1. A COMPARISON OF STOCHASTIC AND DETERMINISTIC TRAFFIC ASSIGNMENT OVER CONGESTED NETWORKS

1. SHEFFI, Y; POWELL, W
2. TRANSPORT RES B-METH

> nan

2. ALGORITHMS FOR SOLVING FISK STOCHASTIC TRAFFIC ASSIGNMENT MODEL

1. CHEN, MY; ALFA, AS
2. TRANSPORT RES B-METH

> In this paper, the logit-based stochastic traffic assignment model is explored. Two new improved algorithms are presented for solving this type of stochastic assignment problem. The major improvement achieved in these algorithms is that the step length in each iteration of the search process is optimized instead of using fixed step lengths as in the existing method of successive averages (MSA).

3. A NETWORK DESIGN ALGORITHM USING A STOCHASTIC INCREMENTAL TRAFFIC ASSIGNMENT APPROACH

1. CHEN, MY; ALFA, AS
2. TRANSPORT SCI

> nan

4. LARGE POPULATION APPROXIMATIONS OF A GENERAL STOCHASTIC TRAFFIC ASSIGNMENT MODEL

1. DAVIS, GA; NIHAN, NL
2. OPER RES

> Recent interest in stochastic traffic assignment models has been motivated by a need to determine the stationary probability distribution of a network's traffic volumes and by the possibility of using time-series of traffic counts to fit and test travel demand models. Because of the way traffic volumes are generated as the sum of path flows from different origin-destination pairs, and because of the nonlinear nature of the process relating traffic conditions to traveler route selection, most plausible assignment models tend to be intractable. In this paper, we first pose a general stochastic assignment model that includes as special cases most models which have appeared in the literature, and then verify that the probability distributions of an equivalent Markovian model converge to a stationary distribution. We next verify that as the number of individual travelers becomes large, the general model can be approximated by the sum o a nonlinear deterministic process and a time-varying linear Gaussian process. The stationary distribution of this approximation is readily characterized, and the approximation also provides a means for employing linear system methods to estimate model parameters from a set of observed traffic counts. For the case where the route choice probabilities are given by the multinomial logit function, computationally feasible procedures for implementing the approximate model exist.

5. A STOCHASTIC USER EQUILIBRIUM ASSIGNMENT MODEL FOR THE EVALUATION OF PARKING POLICIES

1. BIFULCO, GN
2. EUR J OPER RES

> Analytical tools are required in modelling the transportation system and, in turn, the whole urban system. In this paper a model is presented which is useful in the evaluation of parking policies, which play an important role in transportation system management. The model consists of a supply model, a demand model and a supply/demand interaction model. The supply representation is network-based and proper functions are introduced in order to simulate the attributes related to parking choices. In particular, a behavioural approach is presented to simulate the searching time for an available parking space. The demand side of the model consist of a stochastic choice model applied to the path and parking levels of choice within a dynamic approach. Thus, the other levels of mobility choices are descriptively treated, giving rise to O/D matrices characterised by purpose of trip and desired duration of parking. In this implementation the O/D matrices are considered fixed and exogenously given. The removal of this hypothesis does not present theoretical problems. A multi-user equilibrium problem is solved and its theoretical properties are investigated. An application of the model is presented in order to show the capabilities of the model applied to a real network.

6. EXACT LOCAL SOLUTION OF THE CONTINUOUS NETWORK DESIGN PROBLEM VIA STOCHASTIC USER EQUILIBRIUM ASSIGNMENT

1. DAVIS, GA
2. TRANSPORT RES B-METH

> The continuous Network Design Problem (NDP) deals with determining optimal expansions for the capacities of a street network, subject to the constraint that the street traffic volumes must be the outcome of a user-optimal equilibrium assignment. Although the use of deterministic equilibrium methods tends to produce computationally intractable problems, in this paper it is shown that a stochastic user equilibrium based on the logit model leads to a differentiable and large-scale, but tractable, version of the NDP. A procedure for computing the derivatives of the stochastic user equilibrium (SUE) assignment without having to first compute the route choice probabilities is given, and this procedure is coupled with two standard algorithms for solving nonlinear programs, the generalized reduced gradient method and sequential quadratic programming. These algorithms are tested on several example networks, and the results of these tests suggest that the SUE-constrained version of the NDP offers both a promising heuristic for solving DUE-constrained problems as well as a viable procedure in its own right.

7. STOCHASTIC USER EQUILIBRIUM ASSIGNMENT IN NETWORKS WITH QUEUES

1. BELL, MGH
2. TRANSPORT RES B-METH

> A stochastic user equilibrium assignment algorithm is presented for steady state store-and-forward networks. The links of the network have constant travel times and the links or nodes have finite capacities. When capacity is reached, delay sufficient to match demand to the available capacity is generated. It has been shown by others that the equilibrium assignment in networks of this kind is the solution to a particular linear programming problem. By adding an entropy term to the objective

> function, a convex nonlinear programming problem is formed which yields a stochastic user equilibrium assignment. For the case of link constraints, it is proven that the Lagrange multipliers of both the linear and the non-linear programming problems give the equilibrium delays in the network. The requirements for uniqueness are investigated. Iterative algorithms are formulated for solving the nonlinear programming problem with either link or node constraints and convergence is proven. For networks where path enumeration is likely to be a problem, a column generation technique is proposed. An illustrative example is presented.

8. A COMBINED ALGORITHM FOR SOLVING AND CALIBRATING THE STOCHASTIC TRAFFIC ASSIGNMENT MODEL

1. HUANG, HJ
2. J OPER RES SOC

> This paper studies Fisk's stochastic user equilibrium (SUE) assignment model in which travellers are assumed not to have perfect knowledge of the traffic system. It is shown that the stochastic properties of this model completely depend on the calibration parameter. After giving the searching method of an 'efficient paths' set, a modified combined algorithm for solving and calibrating Fisk's stochastic traffic assignment model is developed. In this algorithm, the path enumeration is achieved automatically in the preliminary phase and renewed in the iterative processes, and the number of alternative paths generated can be controlled by a predetermined function. Two numerical examples are presented to illustrate the model's properties and the algorithm's efficiencies.

9. Cyclic flows, Markov process and stochastic traffic assignment

1. Akamatsu, T
2. TRANSPORT RES B-METH

> Dial's stochastic assignment algorithm restricts the assignment path set to ''efficient path.'' As a result, it sometimes produces the unrealistic flow pattern that no flow is loaded on some paths where many vehicles are running in reality. To remove the drawback of Dial's algorithm, this paper presents the LOGIT type assignment that does not restrict the assignment paths. We first show the theoretical relation between the proposed model and Sasaki's assignment model through Markov process. This analysis makes it clear that the proposed assignment model can be calculated by some matrix operations. Next, we propose an efficient algorithm that does not require the matrix operation nor path enumeration over a network. The algorithm solves an equivalent program based on the entropy decomposition derived from the Markov property of LOGIT model. Finally, it is shown that the proposed approach-can be easily extended to the flow dependent case (i.e. stochastic equilibrium assignment). Copyright (C) 1996 Elsevier Science Ltd

10. Asymmetric problems and stochastic process models of traffic assignment

1. Watling, D
2. TRANSPORT RES B-METH

> There is a spectrum of asymmetric assignment problems to which existing results on uniqueness of equilibrium do not apply. Moreover, multiple equilibria may be seen to exist in a number of simple examples of real-life phenomena, including interactions at priority junctions, responsive traffic signals, multiple user classes, and multi-modal choices. In contrast, recent asymptotic results on the stochastic

> process approach to traffic assignment establish the existence of a unique, stationary, joint probability distribution of flows under mild conditions, that include problems with multiple equilibria. In studying the simple examples mentioned above, this approach is seen to be a powerful tool in suggesting the relative, asymptotic attractiveness of alternative equilibrium solutions. It is seen that the stationary distribution may have multiple peaks, approximated by the stable equilibria, or a unimodal shape in cases where one of the equilibria dominates. It is seen, however, that the convergence to stationarity may be extremely slow. In Monte Carlo simulations of the process, this gives rise to different types of pseudo-stable behaviour (flows varying in an apparently stable manner, with a mean close to one of the equilibria) for a given problem, and this may prevail for long periods. The starting conditions and random number seed are seen to affect the type of pseudo-stable behaviour over long, but finite, time horizons. The frequency of transitions between these types of behaviour (equivalently, the average sojourn in a locally attractive, pseudo-stable set of states) is seen to be affected by behavioural parameters of the model. Recommendations are given for the application of stochastic process models, in the light of these issues. Copyright (C) 1996 Elsevier Science Ltd

11. An algorithm for the stochastic user equilibrium problem

1. Damberg, O; Lundgren, JT; Patriksson, M
2. TRANSPORT RES B-METH

> In this paper we present a new algorithm for the approximate solution of the legit-based stochastic user equilibrium problem. The main advantage of this algorithm is that it provides route flows explicitly, of particular interest in the evaluation of route guidance and information systems; in previously proposed methods for the stochastic user equilibrium problem, only link flows are provided. The proposed algorithm alternates between two main phases. In the subproblem phase, profitable routes are generated. In the restricted master problem phase, a descent method is used to solve the restriction to the original problem to the subset of the total set of routes generated so far. We present and evaluate alternative strategies for generating routes algorithmically, and discuss the possibility of utilizing such strategies for reducing the inherent problem of overlapping route flows in legit-based traffic models. Copyright (C) 1996 Elsevier Science Ltd.

