of this paper are hoped to motivate replacing the previous approach with the more often applicable one, not only because of this fact but equally importantly because it is intuitive and also can be much more efficiently utilized: the sensitivity problem that provides the directional derivative is a linearized traffic equilibrium problem, and the sensitivity information can be generated efficiently by only slightly modifying a state-of-the-art traffic equilibrium solver. This is essential for bringing the use of sensitivity analysis in transportation planning beyond the solution of only toy problems. We finally utilize a new

> sensitivity solver in the preliminary testing of a simple heuristic for bilevel optimization in continuous traffic network design, and compare it favourably to previous heuristics on known small-scale problems. {\textcopyright} 2006 Elsevier Ltd. All rights reserved.

A heuristic for the bilevel origin-destination-matrix estimation problem

1. Year: 2008
2. Journal: Transportation Research Part B: Methodological
3. Authors: Lundgren, Jan T. and Peterson, Anders

> In this paper we consider the estimation of an origin-destination (OD)-matrix, given a target OD-matrix and traffic counts on a subset of the links in the network. We use a general nonlinear bilevel minimization formulation of the problem, where the lower level problem is to assign a given OD-matrix onto the network according to the user equilibrium principle. After reformulating the problem to a single level problem, the objective function includes implicitly given link flow variables, corresponding to the given OD-matrix. We propose a descent heuristic to solve the problem, which is an adaptation of the well-known projected gradient method. In order to compute a search direction we have to approximate the Jacobian matrix representing the derivatives of the link flows with respect to a change in the OD-flows, and we propose to do this by solving a set of quadratic programs with linear constraints only. If the objective function is differentiable at the current point, the Jacobian is exact and we obtain a gradient. Numerical experiments are presented which indicate that the solution approach can be applied in practice to medium to large size networks. {\textcopyright} 2007 Elsevier Ltd. All rights reserved.

A variational inequality formulation for inferring dynamic origin-destination travel demands

1. Year: 2008
2. Journal: Transportation Research Part B: Methodological
3. Authors: Nie, Yu (Marco) and Zhang, H. M.

> In this paper, we develop a relaxation strategy to the dynamic O-D estimation problem (DODE) problem. Cast as a variational inequality (VI), the DODE problem endogenizes the determination of the dynamic path-link incidence relationship (i.e., the dynamic assignment matrix) and takes users' response to traffic congestion into account. In our formulation, traffic dynamics on road links can be modeled by the Lighthill, Whitham and Richards theory, a delay-function model, or a point-queue model, coupled with CTM-like flow distribution models at nodes. Which model to use depends, of course, on specific modeling situations. Different from numerous previous studies, our formulation avoids the bi-level structure that poses analytical and numerical difficulties. This is achieved by balancing the path cost and the path deviation (the latter measures the difference between estimated and measured traffic conditions), weighed by a dispersion parameter which determines the extent to which users' behavior is respected. We prove the equivalence between the VI problem and the derived dynamic DODE optimality conditions, and establish the conditions under which a solution to the VI problem exists. A column generation algorithm is proposed to solve the VI problem. Numerical results based on synthetic data are also presented. {\textcopyright} 2008 Elsevier Ltd. All rights reserved.

Multi-period transportation network design under demand uncertainty

1. Year: 2009
2. Journal: Transportation Research Part B: Methodological

3. Authors: Ukkusuri, Satish V. and Patil, Gopal

> The ability to make optimal transportation network investments decision is central to the strategic management of transportation systems. The presence of uncertainty in transportation systems presents new challenges in making optimal network investment decisions. In this paper, we develop a multi time period network design problem considering both demand uncertainty and demand elasticity. Such an approach affords the planner the flexibility to delay, change, or even abandon the future network investment. We measure the flexibility of investing over multiple time periods as compared to a single-stage network design decision. Initially, we provide a taxonomy and define many dimensions of transportation network flexibility. This is followed with the development of a flexible network design formulation (FNDP), in which the investment is staged over multiple time periods. The demand is assumed to be separable and the demand elasticity is captured using a negative exponential distribution. We develop the FNDP formulation as bilevel stochastic mathematical programming with complementarity constraints (STOCH-MPEC) in which the bi-level formulation is converted to a single level using non-linear complementarity constraints conditions for user equilibrium (UE) problem. The formulation is implemented on two test networks and the results show the benefits of FNDP over single-stage NDP-measured in terms of increase in present expected system consumer surplus (PESCS)-are in the range of 10-30%. The results clearly demonstrate that under demand uncertainty there are potential benefits of introducing flexibility in investment decisions. Finally, we conduct a sensitivity analysis of FNDP with different budget values and it is observed that certain paradoxical sharp corners are observed at certain budget values. {\textcopyright} 2009 Elsevier Ltd. All rights reserved.

Global optimum of the linearized network design problem with equilibrium flows

1. Year: 2010
2. Journal: Transportation Research Part B: Methodological
3. Authors: Wang, David Z.W. and Lo, Hong K.

> The road network design problem, typically formulated as a bi-level program or a mathematical program with equilibrium constraints, is generally non-convex. The non-convexity stems from both the traffic assignment equilibrium conditions and the non-linear travel time function. In this study, we formulate the network design problem as a single-level optimization problem with equilibrium constraints, and then we transform the equilibrium constraints into a set of mixed-integer constraints and linearize the travel time function. The final result is that we cast the network design problem with equilibrium flows into a mixed-integer linear program, whose solution possesses the desirable property of global optimality, subject to the resolution of the linearization scheme adopted. {\textcopyright} 2009 Elsevier Ltd. All rights reserved.

Real-time traffic estimation using data expansion

1. Year: 2011
2. Journal: Transportation Research Part B: Methodological
3. Authors: Lederman, Roger and Wynter, Laura

> This paper presents a method for estimating missing real-time traffic volumes on a road network using both historical and real-time traffic data. The method was developed to address urban transportation networks where a non-negligible subset of the network links do not have real-time link volumes, and

> where that data is needed to populate other real-time traffic analytics. Computation is split between an offline calibration and a real-time estimation phase. The offline phase determines link-to-link splitting probabilities for traffic flow propagation that are subsequently used in real-time estimation. The real-time procedure uses current traffic data and is efficient enough to scale to full city-wide deployments. Simulation results on a medium-sized test network demonstrate the accuracy of the method and its robustness to missing data and variability in the data that is available. For traffic demands with a coefficient of variation as high as 40%, and a real-time feed in which as much as 60% of links lack data, we find the percentage root mean square error of link volume estimates ranges from 3.9% to 18.6%. We observe that the use of real-time data can reduce this error by as much as 20%. {\textcopyright} 2011 Elsevier Ltd.

Bush-based sensitivity analysis for approximating subnetwork diversion

1. Year: 2012
2. Journal: Transportation Research Part B: Methodological
3. Authors: Boyles, Stephen D.

> Subnetwork analysis is often used in traffic assignment problems to reduce the size of the network being analyzed, with a corresponding decrease in computation time. This is particularly important in network design, second-best pricing, or other bilevel problems in which many equilibrium runs must be solved as a subproblem to a master optimization program. A fixed trip table based on an equilibrium path flow solution is often used, but this ignores important attraction and diversion effects as drivers (globally) change routes in response to (local) subnetwork changes. This paper presents an approach for replacing a regional network with a smaller one, containing all of the subnetwork, and zones. Artificial arcs are created to represent " all paths" between each origin and subnetwork boundary node, under the assumption that the set of equilibrium routes does not change. The primary contribution of the paper is a procedure for estimating a cost function on these artificial arcs, using derivatives of the equilibrium travel times between the end nodes to create a Taylor series. A bush-based representation allows rapid calculation of these derivatives. Two methods for calculating these derivatives are presented, one based on network transformations and resembling techniques used in the analysis of resistive circuits, and another based on iterated solution of a nested set of linear equations. These methods are applied to two networks, one small and artificial, and the other a regional network representing the Austin, Texas metropolitan area. These demonstrations show substantial improvement in accuracy as compared to using a fixed table, and demonstrate the efficiency of the proposed approach. {\textcopyright} 2011 Elsevier Ltd.