12. A stochastic user equilibrium path flow estimator

1. Bell, MGH; Shield, CM; Busch, F; Kruse, G
2. TRANSPORT RES C-EMER

> The paper sets out a path flow estimator suitable for use in conjunction with urban traffic monitoring, control and guidance. Travel time for each link in the network is partitioned into undelayed travel time and delay. The links are assumed to be of two types. For the first type of link, an external estimate of flow and travel time over the estimation interval is provided. The second type of link is characterised by a finite capacity, and delay is incurred where demand would otherwise be in excess of capacity. Demand is determined by a legit route choice model. An equivalent convex programming problem is formulated and an iterative solution procedure is set out. The estimation of the dispersion parameter in the legit model is discussed, and a column generation method to avoid path enumeration is proposed. Diagnostic procedures and a number of other practical enhancements to the procedure, in particular the incorporation of prior information on the relative magnitudes of origin-destination movements, are considered. (C) 1997 Elsevier Science Ltd. All rights reserved.

13. A probit-based stochastic user equilibrium assignment model

1. Maher, MJ; Hughes, PC
2. TRANSPORT RES B-METH

> Stochastic methods of traffic assignment have received much less attention in the literature than those based on deterministic user equilibrium (UE). The two best known methods for stochastic assignment are those of Burrell and Dial, both of which have certain weaknesses which have limited their usefulness. Burrell's is a Monte Carlo method, whilst Dial's legit method takes no account of the correlation, or overlap, between alternative routes. This paper describes, firstly, a probit stochastic method (SAM) which does not suffer from these weaknesses and which does not require path enumeration. While SAM has a different route-finding methodology to Burrell, it is shown that assigned flows are similar. The paper then goes on to show how, by incorporating capacity restraint (in the form of link-based cost-flow functions) into this stochastic loading method, a new stochastic user equilibrium (SUE) model can be developed. The SUE problem can be expressed as a mathematical programming problem, and its solution found by an iterative search procedure similar to that of the Frank-Wolfe algorithm commonly used to solve the UE problem. The method is made practicable because quantities calculated during the stochastic loading process make the SUE objective function easy to compute. As a consequence, at each iteration, the optimal step length along the search direction can be estimated using a simple interpolation method. The algorithm is demonstrated by applying it successfully to a number of test problems, in which the algorithm shows good behaviour. It is shown that, as the values of parameters describing the variability and degree of capacity restraint are varied, the SUE solution moves smoothly between the UE and pure stochastic solutions. (C) 1997 Elsevier Science Ltd.

14. Some remarks on stochastic user equilibrium

1. Hazelton, ML
2. TRANSPORT RES B-METH

> The behavioural foundation of Stochastic User Equilibrium is that each traveller attempts to minimize his or her perceived travel costs, where these costs are composed of a deterministic measured cost and a random term which can be interpreted as perceptual error. In principle such a definition, which is in terms of random errors, should imply an equilibrium probability distribution over feasible flow patterns on the transport network. Such a probability distribution could potentially allow between day variability in network hows to be represented. However, traditionally a deterministic, large sample approximation has been used as the 'solution' of Stochastic User Equilibrium. In this paper a representation of Stochastic User Equilibrium as a probability distribution is developed. This distribution is defined by the conditional route selection of each individual given the choices of all other travellers. An interpretation of the resulting assignment model as the limit (in the infinite future) of a continuous time assignment process is discussed. The limiting behaviour as the travel demand becomes large is also investigated and convergence to the traditional deterministic form of Stochastic User Equilibrium is proved. (C) 1998 Elsevier Science Ltd. All rights reserved.

15. Algorithms for logit-based stochastic user equilibrium assignment

1. Maher, M
2. TRANSPORT RES B-METH

> The paper proposes an efficient algorithm for determining the stochastic user equilibrium solution for logit-based loading. The commonly used Method of Successive Averages typically has a very slow convergence rate. The new algorithm described here uses Williams' result [Williams, H. C. W. L. (1977) On the formation of travel demand models and economic evaluation measures of user benefit. Environment and Planning 9A(3), 285-344] which enables the expected value of the perceived travel costs S-rs to be readily calculated for any flow vector x. This enables the value of the Sheffi and Powell objective function [Sheffi, Y. and Powell, W. B. (1982) An algorithm for the equilibrium assignment problem with random link times. Networks 12(2), 191-207], and its gradient in any specified search direction, to be calculated. It is then shown how, at each iteration, an optimal step length along the search direction can be easily estimated, rather than using the pre-set step lengths, thus giving much faster convergence. The basic algorithm uses the standard search direction (towards the auxiliary solution). In addition the performance of two further versions of the algorithm are investigated, both of which use an optimal step length but alternative search directions,based on the Davidon-Fletcher-Powell function minimisation method. The first is an unconstrained and the second a constrained version. Comparisons are made of all three versions of the algorithm, using a number of test networks ranging from a simple three-link network to one with almost 3000 links. It is found that for all but the smallest network the version using the standard search direction gives the fastest rate of convergence. Extensions to allow for multiple user classes and elastic demand are also possible. (C) 1998 Elsevier Science Ltd. All rights reserved.

16. Evaluation of network reliability using stochastic user equilibrium

1. Asakura, Y
2. J ADV TRANSPORT

> When we evaluate the performance reliability of a network, it is necessary to describe user's behaviour in a partially degraded network. This paper shows that the Stochastic User Equilibrium (SUE) model assuming user's route choice behaviour under uncertain network conditions can be incorporated in the performance reliability model. The effects of providing information are analyzed using the SUE model with two different groups of route choice; informed drivers and non informed drivers. it is found that providing information generally increases network performance reliability. This depends, however, on the probability distribution of the network states.

17. System optimum, stochastic user equilibrium, and optimal link tolls

1. Yang, H
2. TRANSPORT SCI

> Previous studies have shown that the Wardropian. system optimum may not necessarily be supported as a (logit-based) stochastic user equilibrium (SUE) by finite and meaningful link tolls. This paper demonstrates that the classical principle of marginal-cost pricing is still applicable in ct network under SUE from the standpoint of economic benefit maximization within the context of the classical consumer behavior theory. The marginal-cost link tolls are shown to be meaningful from both economic and behavioral viewpoints, and therefore proposed to be a good alternative to drive a SUE flow pattern toward system optimum.

18. A stochastic user equilibrium assignment model for congested transit networks

1. Lam, WHK; Gao, ZY; Chan, KS; Yang, H

2. TRANSPORT RES B-METH

> This paper proposes a stochastic user equilibrium assignment model for congested transit networks, together with a solution algorithm. A mathematical programming problem is formulated, that is equivalent to the stochastic user equilibrium assignment model for congested transit system. When the transit link capacity constraints are reached, it is proven that the Lagrange multipliers of the mathematical programming problem are equivalent to the equilibrium passenger overload delays in the congested transit network. The proposed model can simultaneously predict how passengers will choose their optimal routes and estimate the total passenger travel cost in a congested transit network. Numerical examples are used to illustrate the applications of the proposed model.

19. Robustness of the off-line a priori stochastic dynamic traffic assignment solution for on-line operations

1. Peeta, S; Zhou, C
2. TRANSPORT RES C-EMER

> This paper focuses on the off-line stochastic dynamic traffic assignment (DTA) problem as part of a hybrid framework that combines off-line and on-line strategies to solve the on-line DTA problem. The primary concept involves the explicit recognition of stochasticity in O-D demand and/or network supply conditions to determine a robust off-line a priori solution that serves as the initial solution on-line. This strategy ensures that the computationally intensive components, which exploit historical data, are executed off-line while circumventing the need for very accurate on-line O-D demand forecast models. Thereby, efficient on-line reactive strategies could be used to address unfolding traffic conditions. The paper investigates the robustness of the off-line a priori DTA solution under plausible on-line situations. The results illustrate the superiority of the a priori solution over the currently used mean O-D demand-based solution for on-line route guidance applications.

20. Some observations on stochastic user equilibrium and system optimum of traffic assignment

1. Prashker, JN; Bekhor, S
2. TRANSPORT RES B-METH

> Traffic assignment models can be classified according to the behavioral assumption governing route choice. The deterministic user equilibrium (UE), stochastic user equilibrium (SUE) and system optimum (SO) models have been studied extensively in the literature. The relationship between the UE solution and the SO solution for a given network is well known, as is the relationship between UE and SUE. The question that arises concerns the relationship between SUE and (deterministic) SO. The flow pattern obtained from the SO solution serves as a yardstick for comparison with the flow patterns obtained from the UE and SUE solutions. The investigation examines whether the stochastic equilibriums closer than the deterministic user equilibrium to the system optimum. This paper compares the performance of the different solutions for simple networks. The comparison is made by evaluating the relative difference in total system times for UE and SUE solutions with respect to the SO solution. This paper also presents an extension of previous results to show that the Braess' paradox can occur for certain

> ranges of demand volumes in the case of stochastic equilibrium and non-linear cost functions. (C) 2000 Elsevier Science Ltd. All rights reserved.

21. Congestion, stochastic, and similarity effects in stochastic user-equilibrium models

1. Prashker, JN; Bekhor, S
2. TRANSPORT RES REC

> Different effects in stochastic user-equilibrium formulations are compared. The starting point is the logit assignment formulation for the stochastic user-equilibrium model. Recently, extended logit-based models were developed as solutions of equivalent stochastic user-equilibrium problems. These extended logit models are theoretically superior to the simple logit model, because they take into account the similarity among routes. The similarity indexes were defined based on physical parameters of the network, such as link lengths, and therefore did not depend on congestion. The assumption that similarity coefficients are independent of congestion means that the similarity effect and the congestion effect are treated separately. However, both similarity and congestion effects are taken into account in the equilibrium formulations. Simple network examples are presented to illustrate the sensitivity of the link flow pattern (and path flow pattern) to the three different effects in stochastic assignment models: the congestion effect, the stochastic effect, and the similarity effect. The relative influence of those effects on the flow patterns is discussed.

22. Sensitivity analysis for stochastic user equilibrium network flows - A dual approach

1. Ying, JQ; Miyagi, T
2. TRANSPORT SCI

> Recently, extensive studies have been conducted on the computational methods of sensitivity analysis for the Wardropian equilibrium modeling of traffic networks and their applications. But the same problems in the context of the stochastic user equilibrium modeling seem not to have been addressed. In this paper, we present a method for sensitivity analysis for network flows at stochastic user equilibrium. Our method is developed from a dual formulation of the stochastic user equilibrium analysis. By adopting Dial's algorithm for stochastic traffic assignment, we are able to formulate a computationally efficient link-based algorithm for the sensitivity analysis. Since the Wardropian equilibrium in a traffic network is an extreme case of stochastic user equilibrium with theta --> infinity, theta a being a dispersion parameter in the expected utility function for stochastic route choice, the method presented here can also be used for sensitivity analysis of the Wardropian equilibrium by setting theta large enough.

23. Simultaneous estimation of the origin-destination matrices and travel-cost coefficient for congested networks in a stochastic user equilibrium

1. Yang, H; Meng, Q; Bell, MGH
2. TRANSPORT SCI

> This article proposes an optimization model for simultaneous estimation of an origin-destination (O-D) matrix and a travel-cost coefficient for congested networks in a logit-based stochastic user equilibrium (SUE). The model is formulated in the form of a standard differentiable, nonlinear optimization problem with analytical stochastic user equilibrium constraints. Explicit expressions of the derivatives of the stochastic user equilibrium constraints with respect to origin-destination demand, link flow, and travel-

> cost coefficient are derived and computed efficiently through a stochastic network-loading approach. A successive quadratic-programming algorithm using the derivative information is applied to solve the simultaneous Estimation model. This algorithm converges to a Karusch-Kuhn-Tucker point of the problem under certain conditions. The proposed model and algorithm are illustrated with a numerical example.

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

1. Maher, MJ; Zhang, XY; Van Vliet, D
2. TRANSPORT RES B-METH

> This paper deals with two mathematically similar problems in transport network analysis: trip matrix estimation and traffic signal optimisation 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 optimisation 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 lest the algorithm on several networks. (C) 2000 Elsevier Science Ltd. All rights reserved.

25. Stochastic user equilibrium formulation for generalized nested logit model

1. Bekhor, S; Prashker, JN
2. TRANSPORT RES REC

> The route choice problem is complicated in typical transportation networks because of the size of the choice set and because of the overlapping problem since many routes share links. Well-known models like the probit and the logit were further developed in an attempt to overcome these problems. The logit model has the appeal of being relatively close to the probit model while keeping a convenient analytical closed form. However, the simple multinomial logit model cannot correctly represent route choice, especially with respect to the overlapping problem. Other hierarchical logit models can potentially overcome the overlapping problem. The recently developed generalized nested logit (GNL) model is found to be very suitable for route choice, as is the cross-nested logit (CNL) model. The inclusion of the congestion effect in the route choice problem is accounted for in stochastic user equilibrium (SUE) problems. The development of a SUE formulation for the GNL model is presented. In addition, how to adapt the GNL model to route choice in a way similar to that of the CNL model is shown. An equivalent SUE formulation for the GNL model is developed. In this way, a unified framework is presented to relate GNL-type models, which are derived from discrete choice theory, with aggregate entropy formulations. A preliminary algorithm is developed to illustrate the potential application of the GNL formulation for real networks.

26. Multistage stochastic system optimum dynamic traffic assignment program with recourse for incident traffic management

1. Sawaya, OB; Doan, DL; Ziliaskopoulos, AK; Fourer, R
2. TRANSPORT RES REC

> Robust real-time traffic management methodologies are needed to respond to freeway congestion caused by unexpected incidents. A multistage stochastic mathematical model with recourse is introduced to compute and disseminate real-time traffic control actions, which account for system uncertainties such as demand variation and incident severity. The benefits include the provision of a priori robust traffic control actions that are ideal under all circumstances of system uncertainties across all considered time periods, with significant reduction in the online computational effort. As a result, more insights on the relationship between traffic control actions and network properties across time periods are obtained.

27. Sensitivity analysis of the probit-based stochastic user equilibrium assignment model

1. Clark, SD; Watling, DP
2. TRANSPORT RES B-METH

> The probit-based stochastic user equilibrium (SUE) model has the advantage of being able to represent perceptual differences in utility across the driver population, while taking proper account of the natural correlations in these utilities between overlapping routes within the network (which the simpler logit SUE is unable to do). Its main drawback is the potentially heavy computational demands, and this has previously been thought to preclude a consideration of the sensitivity analysis of probit-based SUE, whereby an approximation to changes in the equilibrium solution is deduced as its input parameters (specifically origin/destination (O D) flows and link cost-flow function parameters) are perturbed. In the present paper, an efficient computational method for performing such an analysis for general networks is described. This approach uses information on SUE path flows, but is not specific to any particular equilibrium solution algorithm. Problems inherent in the consideration of general network topologies are identified, and methods proposed for overcoming them. The paper concludes with an application of the method to a realistic network, and compares the approximate solutions with those obtained by direct estimation methods. (C) 2002 Elsevier Science Ltd. All rights reserved.

28. Dynamic traffic modelling and dynamic stochastic user equilibrium assignment for general road networks

1. Han, SJ
2. TRANSPORT RES B-METH

> This paper investigates the requirements of dynamic traffic modelling, and proposes the deterministic queuing model as a plausible link performance function to describe the relationship between inflows, outflows, and link travel costs in time-varying condition. Then, it explains how we can perform logit-based stochastic network loading for general road networks in the dynamic case. In particular, this paper shows how to perform dynamic stochastic network loadings for many-to-many origin-destination pairs, and what should be considered to maintain correct flow propagation in the network loading process. Next, this paper shows how the stochastic dynamic user equilibrium (SDUE) assignment problem can be solved without direct evaluation of the objective function. For this purpose, a quadratic interpolation, the method of successive average, and the pure network loading method are adopted at the line-search step in the solution algorithm. Numerical examples show that the present SDUE assignment model with a quadratic interpolation gives rise to a convergent solution

> with good quality whilst needing less computation time. Furthermore, it is found that the predictive cost-flow association (Proceedings of the European Transport Conferences, Seminar F, P434, 1999, p. 79) is preferable to the reactive one because the former can produce consistent assignment patterns regardless of the size of dispersion parameter theta in the logit model for route choice. (C) 2002 Elsevier Science Ltd. All rights reserved.

29. Logit-based stochastic user equilibrium problem for entry-exit toll schemes

1. Meng, Q; Lee, DH; Cheu, RL; Yang, H
2. J TRANSP ENG

> This paper proposes a logit-based stochastic user equilibrium (SUE) problem for networks with entry-exit toll schemes that result in nonadditive path costs. First, it develops a strictly convex minimization model in terms of path flows for the problem. Second, by decomposing the original problem into two kinds of subproblems that possess the additive path costs, this study designs a novel two-stage stochastic loading algorithm exempted from path enumeration or generation. Hence, the method of successive average embedded with the proposed stochastic loading algorithm can identify the logit-based SUE link and entry-exit flows. Finally, two numerical examples are used to demonstrate the proposed model and algorithm.

30. Transportation network optimization problems with stochastic user equilibrium constraints

1. Meng, Q; Lee, DH; Yang, H; Huang, HJ
2. TRANSPORT RES REC

> A comprehensive study of static transportation network optimization problems with stochastic user equilibrium constraints is presented. It is explicitly demonstrated that the formulation of the fixed-point problem - in terms of link flows for the general stochastic user equilibrium problem in which the Jacobian matrix of link travel cost functions may not be symmetric-possesses a unique solution with mild conditions. By developing a sensitivity analysis method for the stochastic user equilibrium problem, the study proves that the perturbed equilibrium link flows are continuously differentiable implicit functions with respect to perturbation parameters. Accordingly, it can be concluded that the proposed unified bilevel programming model, which can characterize transportation network optimization problems subject to stochastic user equilibrium constraints, is a smooth optimization problem. In addition, the study presents a single-level continuously differentiable optimization formulation that is equivalent to the unified bilevel programming model. Furthermore, as a unified solution method, a successive quadratic programming algorithm based on the sensitivity analysis method is used to solve the transportation network optimization problems with stochastic user equilibrium constraints. Finally, two examples are used to demonstrate the proposed models and algorithm.

31. Stochastic social optimum traffic assignment

1. Maher, M; Stewart, K; Rosa, A
2. TRANSPORT RES B-METH

> This paper formulates a Stochastic Social Optimum (SSO) that relates to the Stochastic User Equilibrium (SUE) in the same way as the Social Optimum (SO) relates to the User Equilibrium (UE) in a deterministic environment. At the SSO solution, the total of the users' perceived costs is minimised. The

> formulation and analysis is carried out in a general utility-maximising framework, with the probit and logit models being special cases. Conditions for the SSO flow pattern are derived, from which it can be seen that the marginal social costs play the same role in the SSO as the standard costs play in SUE. In particular, it is shown that the SSO solution can be obtained through the use of an algorithm for SUE, but with the marginal costs replacing the standard costs in the stochastic loading and that optimal tolls are the differences between the marginal social costs and the standard costs. For the case of the logit model an explicit path-based objective function is obtained which is of a pleasing symmetrical form when compared with the objective functions for SUE, SO and UE. Additionally, a link-based objective function for the general utility-maximising case is formulated for SSO, which is similar in form to the SUE objective function of Sheffi and Powell.