Dynamic congestion pricing with demand uncertainty: A robust optimization approach

1. Year: 2012
2. Journal: Transportation Research Part B: Methodological
3. Authors: Chung, Byung Do and Yao, Tao and Friesz, Terry L. and Liu, Hongcheng

> In this paper, we consider dynamic congestion pricing in the presence of demand uncertainty. In particular, we apply a robust optimization (RO) approach based on a bi-level cellular particle swarm optimization (BCPSO) to optimal congestion pricing problems when flows correspond to dynamic user equilibrium on the network of interest. Such a formulation is recognized as a second-best pricing problem, and we refer to it as the dynamic optimal toll problem with equilibrium constraints (DOTPEC). We then present numerical experiments in which BCPSO is compared with two alternative robust

> dynamic solution approaches: bi-level simulated annealing (BSA) and cutting plane-based simulated annealing (CPSA), as well as a nominal dynamic solution and a robust static solution. We show that robust dynamic solutions improve the worst case, average, and stability of total travel cost in comparison with the nominal dynamic and the robust static solutions. The numerical results also show that BCPSO outperforms BSA and CPSA in terms of solution quality and computational efficiency. {\textcopyright} 2012 Elsevier Ltd.

Integrated operations planning and revenue management for rail freight transportation

1. Year: 2012
2. Journal: Transportation Research Part B: Methodological
3. Authors: Crevier, Benoit and Cordeau, Jean Fran{\c{c}}ois and Savard, Gilles

> In the rail industry, profit maximization relies heavily on the integration of logistics activities with an improved management of revenues. The operational policies chosen by the carrier have an important impact on the network yield and thus on global profitability. This paper bridges the gap between railroad operations planning and revenue management. We propose a new bilevel mathematical formulation which encompasses pricing decisions and network planning policies such as car blocking and routing as well as train make-up and scheduling. An exact solution approach based on a mixed integer formulation adapted to the problem structure is presented, and computational results are reported on randomly generated instances. {\textcopyright} 2011 Elsevier Ltd.

Optimizing toll locations and levels using a mixed integer linear approximation approach

1. Year: 2012
2. Journal: Transportation Research Part B: Methodological
3. Authors: Ekstr{"{o}}m, Joakim and Sumalee, Agachai and Lo, Hong K.

> This paper addresses the toll design problem of finding the toll locations and levels in a congestion pricing scheme, which minimize the total travel time and the toll-point cost (set-up and operational costs of the toll collecting facilities). Road users in the network are assumed to be distributed according to the principle of user equilibrium, with the demand assumed to be fixed and given a priori. The toll design problem is commonly formulated as a non-linear program, which in general is non-convex and non-smooth, and thus difficult to solve for a global optimum. In this paper, the toll design problem is approximated by a mixed integer linear program (MILP), which can be solved to its globally optimal solution. The MILP also gives a lower bound estimation of the original non-linear problem, and the accuracy of the approximation is improved by iteratively updating the MILP. To demonstrate the approach, we apply the algorithm to two networks: a smaller network with 18 links and 4 OD-pairs to illustrate the properties of the approach, and the Sioux Falls network with 87 links and 30 OD-pairs to demonstrate the applicability of the approach. {\textcopyright} 2012 Elsevier Ltd.

Optimizing the freight train connection service network of a large-scale rail system

1. Year: 2012
2. Journal: Transportation Research Part B: Methodological
3. Authors: Lin, Bo Liang and Wang, Zhi Mei and Ji, Li Jun and Tian, Ya Ming and Zhou, Guo Qing

> This paper presents a formulation and solution for the train connection services (TCSs) problem in a large-scale rail network in order to determine the optimal freight train services, the frequency of

> services, and the distribution of classification workload among yards. TCS problem is modeled as a bi-level programming problem. The upper-level is intended to find an optimal train connection service, and the lower-level is used for assigning each shipment to a sequence of train services and determining the frequency of services.Our model solves the TCS problem of the China railway system, which is one of the largest railway systems in the world. The system consists of 5544 stations, and over 520,000 shipments using this system for a year period. A subnetwork is defined with 127 yards having some minimum level of reclassification resources and 14,440 demands obtained by aggregating 520,000 shipments to the subnetwork. We apply a simulated annealing algorithm to the data for optimal computation after pre-processing and get an excellent result. Comparing our optimal solution with the existing plan result, there are improvements of about 20.8% in the total cost. {\textcopyright} 2011 Elsevier Ltd.

A new one-level convex optimization approach for estimating origin-destination demand

1. Year: 2012
2. Journal: Transportation Research Part B: Methodological
3. Authors: Shen, Wei and Wynter, Laura

> Accurately estimating Origin-Destination (OD) trip tables based on traffic data has become crucial in many real-time traffic applications. The problem of OD estimation is traditionally modeled as a bilevel network design problem (NDP), which is challenging to solve in large-scale networks. In this paper, we propose a new one-level convex optimization formulation to reasonably approximate the bilevel structure, thus allowing the development of more efficient solution algorithms. This one-level approach is consistent with user equilibrium conditions, and improves previous one-level relaxed OD estimation formulations in the literature by 'equilibrating' path flows using external path cost parameters. Our new formulation can, in fact, be viewed as a special case of the user equilibrium assignment problem with elastic demand, and hence can be solved efficiently by standard path-based traffic assignment algorithms with an iterative parameter updating scheme. Numerical experiments indicate that this new one-level approach performs very well. Estimation results are robust to network topology, sensor coverage, and observation error, and can achieve further improvements when additional data sources are included. {\textcopyright} 2012 Elsevier Ltd.

Two-stage stochastic bilevel programming over a transportation network

1. Year: 2013
2. Journal: Transportation Research Part B: Methodological
3. Authors: Alizadeh, S. M. and Marcotte, P. and Savard, G.

> We consider a two-stage stochastic extension of the bilevel pricing model introduced by Labb{'{e}} et al. (1998). In the first stage, the leader sets tariffs on a subset of arcs of a transportation network, with the aim of maximizing profits while, at the lower level, flows are assigned to cheapest paths of a multicommodity transportation network. In the second stage, the situation repeats itself under the constraint that tariffs should not differ too widely from those set at the first stage, a condition that frequently arises in practice. We analyze properties of the model, provide numerical illustrations, and open avenues for further research into this area. {\textcopyright} 2013 Elsevier Ltd.

On activity-based network design problems

1. Year: 2013

2. Journal: Transportation Research Part B: Methodological
3. Authors: Kang, Jee Eun and Chow, Joseph Y.J. and Recker, Will W.

This paper examines network design where OD demand is not known a priori, but is the subject of responses in household or user itinerary choices to infrastructure improvements. Using simple examples, we show that falsely assuming that household itineraries are not elastic can result in a lack in understanding of certain phenomena; e.g., increasing traffic even without increasing economic activity due to relaxing of space-time prism constraints, or worsening of utility despite infrastructure investments in cases where household objectives may conflict. An activity-based network design problem is proposed using the location routing problem (LRP) as inspiration. The bilevel formulation includes an upper level network design and shortest path problem while the lower level includes a set of disaggregate household itinerary optimization problems, posed as household activity pattern problem (HAPP) (or in the case with location choice, as generalized HAPP) models. As a bilevel problem with an NP-hard lower level problem, there is no algorithm for solving the model exactly. Simple numerical examples show optimality gaps of as much as 5% for a decomposition heuristic algorithm derived from the LRP. A large numerical case study based on Southern California data and setting suggest that even if infrastructure investments do not result in major changes in link investment decisions compared to a conventional model, the results provide much higher resolution temporal OD information to a decision maker. Whereas a conventional model would output the best set of links to invest given an assumed OD matrix, the proposed model can output the same best set of links, the same daily OD matrix, and a detailed temporal distribution of activity participation and travel from which changes in peak period OD patterns can be observed. {\textcopyright} 2013 Elsevier Ltd.