32. Dynamic departure time and stochastic user equilibrium assignment

1. Lim, Y; Heydecker, B
2. TRANSPORT RES B-METH

> This paper investigates a logit-based combined departure time and dynamic stochastic user equilibrium assignment (DDSUE) problem and shows the existence of DDSUE condition as well as exploring its properties: a novel invariant quantity of DDSUE assignments is established. The relations between daily volume of traffic and cost incurred from travelling are also investigated. In order to calculate the equilibrium, we propose a solution algorithm that can solve the problem directly, and without appealing to an equivalent mathematical programme. Since the model is based on paths where all feasible paths are enumerated in advance, we propose an efficient method that works within a reasonable path set. Through two numerical examples, we show the DDSUE and some valuable results from the model such as relation between departure flow (or path inflow) and departure cost (or path cost). Sensitivity analysis of travel volumes with respect to travel costs and model parameters is also undertaken.

33. Investigating path-based solution algorithms to the stochastic user equilibrium problem

1. Bekhor, S; Toledo, T
2. TRANSPORT RES B-METH

> This paper focuses on path-based solution algorithms to the stochastic user equilibrium (SUE) and investigates their convergence properties. Two general optimization methods are adapted to solve the logit SUE problem. First, a method that closely follows the Gradient Projection (GP) algorithm developed for the deterministic problem is derived. While this method is very efficient for the deterministic user equilibrium problem, we use a simple example to illustrate why it is not suitable for the SUE problem. Next, a different variant of gradient projection, which exploits special characteristics of the SUE solution, is presented. In this method the projection is on the linear manifold of active constraints. The algorithms are applied to solve simple networks. The examples are used to compare the convergence properties of the algorithms with a path-based variant of the Method of Successive Averages (MSA) and with the Disaggregate Simplicial Decomposition (DSD) algorithm.

34. A continuous network design model in stochastic user equilibrium based on sensitivity analysis

1. Lim, Y; Heydecker, BG; Lee, S

2. J ADV TRANSPORT

> The continuous network design problem (CNDP) is known to be difficult to solve due to the intrinsic properties of non-convexity and nonlinearity. Such kinds of CNDP can be formulated as a bi-level programme, in which the upper level represents the designer's decisions and the lower level the travellers' responses. Formulations of this kind can be classified as either Stackelberg approaches or Nash ones according to the relationship between the upper level and the lower level parts. This paper formulates the CNDP for road expansion based on Stackelberg game where leader and follower exist, and allows for variety of travellers' behaviour in choosing their routes. In order to solve the problem by the Stackelberg approach, we need a relation between link flows and design parameters. For this purpose, we use a logit route choice model, which provides this in an explicit closed-form function. This model is applied to two example road networks to test and briefly compare the results between the Stackelberg and Nash approaches to explore the differences between them.

35. Sensitivity analysis of stochastic user equilibrium flows in a bi-modal network with application to optimal pricing

1. Ying, JQ; Yang, H
2. TRANSPORT RES B-METH

> Sensitivity analysis methods for transport systems having an automobile road network and a physically separate transit network are studied. For the case that both the automobile and transit networks are congested in the sense that link cost functions increase with the flow, a general computational method is presented for sensitivity analysis. For another case where the automobile network is congested but the transit network simply consists of independent lines connecting Origin-Destination pairs and may have economies of scale with the increase of the passengers, conditions under which sensitivity analysis can be properly conducted are investigated. The sensitivity analysis algorithm is applied to the optimal pricing problem in a combined network with transit lines exhibiting economies of scale as well as congestion diseconomies. (c) 2004 Elsevier Ltd. All rights reserved.

36. User equilibrium traffic network assignment with stochastic travel times and late arrival penalty

1. Watling, David
2. EUR J OPER RES

> The classical Wardrop User Equilibrium (UE) assignment model assumes traveller choices are based on fixed, known travel times, yet these times are known to be rather variable between trips, both within and between days; typically, then, only mean travel times are represented. Classical Stochastic User Equilibrium (SUE) methods allow the mean travel times to be differentially perceived across the population, yet in a conventional application neither the UE or SUE approach recognises the travel times to be inherently variable. That is to say, there is no recognition that drivers risk arriving late at their destinations, and that this risk may vary across different paths of the network and according to the arrival time flexibility of the traveller. Recent work on incorporating risky elements into the choice process is seen either to neglect the link to the arrival constraints of the traveller, or to apply only to restricted problems with parallel alternatives and inflexible travel time distributions. In the paper, an alternative approach is described based on the 'schedule delay' paradigm, penalising late arrival under fixed departure times. The approach allows flexible travel time densities, which can be fitted to actual

> surveillance data, to be incorporated. A generalised formulation of UE is proposed, termed a Late Arrival Penalised UE (LAPUE). Conditions for the existence and uniqueness of LAPUE solutions are considered, as well as methods for their computation. Two specific travel time models are then considered, one based on multivariate Normal arc travel times, and an extended model to represent arc incidents, based on mixture distributions of multivariate Normals. Several illustrative examples are used to examine the sensitivity of LAPUE solutions to various input parameters, and in particular its comparison with UE predictions. Finally, paths for further research are discussed, including the extension of the model to include elements such as distributed arrival time constraints and penalties.

37. Stochastic quasi-gradient algorithm for the off-line stochastic dynamic traffic assignment problem

1. Peeta, S; Zhou, C
2. TRANSPORT RES B-METH

> This paper proposes a stochastic quasi-gradient (SQG) based algorithm to solve the off-line stochastic dynamic traffic assignment (DTA) problem that explicitly incorporates randomness in O-D demand, as part of a hybrid DTA deployment framework for real-time operations. The problem is formulated as a stochastic programming DTA model with multiple user classes. Due to the complexities introduced by real-time traffic dynamics and system characteristics, well-behaved properties cannot be guaranteed for the resulting formulation and analytical functional forms that adequately capture traffic realism typically do not exist for the associated objective functions. Hence, a simulation-based SQG method that is applicable for a generalized differentiable (locally Lipschitz) non-convex objective function and non-convex constraint set is proposed to solve the problem. Simulation is used to estimate quasi-gradients that are stochastic to incorporate demand randomness. The solution approach is a generalization of the deterministic DTA solution methodology; under it, deterministic DTA models are special cases. Of practical significance, it provides a robust solution for the field deployment of DTA, or an initial solution for hybrid real-time strategies. The solution algorithm searches a larger feasible domain of the solution space, leading to a potentially more robust and computationally more efficient solution than its deterministic counterparts. These advantages are highlighted through simulation experiments.

38. A chance-constrained based stochastic dynamic traffic assignment model: Analysis, formulation and solution algorithms

1. Waller, S. Travis; Ziliaskopoulos, Athanasios K.
2. TRANSPORT RES C-EMER

> This paper is concerned with the system optimum-dynamic traffic assignment (SO-DTA) problem when the time-dependent demands are random variables with known probability distributions. The model is a stochastic extension of a deterministic linear programming formulation for SO-DTA introduced by Ziliaskopoulos (Ziliaskopoulos, A.K., 2000. A linear programming model for the single destination system optimum dynamic traffic assignment problem, Transportation Science, 34, 1-12). The proposed formulation is chance-constrained based and we demonstrate that it provides a robust SO solution with a user specified level of reliability. The model provides numerous insights and can be a useful tool in producing robust control and management strategies that account for uncertainty in applications where SO-DTA is relevant (e.g. evacuation modeling, computing alternate routes around freeway

> incidents and establishing lower bounds on network performance). (c) 2006 Elsevier Ltd. All rights reserved.

39. On-line marginal-cost pricing across networks: Incorporating heterogeneous users and stochastic equilibria

1. Zhao, Y; Kockelman, KM
2. TRANSPORT RES B-METH

> This paper discusses an on-line, trial-and-error implementation of marginal-cost pricing for networks with users whose values of travel time vary, whose demand functions are unknown, and whose route choices conform to random-utility maximization. It is an extension of Yang et al.'s [Yang, H., Meng, Q., Lee, D.-H., 2004. Trial-and-error implementation of marginal-cost pricing on networks in the absence of demand functions. Transportation Research Part B 38 (6), 477-493] calculations of optimal congestion tolls with homogenous travelers and shortest-path choices. The numerical example on an actual, large-scale network suggests the heuristic iterative procedure does converge in searching for optimal tolls. (c) 2005 Elsevier Ltd. All rights reserved.

40. A reliability-based stochastic traffic assignment model for network with multiple user classes under uncertainty in demand

1. Shao, Hu; Lam, William H. K.; Tam, Mei Lam
2. NETW SPAT ECON

> This paper presents a novel reliability-based stochastic user equilibrium traffic assignment model in view of the day-to-day demand fluctuations for multiclass transportation networks. In the model, each class of travelers has a different safety margin for on-time arrival in response to the stochastic travel times raised from demand variations. Travelers' perception errors on travel time are also considered in the model. This model is formulated as an equivalent variational inequality problem, which is solved by the proposed heuristic solution algorithm. Numerical examples are presented to illustrate the applications of the proposed model and the efficiency of solution algorithm.

41. Stochastic heuristic dynamic assignment based on AIMSUN microscopic traffic simulator

1. Barcelo, Jaime; Casas, Jordi
2. TRANSPORT RES REC

> The deployment of intelligent transportation systems must be assisted by suitable tools to conduct the feasibility studies required to test the designs and evaluate the expected impacts. Microscopic traffic simulation has proved to be the suitable methodological approach to achieve these goals. One of the most critical aspects of the dynamic simulation of-road networks based on a microscopic approach-namely, how to perform a heuristic dynamic assignment, the implied route choice models, and whether under certain criteria the approach can achieve stochastic user equilibrium-is discussed.

42. Application of cross-nested logit route choice model in stochastic user equilibrium traffic assignment

1. Bekhor, Shlomo; Reznikova, Lena; Toledo, Tomer
2. TRANSPORT RES REC

> Most stochastic user equilibrium (SUE) model applications reported in the literature are based on the multinomial logit (MNL) model. This paper presents a SUE assignment based on the cross-nested logit (CNL) route choice model, which can better represent route choice behavior. The paper develops path-based algorithms to solve the CNL-SUE problem based on adaptation of the disaggregate simplicial decomposition method. The algorithms differ for the step-size determination; three different methods are considered. The algorithms are tested in two well-known networks. Two main tests are conducted: (a) the impact of the CNL model parameters on the assignment results is analyzed and (b) the differences between the CNL-SUE and the MNL-SUE solutions are investigated. The results indicate that the path-based algorithm with Armijo's step-size rule outperforms other step-size determinations. This paper indicates that depending on the model parameters, particularly the nesting coefficient, the CNL-SUE path flows may be quite different from the MNL-SUE path flows.

43. Sensitivity analysis of the variable demand probit stochastic user equilibrium with multiple user-classes

1. Connors, Richard D.; Sumalee, Agachai; Watling, David P.
2. TRANSPORT RES B-METH

> This paper presents a formulation of the multiple user class, variable demand, probit stochastic user equilibrium model (SUE). Sufficient conditions are stated for differentiability of the equilibrium flows of this model. This justifies the derivation of sensitivity expressions for the equilibrium flows. This paper then considers the network design problem (NDP), assuming that users' responses to changes in the design variables follow the probit SUE. With probit SUE stated as a fixed-point condition, the NDP is a mathematical program with equilibrium constraints (MPEC). The probit. SUE sensitivity expressions provide the information necessary to adopt a gradient-based approach to solving the probit SUE NDP. Numerical examples verify the sensitivity expressions, and the NDP solution. (c) 2006 Elsevier Ltd. All rights reserved.

44. Tolling traffic links under stochastic assignment: Modelling the relationship between the number and price level of tolled links and optimal traffic flows

1. Stewart, Kathryn
2. TRANSPORT RES A-POL

> The classical road-tolling problem is to toll network links such that under the principles of Wardropian User Equilibrium Assignment a System Optimising (SO) flow pattern is obtained. Stochastic assignment methods are accepted to be more realistic than deterministic and it is of interest to examine the potential for optimal tolling in the case of Stochastic User Equilibrium (SUE). In examining the case of Stochastic User Equilibrium the 'desired flow pattern' to be created must first be determined. The classical economics solution of replacing unit-cost flow functions with marginal-cost flow functions which under deterministic assignment produces the System Optimal solution (where Total Network Travel Cost (TNTC) is minimised) does not generally result in TNTC being minimised in the Stochastic Case. Instead such tolls produce a 'Stochastic System Optimal' (SSO) solution where the Total Perceived Network Travel Cost (TPNTC) is minimised. This paper examines and compares link-based tolling solutions to achieve both the SSO (TPNTC minimised) and true SO (TNTC minimised) under SUE and illustrates the concept with numerical examples. Such link-based tolling schemes produce network benefit by re-routing rather than traffic suppression as opposed to the cordon-based charging schemes which have been implemented in practice. Equity issues relating to charging schemes are

> discussed and the desirability of zero-toll routes is highlighted associated with greater potential political acceptability of charging schemes that do not impose excessive charges upon users (such as minimal or low revenue tolls). A heuristic is developed to toll network links in such a way as to balance the number of links tolled against the revenue required to produce a desired reduction in TNTC such that optimal network flow patterns are approached.

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

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

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

46. Probit-Based Time-Dependent Stochastic User Equilibrium Traffic Assignment Model

1. Zhang, Kuilin; Mahmassani, Hani S.; Lu, Chung-Cheng
2. TRANSPORT RES REC

> This study presents a time-dependent stochastic user equilibrium (TDSUE) traffic assignment model within a probit-based path choice decision framework that explicitly takes into account temporal and spatial correlation (traveler interactions) in travel disutilities across a set of paths. The TDSUE problem, which aims to find time-dependent SUE path flows, is formulated as a fixed-point problem and solved by a simulation-based method of successive averages algorithm. A mesoscopic traffic simulator is employed to determine (experienced) time-dependent travel disutilities. A time-dependent shortest-path algorithm is applied to generate new paths and augment a grand path set. Two vehicle-based implementation techniques are proposed and compared in order to show their impact on solution quality and computational efficiency. One uses the classical Monte Carlo simulation approach to explicitly compute path choice probabilities, and the other determines probabilities by sampling vehicles' path travel costs from an assumed perception error distribution (also using a Monte Carlo simulation process). Moreover, two types of variance-covariance error structures are discussed: one considers temporal and spatial path choice correlation (due to path overlapping) in terms of aggregated path travel times, and the other uses experienced (or empirical) path travel times from a sample of individual vehicle trajectories. A set of numerical experiments are conducted to investigate the convergence pattern of the solution algorithms and to examine the impact of temporal and spatial correlation on path choice behavior.

47. General stochastic user equilibrium traffic assignment problem with link capacity constraints

1. Meng, Qiang; Lam, William H. K.; Yang, Liu
2. J ADV TRANSPORT

> This paper addresses a general stochastic user equilibrium (SUE) traffic assignment problem with link capacity constraints. It first proposes a novel linearly constrained minimization model in terms of path flows and then shows that any of its local minimums satisfies the generalized SUE conditions. As the objective function of the proposed model involves path-specific delay functions without explicit mathematical expressions, its Lagrangian dual formulation is analyzed. On the basis of the Lagrangian dual model, a convergent Lagrangian dual method with a predetermined step size sequence is developed. This solution method merely invokes a subroutine at each iteration to perform a conventional SUE traffic assignment excluding link capacity constraints. Finally, two numerical examples are used to illustrate the proposed model and solution method.

48. Stochastic Multiclass Traffic Assignment with Consideration of Risk-Taking Behaviors

1. Di, Shan; Pan, Changxuan; Ran, Bin
2. TRANSPORT RES REC

> A study of the problem of predicting traffic flows under traffic equilibrium in a stochastic transportation network is presented. Travelers' risk-taking behaviors are explicitly modeled with respect to probabilistic travel times. Traveling risks are quantified from the travel time distributions directly and are embedded in the route choice conditions. The classification of risk-neutral, risk-averse, and risk-prone travelers is based on their preferred traveling risks. The formulation of the model clarifies that travelers with different risk preferences have the same objective-to save travel time cost-though they may make different route choices. The proposed solution algorithm is applicable for networks with normal distribution link travel times theoretically. Further simulation analysis shows that it can also be applied to approximate the equilibrium network flows for other frequently used travel time distribution families: gamma, Weibull, and log-normal. The proposed model was applied to a test network and a medium-sized transportation network. The results demonstrate that the model captures travelers' risk-taking behaviors more realistically and flexibly compared with existing stochastic traffic equilibrium models.

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

1. Lee, Seungiae
2. J ADV TRANSPORT

> A multimodal, multiclass stochastic dynamic traffic assignment model was developed to evaluate pre-trip and enroute travel information provision strategies. Three different information strategies were examined: user optimum [UO], system optimum [SO] and mixed optimum [MO]. These information provision strategies were analyzed based on the levels of traffic congestion and market penetration rate for the information equipment. Only two modes, bus and car, were used for evaluating and calculating the modal split ratio. Several scenarios were analyzed using day-to-day and within day dynamic models. From the results analyzed, it was found that when a traffic manager provides information for drivers using the UO strategy and drivers follow the provided information absolutely,

> the total travel time may increases over the case with no information. Such worsening occurs when drivers switch their routes and face traffic congestion on the alternative route. This phenomenon is the 'Braess Paradox'.

50. Comparative analysis of three user equilibrium models under stochastic demand

1. Zhou, Zhong; Chen, Anthony
2. J ADV TRANSPORT

> Recent empirical studies on the value of time and reliability reveal that travel time variability plays an important role on travelers' route choice decision process. It can be considered as a risk to travelers making a trip. Therefore, travelers are not only interested in saving their travel time but also in reducing their risk. Typically, risk can be represented by two different aspects: acceptable risk and unacceptable risk. Acceptable risk refers to the reliability aspect of acceptable travel time, which is defined as the average travel time plus the acceptable additional time (or buffer time) needed to ensure more frequent on-time arrivals, while unacceptable risk refers to the unreliability aspect of unacceptable late arrivals (though infrequent) that have a travel time excessively higher than the acceptable travel time. Most research in the network equilibrium based approach to modeling travel time variability ignores the unreliability aspect of unacceptable late arrivals. This paper examines the effects of both reliability and unreliability aspects in a network equilibrium framework. Specifically, the traditional user equilibrium model, the demand driven travel time reliability-based user equilibrium model, and the alpha-reliable mean-excess travel time user equilibrium model are considered in the investigation under an uncertain environment due to stochastic travel demand. Numerical results are presented to examine how these models handle risk under travel time variability.