Global optimization methods for the discrete network design problem

1. Year: 2013
2. Journal: Transportation Research Part B: Methodological
3. Authors: Wang, Shuaian and Meng, Qiang and Yang, Hai

This paper addresses the discrete network design problem (DNDP) with multiple capacity levels, or multi-capacity DNDP for short, which determines the optimal number of lanes to add to each candidate link in a road network. We formulate the problem as a bi-level programming model, where the upper level aims to minimize the total travel time via adding new lanes to candidate links and the lower level is a traditional Wardrop user equilibrium (UE) problem. We propose two global optimization methods by taking advantage of the relationship between UE and system optimal (SO) traffic assignment principles. The first method, termed as SO-relaxation, exploits the property that an optimal network design solution under SO principle can be a good approximate solution under UE principle, and successively sorts the solutions in the order of increasing total travel time under SO principle. Optimality is guaranteed when the lower bound of the total travel time of the unexplored solutions under UE principle is not less than the total travel time of a known solution under UE principle. The second method, termed as UE-reduction, adds the objective function of the Beckmann-McGuire-Winsten transformation of UE traffic assignment to the constraints of the SO-relaxation formulation of the multi-capacity DNDP. This constraint is convex and strengthens the SO-relaxation formulation. We also develop a dynamic outer-approximation scheme to make use of the state-of-the-art mixed-integer linear programming solvers to solve the SO-relaxation formulation. Numerical experiments based on a two-link network and the Sioux-Falls network are conducted. {\textcopyright} 2013 Elsevier Ltd.

Travel time resilience of roadway networks under disaster

1. Year: 2014
2. Journal: Transportation Research Part B: Methodological
3. Authors: Faturechi, Reza and Miller-Hooks, Elise

> A bi-level, three-stage Stochastic Mathematical Program with Equilibrium Constraints (SMPEC) is proposed for quantifying and optimizing travel time resilience in roadway networks under non-recurring natural or human-induced disaster events. At the upper-level, a sequence of optimal preparedness and response decisions is taken over pre-event mitigation and preparedness and post-event response stages of the disaster management life cycle. Assuming semi-adaptive user behavior exists shortly after the disaster and after the implementation of immediate response actions, the lower-level problem is formulated as a Partial User Equilibrium, where only affected users are likely to rethink their routing decisions. An exact Progressive Hedging Algorithm is presented for solution of a single-level equivalent, linear approximation of the SMPEC. A recently proposed technique from the literature that uses Schur's decomposition with SOS1 variables in creating a linear equivalent to complementarity constraints is employed. Similarly, recent advances in piecewise linearization are exploited in addressing nonseparable link travel time functions. The formulation and solution methodology are demonstrated on an illustrative example.

Benders decomposition for discrete-continuous linear bilevel problems with application to traffic network design

1. Year: 2014
2. Journal: Transportation Research Part B: Methodological
3. Authors: Fontaine, Pirmin and Minner, Stefan

> We propose a new fast solution method for linear Bilevel Problems with binary leader and continuous follower variables under the partial cooperation assumption. We reformulate the Bilevel Problem into a single-level problem by using the Karush-Kuhn-Tucker conditions. This non-linear model can be linearized because of the special structure achieved by the binary leader decision variables and subsequently solved by a Benders Decomposition Algorithm to global optimality. We illustrate the capability of the approach on the Discrete Network Design Problem which adds arcs to an existing road network at the leader stage and anticipates the traffic equilibrium for the follower stage. Because of the non-linear objective functions of this problem, we use a linearization method for increasing, convex and non-linear functions based on continuous variables. Numerical tests show that this algorithm can solve even large instances of Bilevel Problems.

Joint optimization of freight facility location and pavement infrastructure rehabilitation under network traffic equilibrium

1. Year: 2014
2. Journal: Transportation Research Part B: Methodological
3. Authors: Hajibabai, Leila and Bai, Yun and Ouyang, Yanfeng

> Establishment of industry facilities often induces heavy vehicle traffic that exacerbates congestion and pavement deterioration in the neighboring highway network. While planning facility locations and land use developments, it is important to take into account the routing of freight vehicles, the impact on public traffic, as well as the planning of pavement rehabilitation. This paper presents an integrated

> facility location model that simultaneously considers traffic routing under congestion and pavement rehabilitation under deterioration. The objective is to minimize the total cost due to facility investment, transportation cost including traffic delay, and pavement life-cycle costs. Building upon analytical results on optimal pavement rehabilitation, the problem is formulated into a bi-level mixed-integer non-linear program (MINLP), with facility location, freight shipment routing and pavement rehabilitation decisions in the upper level and traffic equilibrium in the lower level. This problem is then reformulated into an equivalent single-level MINLP based on Karush-Kuhn-Tucker (KKT) conditions and approximation by piece-wise linear functions. Numerical experiments on hypothetical and empirical network examples are conducted to show performance of the proposed algorithm and to draw managerial insights. {\textcopyright} 2014 Elsevier Ltd.

Estimation of mean and covariance of peak hour origin-destination demands from day-to-day traffic counts

1. Year: 2014
2. Journal: Transportation Research Part B: Methodological
3. Authors: Shao, Hu and Lam, William H.K. and Sumalee, Agachai and Chen, Anthony and Hazelton, Martin L.

> This paper proposes a generalized model to estimate the peak hour origin-destination (OD) traffic demand variation from day-to-day hourly traffic counts throughout the whole year. Different from the conventional OD estimation methods, the proposed modeling approach aims to estimate not only the mean but also the variation (in terms of covariance matrix) of the OD demands during the same peak hour periods due to day-to-day fluctuation over the whole year. For this purpose, this paper fully considers the first- and second-order statistical properties of the day-to-day hourly traffic count data so as to capture the stochastic characteristics of the OD demands. The proposed model is formulated as a bi-level optimization problem. In the upper-level problem, a weighted least squares method is used to estimate the mean and covariance matrix of the OD demands. In the lower-level problem, a reliability-based traffic assignment model is adopted to take account of travelers' risk-taking path choice behaviors under OD demand variation. A heuristic iterative estimation-assignment algorithm is proposed for solving the bi-level optimization problem. Numerical examples are presented to illustrate the applications of the proposed model for assessment of network performance over the whole year. {\textcopyright} 2014 Elsevier Ltd.

Transit route and frequency design: Bi-level modeling and hybrid artificial bee colony algorithm approach

1. Year: 2014
2. Journal: Transportation Research Part B: Methodological
3. Authors: Szeto, W. Y. and Jiang, Y.

> This paper proposes a bi-level transit network design problem where the transit routes and frequency settings are determined simultaneously. The upper-level problem is formulated as a mixed integer non-linear program with the objective of minimizing the number of passenger transfers, and the lower-level problem is the transit assignment problem with capacity constraints. A hybrid artificial bee colony (ABC) algorithm is developed to solve the bi-level problem. This algorithm relies on the ABC algorithm to design route structures and a proposed descent direction search method to determine an optimal frequency setting for a given route structure. The descent direction search method is developed by

> analyzing the optimality conditions of the lower-level problem and using the relationship between the lower- and upper-level objective functions. The step size for updating the frequency setting is determined by solving a linear integer program. To efficiently repair route structures, a node insertion and deletion strategy is proposed based on the average passenger demand for the direct services concerned. To increase the computation speed, a lower bound of the objective value for each route design solution is derived and used in the fitness evaluation of the proposed algorithm. Various experiments are set up to demonstrate the performance of our proposed algorithm and the properties of the problem. {\textcopyright} 2014 Elsevier Ltd.

Mathematical programming formulations for transit network design

1. Year: 2015
2. Journal: Transportation Research Part B: Methodological
3. Authors: Cancela, H{'{e}}ctor and Mauttone, Antonio and Urquhart, Mar{'{i}}a E.