51. Stochastic User Equilibrium Model with Implicit Travel Time Budget Constraint

1. Smith, Tony E.; Hsu, Chao-Che; Hsu, Yueh-Ling
2. TRANSPORT RES REC

> Although time constraints on travel behavior have been widely recognized, little effort has been made to incorporate such constraints into the traditional stochastic user equilibrium (SUE) framework. The major objective of this research is to rill this gap by incorporating travel time constraints into the SUE model by means of a nonlinear perceived travel time function. This modified model, designated the travel time budget model, focuses primarily on discretionary travel behavior (such as shopping trips) and hence also allows the possibility of deferring travel decisions by incorporating an additional choice alternative designated the shop-less-frequently alternative. This model is compared with the traditional SUE model by using a simulated travel scenario on a test network designed to reflect a practical planning situation. The simulation shows that when attractiveness levels are increased by the introduction of a new shopping opportunity, the presence of travel time constraints can lead to significantly smaller predicted travel volumes than those of the traditional SUE model. More important, it shows that the overall pattern of travel can be quite different. In particular, travel to the shopping destination with enhanced attractiveness can actually decrease for some origin locations. The findings suggest that when an attempt is made to evaluate the impact of planning alternatives on future traffic patterns, it is vital to consider not only the cost of time itself but also the time trade-off's between travel and other human activities.

52. Sensitivity Analysis of Logit-Based Stochastic User Equilibrium Network Flows with Entry-Exit Toll Schemes

1. Meng, Qiang; Wang, Xiubin
2. COMPUT-AIDED CIV INF

> This article addresses sensitivity analysis of logit-based stochastic user equilibrium (SUE) network flows on transportation networks with entry-exit toll schemes. These schemes have a technical challenge that the generalized travel time including tolls on a path is nonadditive. First, it shows that the perturbed logit-based network flows-link and entry-exit flows-are implicit but continuously differentiable functions with respect to the perturbation parameters arising from link travel time functions, origin-destination demands, and entry-exit tolls. Second, this article derives elegant analytical expressions of gradients of perturbed logit-based SUE network flows, and elaborates that these gradients can be calculated by the two-stage stochastic network loading algorithm, which obviates the need for path enumeration. Finally, two numerical examples are presented to demonstrate the calculation process and computational capability.

53. Modeling the evolutions of day-to-day route choice and year-to-year ATIS adoption with stochastic user equilibrium

1. Huang, Hai-Jun; Liu, Tian-Liang; Yang, Hai
2. J ADV TRANSPORT

> Suppose that in an urban transportation network there is a specific advanced traveler information system (ATIS) which acts for reducing the drivers' travel time uncertainty through provision of pre-trip route information. Because of the imperfect information provided, some travelers are not in compliance with the ATIS advice although equipped with the device. We thus divide all travelers into three groups, one group unequipped with ATIS, another group equipped and in compliance with ATIS advice and the third group equipped but without compliance with the advice. Each traveler makes route choice in a logit-based manner and a stochastic user equilibrium with multiple user classes is reached for every day. In this paper, we propose a model to investigate the evolutions of daily path travel time, daily ATIS compliance rate and yearly ATIS adoption, in which the equilibrium for every day's route choice is kept. The stability of the evolution model is initially analyzed. Numerical results obtained from a test network are presented for demonstrating the model's ability in depicting the day-to-day and year-to-year evolutions.

54. A Path-Based Algorithm for the Cross-Nested Logit Stochastic User Equilibrium Traffic Assignment

1. Bekhor, Shlomo; Toledo, Tomer; Reznikova, Lena
2. COMPUT-AIDED CIV INF

> This article investigates the single-class static stochastic user equilibrium (SUE) problem with separable and additive link costs. A SUE assignment based on the Cross-Nested Logit (CNL) route choice model is presented. The CNL model can better represent route choice behavior compared to the Multinomial Logit (MNL) model, while keeping a closed form equation. The article uses a specific optimization formulation developed for the CNL model, and develops a path-based algorithm for the solution of the CNL-SUE problem based on adaptation of the disaggregate simplicial decomposition (DSD) method.

> The article illustrates the algorithmic implementation on a real size network and discusses the trade-offs between MNL-SUE and CNL-SUE assignment.

55. Mixed Stochastic User Equilibrium Behavior under Traveler Information Provision Services with Heterogeneous Multiclass, Multicriteria Decision Making

1. Jaber, Xiaoqing; O'Mahony, Margaret
2. J INTELL TRANSPORT S

> This article studies travelers' mixed stochastic user equilibrium (SUE) behaviors under traveler information provision services with heterogeneous multiclass multicriteria decision making. A multiclass, multicriteria mixed SUE assignment model under traveler information provision services is proposed and modeled as a nonlinear complementary problem (NCP). The model considers heterogeneous road travelers who are assumed to be multicriteria decision makers. The route choice behaviors of equipped and unequipped travelers under traveler information provision services is then formulated as an optimization program, in which the net economic benefit is maximized and the total generated emissions are constrained. The optimization model has an interpretation from economic, behavioral, and environmental viewpoints. The solution of this program satisfies the logit-based SUE assignment. By deriving first-order optimality conditions from this program, the marginal cost pricing policy is obtained. This pricing is not only class dependent but also link dependent.

56. Method of Successive Weighted Averages (MSWA) and Self-Regulated Averaging Schemes for Solving Stochastic User Equilibrium Problem

1. Liu, Henry X.; He, Xiaozheng; He, Bingsheng
2. NETW SPAT ECON

> Although stochastic user equilibrium (SUE) problem has been studied extensively in the past decades, the solution convergence of SUE is generally quite slow because of the use of the method of successive averages (MSA), in which the auxiliary flow pattern generated at each iteration contributes equally to the final solution. Realizing that the auxiliary flow pattern is in fact approaching to the solution point when the iteration number is large, in this paper, we introduce the method of successive weighted averages (MSWA) that includes a new step size sequence giving higher weights to the auxiliary flow patterns from the later iterations. We further develop a self-regulated averaging method, in which the step sizes are varying, rather than fixed, depending on the distance between intermediate solution and auxiliary point. The proposed step size sequences in both MSWA and self-regulated averaging method satisfy the Blum theorem, which guarantees the convergence of SUE problem. Computational results demonstrate that convergence speeds of MSWA and self-regulated averaging method are much faster than those of MSA and the speedup factors are in a manner of magnitude for high accuracy solutions. Besides SUE problem, the proposed methods can also be applied to other fixed-point problems where MSA is applicable, which have wide-range applications in the area of transportation networks.

57. Origin-Based Partial Linearization Method for the Stochastic User Equilibrium Traffic Assignment Problem

1. Lee, Der-Horng; Meng, Qiang; Deng, Weijia
2. J TRANSP ENG-ASCE

> This paper proposes a modified origin-based partial linearization method for solving the logit-based stochastic user equilibrium traffic assignment problem formulated by a strictly convex minimization model in terms of origin-based link flows. As a feasible descent direction method, it first generates a feasible descent direction in terms of the origin-based link flows by Bell's second logit-based stochastic network loading algorithm without path enumeration, and it proceeds to improve the descent direction according to the Fukushima's strategy and the PARTAN technique which haven been successfully applied to accelerate convergence of the link-based Frank-Wolfe method for solving the deterministic user equilibrium traffic assignment problem. To tackle the numerical overflow or underflow issue of the exponential function calculation arising in the computerized logit-based stochastic network loading algorithms, this paper develops a scientific notation based engineering approach for large-scale problems. Two numerical examples are carried out to compare the proposed solution method with the conventional origin-based partial linearization method and the method of successive averages in computational time and accuracy of solution.

58. Bounding the inefficiency of logit-based stochastic user equilibrium

1. Guo, Xiaolei; Yang, Hai; Liu, Tian-Liang
2. EUR J OPER RES

> Bounding the inefficiency of selfish routing has become an emerging research subject. A central result obtained in the literature is that the inefficiency of deterministic User Equilibrium (UE) is bounded and the bound is independent of network topology. This paper makes a contribution to the literature by bounding the inefficiency of the logit-based Stochastic User Equilibrium (SUE). In a stochastic environment there are two different definitions of system optimization: one is the traditional System Optimum (SO) which minimizes the total actual system travel time, and the other is the Stochastic System Optimum (SSO) which minimizes the total perceived travel time of all users. Thus there are two ways to define the inefficiency of SUE, i.e. to compare SUE with SO in terms of total actual system travel time, or to compare SUE with SSO in terms of total perceived travel time. We establish upper bounds on the inefficiency of SUE in both situations. (C) 2009 Elsevier B.V. All rights reserved.

59. Applying a Structured Dispersion Parameter to Multiclass Stochastic User Equilibrium Assignment Model

1. Miwa, Tomio; Okada, Yoshiyuki; Morikawa, Takayuki
2. TRANSPORT RES REC

> In recent practical transportation planning in Japan, the adoption of stochastic user equilibrium assignment models for traffic assessment has been discussed. Such models include a dispersion parameter that accounts for drivers' errors in perception of travel time at the time of route choice decision. In practice, setting a rational value for this parameter is an issue. Generally, the dispersion parameter is exogenously set to the same value for all origin destination (O-D) pairs. However, it is not guaranteed that errors in drivers' perception of travel costs are equal for all O-D pairs. This study examines how the parameter is set and applies a multiclass stochastic user equilibrium assignment model to consider differences in drivers' errors in perception of travel costs in using an existing general-purpose road network. Results show that changes in the dispersion parameter affect the user class flows that make up the link flows rather than the link flows themselves. Setting a dispersion parameter according to the travel cost of an O-D pair rather than setting a constant parameter improves the reproducibility of the user class flows on each link. These findings encourage practical

> transportation planners to evaluate qualitative measures of traffic flows in the road network, such as the utilization of road links.

60. Stochastic cell transmission model (SCTM): A stochastic dynamic traffic model for traffic state surveillance and assignment

1. Sumalee, A.; Zhong, R. X.; Pan, T. L.; Szeto, W. Y.
2. TRANSPORT RES B-METH

> The paper proposes a first-order macroscopic stochastic dynamic traffic model, namely the stochastic cell transmission model (SCTM), to model traffic flow density on freeway segments with stochastic demand and supply. The SCTM consists of five operational modes corresponding to different congestion levels of the freeway segment. Each mode is formulated as a discrete time bilinear stochastic system. A set of probabilistic conditions is proposed to characterize the probability of occurrence of each mode. The overall effect of the five modes is estimated by the joint traffic density which is derived from the theory of finite mixture distribution. The SCTM captures not only the mean and standard deviation (SD) of density of the traffic flow, but also the propagation of SD over time and space. The SCTM is tested with a hypothetical freeway corridor simulation and an empirical study. The simulation results are compared against the means and SDs of traffic densities obtained from the Monte Carlo Simulation (MCS) of the modified cell transmission model (MCTM). An approximately two-miles freeway segment of Interstate 210 West (I-210W) in Los Ageles, Southern California, is chosen for the empirical study. Traffic data is obtained from the Performance Measurement System (PeMS). The stochastic parameters of the SCTM are calibrated against the flow-density empirical data of I-210W. Both the SCTM and the MCS of the MCTM are tested. A discussion of the computational efficiency and the accuracy issues of the two methods is provided based on the empirical results. Both the numerical simulation results and the empirical results confirm that the SCTM is capable of accurately estimating the means and SDs of the freeway densities as compared to the MCS.

61. A Cell-Based Model for Multi-class Doubly Stochastic Dynamic Traffic Assignment

1. Szeto, W. Y.; Jiang, Y.; Sumalee, A.
2. COMPUT-AIDED CIV INF

> This article proposes a cell-based multi-class dynamic traffic assignment problem that considers the random evolution of traffic states. Travelers are assumed to select routes based on perceived effective travel time, where effective travel time is the sum of mean travel time and safety margin. The proposed problem is formulated as a fixed point problem, which includes a Monte-Carlo-based stochastic cell transmission model to capture the effect of physical queues and the random evolution of traffic states during flow propagation. The fixed point problem is solved by the self-regulated averaging method. The results illustrate the properties of the problem and the effectiveness of the solution method. The key findings include the following: (1) Reducing perception errors on traffic conditions may not be able to reduce the uncertainty of estimating system performance, (2) Using the self-regulated averaging method can give a much faster rate of convergence in most test cases compared with using the method of successive averages, (3) The combination of the values of the step size parameters highly affects the speed of convergence, (4) A higher demand, a better information quality, or a higher degree of the risk aversion of drivers can lead to a higher computation time, (5) More driver classes do not

> necessarily result in a longer computation time, and (6) Computation time can be significantly reduced by using small sample sizes in the early stage of solution processes.

62. Stochastic User Equilibrium and Value-of-time Analysis with Reference-dependent Route Choice

1. Delle Site, Paolo; Filippi, Francesco
2. EUR J TRANSP INFRAST

> Reference-dependent theory of riskless choice assumes that carriers of utility are gains and losses relative to a reference point and that individuals are loss averse, i.e. losses are valued more highly than gains. Reference-dependent money measures of the attributes in the utility functions are defined: the willingness to pay, the willingness to accept, the equivalent gain and the equivalent loss. Experimental evidence has been provided which supports reference-dependent theory for riskless route choice. A natural next development is the application of the theory to network analysis. This is an under-researched area. In the paper, the multi-class reference-dependent stochastic user equilibrium (RDSUE) problem under the status-quo assumption for the reference point is formulated. Conditions that guarantee the properties of existence and uniqueness of RDSUE are considered. The property of reflexivity of RDSUE is also considered to verify if the equilibrium is maintained when the reference point is updated to the new status quo. A methodology for the reference-dependent valuation of travel time changes over a network is provided. Data from a survey are used to estimate a reference-dependent route choice model and the attendant reference-dependent values of time. The estimation results are in agreement with econometric literature supporting loss aversion. The application to the case of a town bypass with toll illustrates the reference-dependent approach to network analysis and the implications of its use for policy making. It is shown that, if the interventions on the supply are phased, it is possible to exploit loss aversion and obtain advantages in terms of toll revenues and travel time spent.

63. Inefficiency of Logit-Based Stochastic User Equilibrium in a Traffic Network Under ATIS

1. Huang, Hai-Jun; Liu, Tian-Liang; Guo, Xiaolei; Yang, Hai
2. NETW SPAT ECON

> This paper makes a contribution to the literature by bounding the travel time inefficiency of the logit-based stochastic user equilibrium (SUE) under Advanced Traveler Information Systems (ATIS). All drivers are divided into two groups, one equipped with ATIS and another without, and both of which follow the logit-based SUE principle in making route choices. The equipped drivers have less degree of travel time variability than the unequipped ones. The inefficiency of the two-user class SUE is defined in two different ways, i.e., in comparison with the SO in terms of total actual system travel time, or in comparison with the corresponding SSO in terms of total perceptive system travel time of all users. The effects of various parameters on the bounds are further investigated. It is found that the inefficiency bound against the SSO is only dependent upon the degree of link congestion and independent of the network topology. In contrast, besides the effect of the degree of link congestion, the increasing of total demand and network complexity will also make the inefficiency bound against the SO go up, while the promotion of ATIS market penetration and perception benefit will reduce the bound.

64. Robust Wardrop's user equilibrium assignment under stochastic demand and supply: Expected residual minimization approach

1. Zhang, Chao; Chen, Xiaojun; Sumalee, Agachai
2. TRANSPORT RES B-METH

> Various models of traffic assignment under stochastic environment have been proposed recently, mainly by assuming different travelers' behavior against uncertainties. This paper focuses on the expected residual minimization (ERM) model to provide a robust traffic assignment with an emphasis on the planner's perspective. The model is further extended to obtain a stochastic prediction of the traffic volumes by the technique of path choice approach. We show theoretically the existence and the robustness of the ERM solution. In addition, we employ an improved solution algorithm for solving the ERM model. Numerical experiments are carried out to illustrate the characteristics of the proposed model, by comparing with other existing models.

65. Trial-and-error method for congestion pricing scheme under side-constrained probit-based stochastic user equilibrium conditions

1. Meng, Qiang; Liu, Zhiyuan
2. TRANSPORTATION

> A toll pattern that can restrict link flows on the tolled links to some predetermined thresholds is named as effective toll solution, which can be theoretically obtained by solving a side-constraint traffic assignment problem. Considering the practical implementation, this paper investigates availability of an engineering-oriented trial-and-error method for the effective toll pattern of cordon-based congestion pricing scheme, under side-constrained probit-based stochastic user equilibrium (SUE) conditions. The trial-and-error method merely requires the observed traffic counts on each entry of the cordon. A minimization model for the side-constrained probit-based SUE problem with elastic demand is first proposed and it is shown that the effective toll solution equals to the product of value of time and optimal Lagrangian multipliers with respect to the side constraints. Then, employing the Lagrangian dual formulation of the minimization method, this paper has built a convergent trial-and-error method. The trial-and-error method is finally tested by a numerical example developed from the cordon-based congestion pricing scheme in Singapore.

66. Stochastic traffic assignment, Lagrangian dual, and unconstrained convex optimization

1. Xie, Chi; Waller, S. Travis
2. TRANSPORT RES B-METH

> In this paper, traffic assignment problems with stochastic travel cost perceptions are reformulated and investigated in a new unconstrained nonlinear programming formulation. The objective function of the unconstrained formulation consists of two terms, in which the first term specifies the routing principle of the target problem through a satisfaction function and the sum of the first and second terms denotes the system cost or optimization objective. This formulation proves to be the Lagrangian dual of a generic primal formulation proposed by Maher et al. (2005) for the stochastic system-optimal problem. The primal-dual modeling framework presents such a common functional form that can accommodate a wide range of different traffic assignment problems. Our particular attention is given to the dual formulation in that its unconstrained feature opens the door of applying unconstrained optimization algorithms for its embraced traffic assignment problems. Numerical examples are provided to support the insights and facts derived from applying the primal and dual formulations to

> model stochastic system-optimal and user-equilibrium problems and justify the conjugate relationship between the primal and dual models. (C) 2012 Elsevier Ltd. All rights reserved.

67. C-logit stochastic user equilibrium model: formulations and solution algorithm

1. Zhou, Zhong; Chen, Anthony; Bekhor, Shlomo
2. TRANSPORTMETRICA

> This article considers the stochastic user equilibrium (SUE) problem with the route choice model based on the C-logit function. The C-logit model has a simple closed-form analytical probability expression and requires relatively lower calibration efforts and represents a more realistic route choice behaviour compared with the multinomial logit model. This article proposes two versions of the C-logit SUE model that captures the route similarity using different attributes in the commonality factors. The two versions differ with respect to the independence assumption between cost and flow. The corresponding stochastic traffic equilibrium models are called the length-based and congestion-based C-logit SUE models, respectively. To formulate the length-based C-logit SUE model, an equivalent mathematical programming formulation is proposed. For the congestion-based C-logit SUE model, we provide two equivalent variational inequality formulations. To solve the proposed formulations, a new self-adaptive gradient projection algorithm is developed. The proposed formulations and new solution algorithm are tested in two well-known networks. Numerical results demonstrate the validity of the formulations and solution algorithm.