> In this work, we study the transit network design problem from the perspective of mathematical programming. More precisely, we consider the problem of defining the number and itinerary of bus routes and their frequencies, for a public transportation system. In this problem, the routes should be defined in terms of a given infrastructure of streets and stops and should cover a given origin-destination demand. The solution (routes and frequencies) should be convenient for the users and the operators. We review existing mathematical programming formulations and propose a new one, paying attention to the following aspects of public transportation systems, that are identified as key elements in order to have a realistic model: (a) the interest of the users, (b) the interest of the operators, (c) the behavior of the users, and (d) constraints regarding transfer, infrastructure and bus capacity. First, we discuss the formulations existing on the literature, in terms of the aspects mentioned above. Second, we propose a mixed integer linear programming (MILP) formulation, that incorporates the waiting time and the existence of multiple lines in the behavior of the users. We validate the proposed formulation using several cases, including a real one. Also, we compare the obtained results against results from the existing literature. In order to include transfer, infrastructure and bus capacity constraints, we propose an extension to the formulation and we discuss its impact in the structure of the model, based on concepts of bi-level mathematical programming. The mathematical formulations developed contribute towards a more realistic modeling effort, taking into account important aspects of the real system which were not included in previous proposals in the literature.

Second best toll pricing within the framework of bounded rationality

1. Year: 2016
2. Journal: Transportation Research Part B: Methodological
3. Authors: Di, Xuan and Liu, Henry X. and Ban, Xuegang Jeff

> The network design problem is usually formulated as a bi-level program, assuming the user equilibrium is attained in the lower level program. Given boundedly rational route choice behavior, the lower-level program is replaced with the boundedly rational user equilibria (BRUE). The network design problem with boundedly rational route choice behavior is understudied due to non-uniqueness of the BRUE. In this study, thus, we mainly focus on boundedly rational toll pricing (BR-TP) with affine link cost functions. The topological properties of the lower level BRUE set are first explored. As the BRUE solution is generally non-unique, urban planners cannot predict exactly which equilibrium flow pattern the transportation network will operate after a planning strategy is implemented. Due to the risk

> caused by uncertainty of people's reaction, two extreme scenarios are considered: the traffic flow patterns with either the minimum system travel cost or the maximum, which is the "risk-prone" (BR-TP-RP) or the "risk-averse" (BR-TP-RA) scenario respectively. The upper level BR-TP is to find an optimal toll minimizing the total system travel cost, while the lower level is to find the best or the worst scenario. Accordingly BR-TP can be formulated as either a min -min or a min -max program. Solution existence is discussed based on the topological properties of the BRUE and algorithms are proposed. Two examples are accompanied to illustrate the proposed methodology.

Regulating hazardous materials transportation by dual toll pricing

1. Year: 2016
2. Journal: Transportation Research Part B: Methodological
3. Authors: Esfandeh, Tolou and Kwon, Changhyun and Batta, Rajan

> We investigate dual-toll setting as a policy tool to mitigate the risk of hazardous material (hazmat) shipment in road networks. We formulate the dual-toll problem as a bi-level program wherein the upper level aims at minimizing the risk, and the lower level explores the user equilibrium decision of the regular vehicles and hazmat carriers given the toll. When the upper level objective is to minimize the risk and all links are tollable, we decompose the formulation into first-stage and second-stage, and suggest a computational method to solve each stage. Our two-stage solution methodology guarantees nonnegative valid dual tolls regardless of the solution accuracy of the first-stage problem. We also consider a general dual-toll setting problem where the regulator rather wishes to minimize a combination of risk and the paid tolls and/or some links are untollable. To solve this truly bilevel problem, we provide heuristic algorithms that decompose the problem into subproblems each being solved by a line search. Case studies based on the Sioux Falls network illustrate the insights on the dual-toll policies.

Optimal design of autonomous vehicle zones in transportation networks

1. Year: 2017
2. Journal: Transportation Research Part B: Methodological
3. Authors: Chen, Zhibin and He, Fang and Yin, Yafeng and Du, Yuchuan

> This paper advocates the need for infrastructure planning to adapt to and further promote the deployment of autonomous vehicle (AV) technology. It is envisioned that in the future government agencies will dedicate certain areas of road networks to AVs only to facilitate the formulation of vehicle platoons to improve throughput and hopefully improve the performance of the whole network. This paper aims to present a mathematical framework for the optimal design of AV zones in a general network. With the presence of AV zones, AVs may apply different routing principles outside of and within the AV zones. A novel network equilibrium model (we refer to it as the “mixed routing equilibrium model”) is thus firstly proposed to capture such mixed-routing behaviors. We then proceed to formulate a mixed-integer bi-level programming model to optimize the deployment plan of AV zones. Numerical examples are presented to demonstrate the performance of the proposed models.

On joint railway and housing development: Housing-led versus railway-led schemes

1. Year: 2017
2. Journal: Transportation Research Part B: Methodological
3. Authors: Ng, Ka Fai and Lo, Hong K.

> This paper develops a time-dependent framework to analyze the revenues and costs of housing and railway developments over time in a Transit Oriented Development, explicitly capturing the housing and railway development phasing. A bi-level mathematical program is formulated, in which the upper level optimizes the housing supply and railway development over time based on the perspective of a joint housing and railway developer, versus that of consumers and that of government. At the lower level, a nested logit framework is formulated to model the combined bid-rent process, residents' location and travel choices in each period. Under certain assumptions, this study derives analytically the lead-lag relationships between housing development and railway development, based on the initial housing and transport conditions, as well as the stakeholders' perspectives. The development strategies are generally different among the stakeholders, whilst possible win-win situations, in terms of developer profitability and consumer surplus, are identified under certain low housing density conditions, leading to a social optimum. This study also conducts sensitivity analyses to extend the results to multiple time periods and heterogeneous income classes, revealing that, for profitability, the joint developer may introduce housing development phasing that segregates residents of different income classes.

A new solution framework for the limited-stop bus service design problem

1. Year: 2017
2. Journal: Transportation Research Part B: Methodological
3. Authors: Soto, Guillermo and Larrain, Homero and Mu{~{n}}oz, Juan Carlos

> Limited-stop services are a key element to the successful operation of bus rapid transit corridors. In this study, we present a framework for addressing the limited-stop service design problem over a corridor, and formally introduce a family of subproblems involved in its solution. Using a bi-level optimization approach, we introduce a method of designing these services while considering bus capacity, transfers, and two behavioral models for passengers: deterministic and stochastic. The algorithm and its variants were tested on nine scenarios with up to 80 stops. Working with deterministic passenger assignment, our model solved the problem in a small fraction of the time required by a benchmark algorithm. We use this algorithm to show that neglecting transfers can lead to suboptimal solutions. We finally show that although it makes the problem much harder, working with stochastic assignment leads to more realistic and robust solutions.

Modeling collusion-proof port emission regulation of cargo-handling activities under incomplete information

1. Year: 2017
2. Journal: Transportation Research Part B: Methodological
3. Authors: Zheng, Shiyuan and Ge, Ying En and Fu, Xiaowen and {Nie (Marco)}, Yu and Xie, Chi

> This study models the emission regulation of a port's cargo-handling activities when the regulatory government agency lacks complete information on the cost of reducing emissions for the port. The goal is to identify rules for determining the optimal port charge and capacity to allow port emissions to be regulated in an environment with incomplete information. We evaluate the effect of introducing a risk-averse environmental monitor as a supervisor to provide the government with additional information (a signal) on the port operator's emission reduction cost. To prevent the environmental monitor from colluding with the port operator, we develop a collusion-proof regulation scheme based on the principal–agent theory. The scheme is modeled as a bi-level problem faced by the government

> and the monitor. We find that, compared to the case with complete information, collusion-proof regulation do not distort optimal port charges only when the port operator is efficient and has low emission reduction costs. When distortion does occur, it depends on the monitor's degree of risk aversion and the accuracy of the signal about emission reduction cost. Besides, information asymmetry leads to less cargo throughput, a lower emission level, and reduced port capacity. Such regulation-induced downward distortion can be either alleviated or aggravated by the collusion-proof regulation, depending on the quality of the information received by the environmental monitor. Our theoretical models are tested using a case study based on container terminals in the Port of Shanghai. The numerical results suggest that a risk-averse environmental monitor can improve port user's social welfare in the presence of imperfect information.

Efficient and fair system states in dynamic transportation networks

1. Year: 2017
2. Journal: Transportation Research Part B: Methodological
3. Authors: Zhu, Feng and Ukkusuri, Satish V.

> This paper sets out to model an efficient and fair transportation system accounting for both departure time choice and route choice of a general multi-OD network within a dynamic traffic assignment environment. Firstly, a bi-level optimization formulation is introduced based on the link-based traffic flow model. The upper level of the formulation minimizes the total system travel time, whereas the lower level captures traffic flow propagation and the user equilibrium constraints. Then the bi-level formulation is relaxed to a linear programming formulation that produces a lower bound of an efficient and fair system state. An efficient iterative algorithm is proposed to obtain the exact solution. It only requires solving one linear program in one iteration. Further, it is shown that the number of iterations is bounded, and the output traffic flow pattern is efficient and fair. Finally, two numerical cases (including a single OD network and a multi-OD network) are conducted to demonstrate the performance of the algorithm. The results consistently show that the departure rate pattern generated from the algorithm leads to an efficient and fair system state, and the algorithm converges within two iterations across all test scenarios.

Co-opetition in enhancing global port network resiliency: A multi-leader, common-follower game theoretic approach

1. Year: 2018
2. Journal: Transportation Research Part B: Methodological
3. Authors: Asadabadi, Ali and Miller-Hooks, Elise

> Ports are key elements of global supply chains, providing connection between land- and maritime-based transportation modes. They operate in cooperative, but competitive, co-opetitive, environments wherein individual port throughput is linked through an underlying transshipment network. Short-term port performance and long-term market share can be significantly impacted by a disaster event; thus, ports plan to invest in capacity expansion and protective measures to increase their reliability or resiliency in times of disruption. To account for the co-opetition among ports, a bi-level multiplayer game theoretic approach is used, wherein each individual port takes protective investment decisions while anticipating the response of the common market-clearing shipping assignment problem in the impacted network. This lower-level assignment is modeled as a cost minimization problem, which allows for consideration of gains and losses from other ports decisions through changes in port and

> service capacities and port cargo handling times. Linear properties of the lower-level formulation permit reformulation of the individual port bi-level optimization problems as single-level problems by replacing the common lower-level by its equivalent Karush Kuhn Tucker (KKT) conditions. Simultaneous consideration of individual port optimization problems creates a multi-leader, common-follower problem, i.e. an unrestricted game, that is modeled as an Equilibrium Problem with Equilibrium Constraints (EPEC). Equilibria solutions are sought by use of a diagonalization technique. Solutions of unrestricted, semi-restricted and restricted games are analyzed and compared for a hypothetical application from the literature involving ports in East Asia and Europe. The proposed co-opetitive approach was found to lead to increased served total demand, significantly increased market share for many ports and improved services for shippers.

A link-node reformulation of ridesharing user equilibrium with network design

1. Year: 2018
2. Journal: Transportation Research Part B: Methodological
3. Authors: Di, Xuan and Ma, Rui and Liu, Henry X. and Ban, Xuegang (Jeff)

> Though the conventional network design is extensively studied, the network design problem for ridesharing, in particular, the deployment of high-occupancy toll (HOT) lanes, remains understudied. This paper focuses on one type of network design problem as to whether existing roads should be retrofit into HOT lanes. It is a continuous bi-level mathematical program with equilibrium constraints. The lower level problem is ridesharing user equilibrium (RUE). To reduce the problem size and facilitate computation, we reformulate RUE in the link-node representation. Then we extend the RUE framework to accommodate the presence of HOT lanes and tolls. Algorithms are briefly discussed and numerical examples are illustrated on the Braess network and the Sioux Falls network, respectively. Results show that carefully selecting the deployment of HOT lanes can improve the overall system travel time.

Transportation network design for maximizing flow-based accessibility

1. Year: 2018
2. Journal: Transportation Research Part B: Methodological
3. Authors: Di, Zhen and Yang, Lixing and Qi, Jianguo and Gao, Ziyou

> One of the significant aims of transportation network design and management is to improve the service level of the network and the accessibility of individual trips in a certain period. By adopting a well-defined accessibility measure, this paper studies a new discrete network design problem for metropolitan areas, in which some concepts, including the accessible flow, travel time budget function and principles of user equilibrium and system optimization with travel time budgets, are proposed. Then, two deterministic bi-level programming models are firstly formulated to maximize the network accessible flow. The upper level focuses on choosing the potential links in the pre-specified candidate set, and the lower level assigns all the flows to the super network with principles of user equilibrium or system optimization with travel time budgets. Moreover, to handle uncertain potential demands in reality, the problem of interest is further formulated as two-stage stochastic programming models. To solve these proposed models, efficient heuristic algorithms are designed on the basis of probability search algorithm, Frank–Wolfe algorithm and Monte Carlo simulation method. Finally, two sets of numerical experiments in the Sioux Falls network and San Diego freeway network, are executed to test and analyze the rationality and efficiency of the proposed approaches.

The Boundedly Rational User Equilibrium: A parametric analysis with application to the Network Design Problem

1. Year: 2018
2. Journal: Transportation Research Part B: Methodological
3. Authors: Eikenbroek, Oskar A.L. and Still, Georg J. and van Berkum, Eric C. and Kern, Walter

> In this paper, we study a static traffic assignment that accounts for the boundedly rational route choice behavior of travelers. This assignment induces uncertainties to the ex-ante evaluation of a policy measure: the boundedly rational assignment is non-unique and the indifference band is an uncertain parameter. We consider two different ways to model the optimization problem that finds the best and worst-performing Boundedly Rational User Equilibrium with respect to the total travel time (Best/Worst-case BRUE). The first is the so-called branch approach, the second is a bilevel model. The latter approach is better suited to exploit techniques from parametric optimization and enables us, e.g., to prove the continuity of the optimal value function corresponding to the Best/Worst-case BRUE with respect to perturbations in the indifference band. We report on some numerical experiments. In addition, we extend our results to the Network Design Problem: we prove the existence of a second-best toll pricing scheme under bounded rationality.

Integrated public transport timetable synchronization and vehicle scheduling with demand assignment: A bi-objective bi-level model using deficit function approach

1. Year: 2018
2. Journal: Transportation Research Part B: Methodological
3. Authors: Liu, Tao and Ceder, Avishai (Avi)

> In the operations planning process of public transport (PT), timetable synchronization is a useful strategy utilized to reduce transfer waiting time and improve service connectivity. However, most of the studies on PT timetable synchronization design have treated the problem independently of other operations planning activities, and have focused only on minimizing transfer waiting time. In addition, the impact of schedule changes on PT users' route/trip choice behavior has not been well investigated yet. This work develops a new bi-objective, bi-level integer programming model, taking into account the interests of PT users and operators in attaining optimization of PT timetable synchronization integrated with vehicle scheduling and considering user demand assignment. Based on the special structure characteristics of the model, a novel deficit function (DF)-based sequential search method combined with network flow and shifting vehicle departure time techniques is proposed to achieve a set of Pareto-efficient solutions. The graphical features of the DF can facilitate a decision-making process for PT schedulers for finding a desirable solution. Two numerical examples are illustrated to demonstrate the methodology developed.

Profit-oriented fixed-charge network design with elastic demand

1. Year: 2019
2. Journal: Transportation Research Part B: Methodological
3. Authors: Zetina, Carlos Armando and Contreras, Ivan and Cordeau, Jean Fran{\c{c}}ois

> This paper extends classic fixed-charge multicommodity network design by explicitly considering demand elasticity with respect to routing cost in a profit maximization context with service commitments. Demand quantity is determined by a spatial interaction model that accounts for routing

> costs, thus capturing the trade-off between infrastructure investment, efficient routing, and increased revenue. A numerical example is presented to demonstrate the added value of incorporating demand elasticity in profit-oriented network design problems. An arc-based and a path-based formulation, both with the flexibility of incorporating O/D pair selection by means of network and data transformations, are presented. The arc-based formulation is solved using state-of-the-art global optimization software while the path-based formulation serves as the basis for a hybrid matheuristic that combines a slope scaling metaheuristic and column generation. Computational experience shows the hybrid matheuristic to be superior in terms of solution quality and computation time.

A bi-level capacitated P-median facility location problem with the most likely allocation solution

1. Year: 2019
2. Journal: Transportation Research Part B: Methodological
3. Authors: Abareshi, Maryam and Zaferanieh, Mehdi

> In this paper, a bi-level model is introduced to evaluate the capacitated p-median facility location problem with the most likely allocation solution. The classical capacitated p-median problem is considered in the upper-level to minimize the cost of locating facilities and serving demands while a log-based model resulting from the minimum information approach is used in the lower-level to determine the most likely allocation solution based on the available information. Using Lagrangian dual theory, the proposed bi-level problem is reduced to a new one-level nonlinear mixed-integer problem whose solution is obtained by comparing two mixed-integer linear problems. Some numerical examples are provided to illustrate the added value of the proposed model.

Congestion and environmental toll schemes for the morning commute with heterogeneous users and parallel routes

1. Year: 2019
2. Journal: Transportation Research Part B: Methodological
3. Authors: Long, Jiancheng and Szeto, W. Y.

> We design a congestion and environmental toll (CET) scheme for the morning commute with heterogeneous users in a single OD network with parallel routes. The designed toll scheme relies upon the concept of marginal-cost pricing and is anonymous. The Henderson approach is used to model road congestion and the tolling problem to examine commuter's arrival time and route choice at the CET equilibrium (CETE). Linear interpolation is applied to approximate the emission cost function and the resulting CETE problem is formulated as an unconstrained optimization problem, which is solved by the modified Broyden-Fletcher-Goldfarb-Shanno (BFGS) method. Unlike the existing approach, this novel approach does not require that the arrival of each group of commuters at the destination at the equilibrium follows a predetermined order, and can handle non-monotone (emission) cost function. As two special cases, no-toll equilibrium (NTE) and the congestion toll equilibrium (CTE) are also examined, and the two resultant equilibrium problems are formulated and solved by the same approach. This approach is shown to be more efficient than the existing approach. Bi-level programming models are proposed to formulate the optimal congestion toll and CET design problems, in which the CTE and CETE problems are the corresponding lower level problem. These models are solved by the double BFGS method, which uses a classical BFGS method to solve the upper level model and the proposed BFGS method to solve the lower level model. Finally, numerical examples are

> provided to illustrate the properties of the models and the efficiency of the proposed solution algorithms.

Stochastic bus schedule coordination considering demand assignment and rerouting of passengers

1. Year: 2019
2. Journal: Transportation Research Part B: Methodological
3. Authors: Wu, Weitiao and Liu, Ronghui and Jin, Wenzhou and Ma, Changxi

> Schedule coordination is a proven strategy to improve the connectivity and service quality for bus networks, whereas current research mostly optimizes schedule design using the a priori knowledge of users' routings and ignores the behavioural reactions to coordination status. This study proposes a novel stochastic bus schedule coordination design with demand assignment and passenger rerouting in case of transfer failure. To this end, we develop a bi-level programming model in which the schedule design (headways and slack times) and passenger route choice are determined simultaneously via two travel strategies: non-adaptive and adaptive routings. In the second strategy, transfer passengers would modify their paths in case of missed connection. In this way, the expected network flow distribution is dependent on both the transfer reliability and network structure. The upper-level problem is formulated as a mixed integer non-linear program with the objective of minimizing the total system cost, including both operation cost and user cost, while the lower-level problem is route choice (pre-trip and on-trip) model for timed-transfer service. A more generalized inter-ratio headways scenario is also taken into account. A heuristic algorithm and the method of successive averages are comprehensively applied for solving the bi-level model. Results show that when the rerouting behaviour is considered, more cost-effective schedule coordination scheme with less slack times can be achieved, and ignoring such effect would underestimate the efficacy of schedule coordination scheme.

Path-based dynamic pricing for vehicle allocation in ridesharing systems with fully compliant drivers

1. Year: 2020
2. Journal: Transportation Research Part B: Methodological
3. Authors: Lei, Chao and Jiang, Zhoutong and Ouyang, Yanfeng

> Rapidly advancing on-demand ridesharing services, including those with self-driving technologies, hold the promise to revolutionize delivery of mobility. Yet, significant imbalance between spatiotemporal distributions of vehicle supply and travel demand poses a pressing challenge. This paper proposes a multi-period game-theoretic model that addresses dynamic pricing and idling vehicle dispatching problems in the on-demand ridesharing systems with fully compliant drivers/vehicles. A dynamic mathematical program with equilibrium constraints (MPEC) is formulated to capture the interdependent decision-making processes of the mobility service provider (e.g., regarding vehicle allocation) and travelers (e.g., regarding ride-sharing and travel path options). An algorithm based on approximate dynamic programming (ADP), with customized subroutines for solving the MPEC, is developed to solve the overall problem. It is shown with numerical experiments that the proposed dynamic pricing and vehicle dispatching strategy can help ridesharing service providers achieve better system performance (as compared with myopic policies) while facing spatial and temporal variations in ridesharing demand.

Incorporating vehicle self-relocations and traveler activity chains in a bi-level model of optimal deployment of shared autonomous vehicles

1. Year: 2020
2. Journal: Transportation Research Part B: Methodological
3. Authors: Li, Qing and Liao, Feixiong

> The combination of autonomous vehicles (AVs) and free-floating car-sharing scheme is expected to deliver high potentials of both through effective AV self-relocations. Little research has been done on the deployment of shared AVs (SAVs) considering the interplays among SAV relocations, supply-demand dynamics, and travelers' multi-modal multi-activity schedules. This study aims to propose a bi-level system optimal model inclusive of a new hub-based relocation strategy to moderate the supply and demand of SAVs. The lower-level captures travelers' activity-travel scheduling behavior by an extended dynamic user equilibrium model and the upper-level determines the hub locations, fleet size, and initial distribution of SAVs. A heuristic algorithm based on Lagrangian relaxation is developed to solve the network design problem. Numerical examples demonstrate that SAV relocations can significantly influence travelers' daily schedules and enhance mobility efficiency in the multi-modal transport system. We also find that the proposed hub-based relocation strategy outperforms two common SAV relocation strategies in the literature.

Modeling and optimizing a fare incentive strategy to manage queuing and crowding in mass transit systems: Modeling and optimizing a fare incentive strategy to manage queuing and crowding in mass transit systems

1. Year: 2020
2. Journal: Transportation Research Part B: Methodological
3. Authors: Tang, Yili and Jiang, Yu and Yang, Hai and Nielsen, Otto Anker

> This paper solves the problem of optimizing a surcharge-reward scheme and analyzes equilibrium properties incorporating commuters' departure time choice to relieve crowding and queuing congestion in mass transit systems. The surcharge-reward scheme incentivizes commuters to switch departure times from a pre-specified central period to shoulder periods. We formulate a bilevel model to design and optimize the surcharge-reward scheme. The upper-level problem minimizes the total equilibrium costs by determining the refundable surcharges, the rewards, and the corresponding central charging period. The lower-level problem determines the equilibrium of commuters' departure times with respect to generalized travel costs. Equilibrium properties are analyzed and a sequential iterative solution algorithm is developed. We found that the existence of an optimal solution depends on the scheme design and there exists a lower bound on the surcharge to achieve the system optimum. Numerical studies are conducted on a commuting rail line in Copenhagen. The proposed algorithm converges efficiently, and the fare incentive scheme can simultaneously reduce the individual trip costs, total crowding costs, and total queuing time costs. The performance of the scheme increases with the rewards and surcharges up to a point and beyond which it stays unchanged.

Emergency vehicle lane pre-clearing: From microscopic cooperation to routing decision making

1. Year: 2020
2. Journal: Transportation Research Part B: Methodological

3. Authors: Wu, Jiaming and Kulcs{'{a}}r, Bal{'{a}}zs and Ahn, Soyoung and Qu, Xiaobo

> Emergency vehicles (EVs) play a crucial role in providing timely help for the general public in saving lives and avoiding property loss. However, very few efforts have been made for EV prioritization on normal road segments, such as the road section between intersections or highways between ramps. In this paper, we propose an EV lane pre-clearing strategy to prioritize EVs on such roads through cooperative driving with surrounding connected vehicles (CVs). The cooperative driving problem is formulated as a mixed-integer nonlinear programming (MINP) problem aiming at (i) guaranteeing the desired speed of EVs, and (ii) minimizing the disturbances on CVs. To tackle this NP-hard MINP problem, we formulate the model in a bi-level optimization manner to address these two objectives, respectively. In the lower-level problem, CVs in front of the emergency vehicle will be divided into several blocks. For each block, we developed an EV sorting algorithm to design optimal merging trajectories for CVs. With resultant sorting trajectories, a constrained optimization problem is solved in the upper-level to determine the initiation time/distance to conduct the sorting trajectories. Case studies show that with the proposed algorithm, emergency vehicles are able to drive at a desired speed while minimizing disturbances on normal traffic flows. We further reveal a linear relationship between the optimal solution and road density, which could help to improve EV routing decision makings when high-resolution data is not available.

Estimation of urban network capacity with second-best constraints for multimodal transport systems

1. Year: 2021
2. Journal: Transportation Research Part B: Methodological
3. Authors: Liu, Zhiyuan and Wang, Zewen and Cheng, Qixiu and Yin, Ruyang and Wang, Meng

> Transport network capacity enhancement is a significant aspect of urban transport planning and demand management, and a suitable measurement of the network capacity is of considerable importance. In this paper, the network capacity with second-best constraints (NCSC) is investigated to meet some specific development requirements of urban transport networks. Herein, the network capacity is restricted to an inferior “second-best solution”, due to various concerns/constraints regarding the public transport mode share, serviceability, and emissions, etc. For the sake of presentation, these constraints are termed as second-best constraints, and the NCSC problem can also be referred as second-best network capacity (SBNC) problem. A bi-level model is formulated to analyse the NCSC problem. The upper-level model maximizes the total origin-destination (OD) demand, which incorporates the second-best constraints into consideration. The lower-level model is a transport network equilibrium model, which measures the network performance under a given OD demand pattern. To better investigate some important second-best constraints (e.g., public transport mode share) and also the demand elasticity, the modelling framework is extended to a multimodal transport network. An exact solution method is developed for the NCSC problem; wherein, a modified improved gradient projection (MIGP) algorithm is designed for the lower-level multimodal flow equilibrium problem, and a tailored sensitivity analysis-based (SAB) method is employed for solving the NCSC problem. The proposed models and solution methods are verified by numerical examples, demonstrating that NCSC can be an efficient tool for transport planning and management.

Influence of dynamic congestion with scheduling preferences on carpooling matching with heterogeneous users

1. Year: 2022
2. Journal: Transportation Research Part B: Methodological
3. Authors: de Palma, Andr{'{e}} and Stokkink, Patrick and Geroliminis, Nikolas

> Carpooling is an efficient measure to fight car ownership and reduce vehicle kilometres travelled. By individuals sharing their commutes, vehicle occupancy increases and congestion is reduced. We develop a dynamic ADL (Arnott, de Palma, Lindsey)–Vickrey approach for a corridor monocentric city {`{a}} la Hotelling. First, we formulate the matching problem of heterogeneous users in carpooling as an MILP problem and we discuss its analytical properties when there is no congestion. Next, we construct a bi-level optimization problem involving matching (first stage) and dynamic traffic congestion with scheduling preferences (second stage) when congestion is endogenous. We provide a heuristic to attain an optimal matching for a dynamic traffic equilibrium with congestion. Such a template allows studying the two-way causality between dynamic congestion and carpooling matching.

Statistical inference of travelers' route choice preferences with system-level data

1. Year: 2024
2. Journal: Transportation Research Part B: Methodological
3. Authors: Guarda, Pablo and Qian, Sean

> Traditional network models encapsulate travel behavior among all origin–destination pairs based on a simplified and generic travelers' utility function. Typically, the utility function consists of travel time solely, and its coefficients are equated to estimates obtained from discrete choice models and stated preference data. While this modeling strategy is reasonable, the inherent sampling bias in individual-level experimental data may be further amplified over network flow aggregation, leading to inaccurate flow estimates. In addition, individual-level data must be collected from surveys or travel diaries, which may be labor-intensive, costly, and limited to a small time horizon. To address these limitations, this study extends classical bi-level formulations to estimate travelers' utility functions with multiple attributes using system-level data. This data tends to be less subject to sampling bias than individual-level data, it is cheaper to collect and it has become increasingly diverse and available. To leverage system-level data, we formulate a methodology grounded on non-linear least squares to statistically infer travelers' utility function in the network context using traffic counts, traffic speeds, the number of traffic incidents, and sociodemographic information obtained from the US Census, among other attributes. The analysis of the mathematical properties of the optimization problem and its pseudo-convexity motivates the use of normalized gradient descent, an algorithm developed in the machine learning community that is suitable for pseudo-convex programs. More importantly, we develop a hypothesis test framework to examine the statistical properties of coefficients attached to utility terms and to perform attribute selection. Experiments on synthetic data show that the travelers' utility function coefficients can be consistently recovered and that hypothesis tests are reliable statistics to identify which attributes are determinants of travelers' route choices. Besides, a series of Monte-Carlo experiments showed that statistical inference is robust to various levels of sensor coverage and to noises in the Origin-Destination matrix and the traffic count measurements. The methodology is also deployed at a large scale using real-world multi-source data in Fresno, CA, collected before and during the COVID-19 outbreak.

Allocation problem in cross-platform ride-hail integration

1. Year: 2024

2. Journal: Transportation Research Part B: Methodological
3. Authors: Li, Ruijie and Liu, Yang and Liu, Xiaobo and Nie, Yu (Marco)

We consider a ride-hail system in which a third-party integrator receives ride requests and allocates them to ride service platforms. The ride allocation problem (RAP) is modeled as a Stackelberg game. The integrator, as the leader, chooses the allocation that maximizes its profit, by pricing the rides such that no platform (i.e., follower) can find a more profitable allocation. In pursuit of self-interest, the integrator may refuse to match as many rides as the platforms are willing to serve, thereby injecting an artificial scarcity into the system. To protect the platforms from over exploitation, an exogenous reserve price is introduced to bound their per capita profit from below. We formulate RAP as a bilevel pricing problem, and convert it to a single-level problem by dualizing the lower level. When artificial scarcity is eliminated and all reserve prices are set to zero, we prove the single-level problem can be turned into a mixed integer-linear program that equals its linear relaxation, thus becoming polynomially solvable. Moreover, this version of RAP is shown to be related to cooperative assignment games. Numerical experiments confirm that artificial scarcity negatively affects matching productivity and social welfare. The integrator is favored to take most profits, and leveraging artificial scarcity strengthens its dominance. Moreover, the tighter the supply, the more the integrator benefit from artificial scarcity. The reserve price helps redistribute benefits from the integrator to the platforms. However, demanding an excessively large reserve price may depress the platforms' profits, while undermining system efficiency.

Risk-aware urban air mobility network design with overflow redundancy

1. Year: 2024
2. Journal: Transportation Research Part B: Methodological
3. Authors: Wei, Qinshuang and Gao, Zhenyu and Clarke, John Paul and Topcu, Ufuk

In urban air mobility (UAM), as envisioned by aviation professionals, novel flight vehicles will transport passengers and cargo at low altitudes within urban and suburban areas. To operate in urban environments, precise air traffic management, in particular the management of traffic overflows due to physical and operational disruptions will be critical to ensuring system safety and efficiency. To this end, we propose UAM network design with reserve capacity, i.e., a design where alternative landing options and flight corridors are explicitly considered as a means of improving contingency management. Similar redundancy considerations are incorporated in the design of many critical infrastructures, yet remain unexploited in the air transportation literature. In our methodology, we first model how disruptions to a given UAM network might impact on the nominal traffic flow and how this flow might be re-accommodated on an extended network with reserve capacity. Then, through an optimization problem, we select the locations and capacities for the backup vertiports with the maximal expected throughput of the extended network over all possible disruption scenarios, while the throughput is the maximal amount of flights that the network can accommodate per unit of time. We show that we can obtain the solution for the corresponding bi-level and bi-linear optimization problem by solving a mixed-integer linear program. We demonstrate our methodology in the case study using networks from Milwaukee, Atlanta, and Dallas–Fort Worth metropolitan areas and show how the throughput and flexibility of the UAM networks with reserve capacity can outcompete those without.

Estimation of schedule preference and crowding perception in urban rail corridor commuting: An inverse optimization method

1. Year: 2024
2. Journal: Transportation Research Part B: Methodological
3. Authors: Xu, Pu and Liu, Tian Liang and Tian, Qiong and Si, Bingfeng and Liu, Wei and Huang, Hai Jun

This paper introduces an inverse optimization method to uncover commuters' schedule preference and crowding perception based on aggregated observations from smart card data for an urban rail corridor system. The assessment of time-of-use preferences typically involves the use of econometric models of discrete choice based on detailed travel survey data. However, discrete choice models often struggle with potential endogeneity issues in behavioral observations when estimating individual samples from massive transit data with limited exogenous identifying information. This motivates us to employ an equilibrium modeling approach to capture the dynamism hidden in commuters' departure time decision-making from aggregations. Assuming user optimality in observed choices, an inverse optimization method is proposed to find a set of preference parameters in the stochastic user equilibrium-based morning commuting model with heterogeneous commuters so that the resulting equilibrium pattern best approximates the observed departure rate distribution over time. The proposed inverse optimization problem can be formulated by a bi-level programming model and a sensitivity analysis-based solution framework is further designed for model estimation. Lastly, the smart card data and train timetable data from the rail corridor along the Beijing Subway Batong Line are synthesized for a case study to estimate commuters' departure time choice preferences during morning peak periods, as well as to validate the robustness and practicality of the proposed method.

Tailored priority allocation in the bottleneck model with general user heterogeneity

1. Year: 2024
2. Journal: Transportation Research Part B: Methodological
3. Authors: Yang, Zhenyu and de Palma, Andr{'{e}} and Geroliminis, Nikolas

We propose to enhance the efficiency of road bottlenecks by strategically implementing metering-based priority (MBP) schemes. Under MBP, a portion of the bottleneck capacity is reserved for priority users but made available for nonpriority users when no priority users are queueing. Previous studies have found that MBP is Pareto-improving regarding individual trip costs with homogeneous users, but its effectiveness becomes ambiguous when users have heterogeneous scheduling preferences. To address this, we consider a finite number of user groups with group-specified scheduling preferences. The design of optimal MBP schemes to minimize the total trip cost is formulated as a bilevel problem, allowing for varying fractions of priority users across groups. Under the identified conditions, convex optimization algorithms can be used to solve optimal MBP schemes. When these conditions are not met, we propose a general solution framework to find solutions with satisfactory accuracy. We study the theoretically optimal system efficiency achievable by MBP through numerical simulations. We also explore the benefits of integrating MBP with other travel demand management policies, such as high-occupancy vehicle lanes. Importantly, the implementation challenges of MBP schemes are also discussed, particularly the difficulty of distinguishing users based on their preferences. We investigate the efficiency of implementing optimal MBP schemes in an aggregated manner, emphasizing the significance of selecting appropriate aggregating patterns. We also propose a type of heuristic MBP scheme that ensures that nonpriority users' departures can be unaffected by MBP. Such schemes are Pareto-improving and remarkably do not require observing individual preferences. These heuristic schemes can be decentralized by assigning priority status through pricing in certain cases. Numerical results demonstrate that the heuristic approach achieves comparable efficiency levels to optimal MBP schemes in considered scenarios.

Design an intermediary mobility-as-a-service (MaaS) platform using many-to-many stable matching framework

1. Year: 2024
2. Journal: Transportation Research Part B: Methodological
3. Authors: Yao, Rui and Zhang, Kenan

> Mobility-as-a-service (MaaS) provides seamless door-to-door trips by integrating different transport modes. Although many MaaS platforms have emerged in recent years, most of them remain at a limited integration level. This study investigates the assignment and pricing problem for a MaaS platform as an intermediary in a multi-modal transportation network, which purchases capacity from service operators and sells multi-modal trips to travelers. The analysis framework of many-to-many stable matching is adopted to decompose the joint design problem and to derive the stability condition such that both operators and travelers are willing to participate in the MaaS system. To maximize the flexibility in route choice and remove boundaries between modes, we design an origin–destination pricing scheme for MaaS trips. On the supply side, we propose a wholesale purchase price for service capacity. Accordingly, the assignment problem is reformulated and solved as a bi-level program, where MaaS travelers make multi-modal trips to minimize their travel costs meanwhile interacting with non-MaaS travelers in the multi-modal transport system. We prove that, under the proposed pricing scheme, there always exists a stable outcome to the overall many-to-many matching problem. Further, given an optimal assignment and under some mild conditions, a unique optimal pricing scheme is ensured. Numerical experiments conducted on the extended Sioux Falls network also demonstrate that the proposed MaaS system could create a win-win-win situation—the MaaS platform is profitable and both traveler welfare and transit operator revenues increase from a baseline scenario without MaaS.

Intermodal container terminal location and capacity design with decentralized flow estimation

1. Year: 2024
2. Journal: Transportation Research Part B: Methodological
3. Authors: Zhang, Jiajie and Lin, Yun Hui and Chew, Ek Peng and Tan, Kok Choon

> This paper studies an intermodal container terminal (IMT) location and design problem, where the IMT operator wants to locate a set of open-access IMTs and design their capacity levels to maximize its profit. Following the IMT operator's decisions, network users, responsible for container transportation, will independently choose their routes and may procure intermodal services from the IMT operator. Since only limited information is available before the existence of the network, we employ the entropy maximization principle as a least-biased approach to estimate the flow distribution resulting from the network users' route choices. This enables the IMT operator to predict profit and evaluate the quality of its network design decisions. We formulate the problem as a mixed-integer bilevel nonlinear program, automatically embedding a decentralized flow estimation scheme into the optimization of IMT location and capacity design. By exploring the rationale behind the entropy maximization principle, our problem can also be interpreted as a leader–follower game, in which the IMT operator (as the leader) aims to maximize its profit and the network users (as the follower) maximize their welfare. Due to the bilevel structure and the nonlinear entropy function, the problem is extremely changeling. To support its application in real-world contexts, we propose both exact and approximation algorithms. Finally, we conduct a real-world case study on Sydney Greater Metropolitan Area and draw managerial implications.

A bilevel hybrid iterated search approach to soft-clustered capacitated arc routing problems

1. Year: 2024
2. Journal: Transportation Research Part B: Methodological
3. Authors: Zhou, Yangming and Qu, Chenhui and Wu, Qinghua and Kou, Yawen and Jiang, Zhibin and Zhou, Meng Chu

> This work studies a soft-clustered capacitated arc routing problem that extends the classical capacitated arc routing problem with an important constraint. The problem has a set of required edges (e.g., the streets to be serviced) that are partitioned into clusters. The constraint ensures that all required edges of the same cluster are served by the same vehicle. This problem can be found in a variety of practical applications, such as waste collection, postal delivery, snow plowing, and meter reading. Due to its non-deterministic polynomial-time hard nature, it is decomposed into capacitated vehicle routing problems at the cluster-level and rural postman problems at the edge-level, and then an effective bilevel hybrid iterated search method is proposed to solve it. The proposed method consists of a bilevel variable neighborhood search that sequentially executes a random order-based variable neighborhood descent at the cluster-level and a lower bound-guided variable neighborhood descent at the edge-level, and a similarity-driven hybrid perturbation that conditionally switches between a backbone-based directed perturbation and a destroy-repair random perturbation. Extensive evaluations on 611 existing benchmark instances show that the proposed method outperforms state-of-the-art algorithms in terms of both solution quality and computation time. Its excellent performance is also verified on 30 newly generated large instances that are derived from real-world road networks. Finally, ablation studies on key algorithmic components are performed to confirm their novelty and effectiveness.