68. Stochastic User Equilibrium for Route Choice Model Based on Random Regret Minimization

1. Bekhor, Shlomo; Chorus, Caspar; Toledo, Tomer
2. TRANSPORT RES REC

> A static stochastic user equilibrium (SUE) problem was formulated: the mode of random regret minimization (RRM) was used for route choices. The RRM approach assumes that individuals minimize anticipated regret, rather than maximize expected utility, when choosing from alternative routes. The cost function for the RRM model is not separable, and so a variational inequality approach was adopted to formulate the problem. A path-based algorithm was applied to solve the RRM-SUE problem with the method of successive averages. Implementation of the algorithm in a real-world network is illustrated, and the trade-offs and differences between the proposed model and the SUE based on random utility models is discussed.

69. Path-Based Algorithms to Solve C-Logit Stochastic User Equilibrium Assignment Problem

1. Xu, Xiangdong; Chen, Anthony; Zhou, Zhong; Bekhor, Shlomo
2. TRANSPORT RES REC

> This paper develops path-based algorithms to solve the C-logit stochastic user equilibrium (SUE) problem on the basis of an adaptation of the gradient projection method. The algorithms' strategies for step size determination differ. Three strategies are investigated: (a) predetermined step size, (b) Armijo line search, and (c) self-adaptive line search. The algorithms are tested on the well-known Winnipeg (Manitoba, Canada) network. Two sets of experiments are conducted: (a) a computational comparison of different line search strategies and (b) the impact of different modeling specifications for route overlapping (a flow-independent or a flow-dependent commonality factor). The results

> indicate that the path-based algorithm with the self-adaptive step size strategy performs better than the other step size strategies. The paper shows that, depending on the model parameters, particularly the commonality factor parameter, the C-logit SUE flows may be quite different from the multinomial logit SUE flows.

70. Semi-dynamic traffic assignment model with mode and route choices under stochastic travel times

1. Nakayama, Sho-ichiro; Takayama, Jun-ichi; Nakai, Junya; Nagao, Kazuki
2. J ADV TRANSPORT

> Transportation network conditions vary significantly during the course of a day. In many urban areas, public transit and (private) automobiles constitute the actual forms of transportation that use such networks. Public transportation by rail is more reliable than by automobiles or buses; therefore, ordinary static and deterministic traffic assignment models with combined mode and route choices may not be suitable to assess a transportation network that includes public railways. Moreover, within-day dynamics and reliability need to be incorporated in such a model. In this paper, we use a semi-dynamic traffic assignment model that considers within-day dynamics by improving the static traffic assignment model. In addition, stochastic travel times are incorporated into the model. Thus, we propose a semi-dynamic traffic assignment model with mode choice between public transit and automobiles, route choice with stochastic travel times, and an accompanying computing algorithm. This model enables us to assess within-day dynamics of transportation networks and travel time reliability of public railways. Copyright (c) 2012 John Wiley & Sons, Ltd.

71. A probability model and sampling algorithm for the inter-day stochastic traffic assignment problem

1. Wei, Chong; Asakura, Yasuo; Iryo, Takamasa
2. J ADV TRANSPORT

> In this study, we consider that inter-day traffic flow fluctuations in a network are caused by stochastic travel behavior. We treat route traffic flows at each time interval as random variables. Therefore, the solution of the stochastic assignment problem should be the conditional joint probability distribution of the route flows given that the network is in stochastic user equilibrium. We formulate the conditional joint distribution and develop a Gibbs sampler to draw samples from the conditional joint distribution. The characteristics of the route flows at each time interval during the time horizon can be estimated on the basis of the simulated samples. Copyright (c) 2012 John Wiley & Sons, Ltd.

72. A computational model for the probit-based dynamic stochastic user optimal traffic assignment problem

1. Meng, Qiang; Khoo, Hooi Ling
2. J ADV TRANSPORT

> This paper focuses on computational model development for the probit-based dynamic stochastic user optimal (P-DSUO) traffic assignment problem. We first examine a general fixed-point formulation for the P-DSUO traffic assignment problem, and subsequently propose a computational model that can find an approximated solution of the interest problem. The computational model includes four components: a strategy to determine a set of the prevailing routes between each origindestination

> pair, a method to estimate the covariance of perceived travel time for any two prevailing routes, a cell transmission model-based traffic performance model to calculate the actual route travel time used by the probit-based dynamic stochastic network loading procedure, and an iterative solution algorithm solving the customized fixed-point model. The Ishikawa algorithm is proposed to solve the computational model. A comparison study is carried out to investigate the efficiency and accuracy of the proposed algorithm with the method of successive averages. Two numerical examples are used to assess the computational model and the algorithm proposed. Results show that Ishikawa algorithm has better accuracy for smaller network despite requiring longer computational time. Nevertheless, it could not converge for larger network. Copyright (c) 2010 John Wiley & Sons, Ltd.

73. Examining the scaling effect and overlapping problem in logit-based stochastic user equilibrium models

1. Chen, Anthony; Pravinvongvuth, Surachet; Xu, Xiangdong; Ryu, Seungkyu; Chootinan, Piya
2. TRANSPORT RES A-POL

> The purpose of this paper is to examine the scaling effect and overlapping problem in a route choice context using the logit-based stochastic user equilibrium (SUE) principle to explicitly account for the congestion effect. Numerical experiments are performed on nine models: the deterministic user equilibrium model, the multinomial logit SUE model with and without scaling, the C-logit SUE model with and without scaling, the path-size logit SUE model with and without scaling, and the paired combinatorial logit SUE model with and without scaling. Sensitivity analysis is conducted to examine the effects of route sets, congestion levels, dispersion intensities, and network asymmetries. A real transportation network in the City of Winnipeg, Canada is also used to compare the network equilibrium flow allocations of different SUE models. The results of the sensitivity analysis and the Winnipeg network reveal that both scaling effect and overlapping problem can have a significant impact on the network equilibrium flow allocations. Published by Elsevier Ltd.

74. Mathematical models and computational algorithms for probit-based asymmetric stochastic user equilibrium problem with elastic demand

1. Meng, Qiang; Liu, Zhiyuan
2. TRANSPORTMETRICA

> This article addresses model development and computational algorithm design for the probit-based asymmetric stochastic user equilibrium (SUE) problem with elastic demand. Two variational inequality (VI) models are first proposed for the SUE problem and then existence and uniqueness of their solutions are examined. These two VI models are, in reality, built by means of a probit-based stochastic network loading (SNL) map. Since there is no computational procedure available for calculating the SNL map, we thus propose a two-stage Monte Carlo simulation-based method to estimate the SNL map. To compromise computational time with accuracy in the estimation, a lower bound of sample size required by the Monte Carlo simulation is also investigated. Based on these two VI models and Monte Carlo simulation-based method, we design two hybrid predictioncorrection (PC) cost averaging (CA) algorithms for solving the SUE problem. Finally, two numerical examples are carried out to assess performance of the proposed algorithms.

75. A path-size weibit stochastic user equilibrium model

1. Kitthamkesorn, Songyot; Chen, Anthony

2. TRANSPORT RES B-METH

> The aim of this paper is to develop a path-size weibit (PSW) route choice model with an equivalent mathematical programming (MP) formulation under the stochastic user equilibrium (SUE) principle that can account for both route overlapping and route-specific perception variance problems. Specifically, the Weibull distributed random error term handles the identically distributed assumption such that the perception variance with respect to different trip lengths can be distinguished, and a path-size factor term is introduced to resolve the route overlapping issue by adjusting the choice probabilities for routes with strong couplings with other routes. A multiplicative Beckmann's transformation (MBec) combined with an entropy term are used to develop the MP formulation for the PSW-SUE model. A path-based algorithm based on the partial linearization method is adopted for solving the PSW-SUE model. Numerical examples are also provided to illustrate features of the PSW-SUE model and its differences Compared to some existing SUE models as well as its applicability on a real-size network. Published by Elsevier Ltd.

76. C-logit stochastic user equilibrium model with elastic demand

1. Xu, Xiangdong; Chen, Anthony
2. TRANSPORT PLAN TECHN

> Modeling the elasticity of travel demand in network equilibrium analysis has several important transportation applications. In this paper, we provide a mathematical programming formulation for the C-logit stochastic user equilibrium problem with elastic demand (CL-SUE-ED) in the route domain. The proposed model is capable of explicitly modeling the elasticity of travel demand and the effect of route overlapping on travel choice and route choice simultaneously. Some qualitative properties of the model, including the equivalency and uniqueness of the solution, are also rigorously proved. To solve the CL-SUE-ED model, a partial linearization method is developed to handle the elastic demand and route overlapping considerations. In addition, a self-regulated averaging stepsize scheme is adopted to smartly determine the stepsize while avoiding evaluating the complex objective function. Numerical examples are also provided to demonstrate the features of the proposed model and solution algorithm.

77. Reference-Dependent Stochastic User Equilibrium with Endogenous Reference Points

1. Delle Site, Paolo; Filippi, Francesco; Castaldi, Claudia
2. EUR J TRANSP INFRAST

> We consider the application of reference-dependent consumer choice theory to traffic assignment on transportation networks. Route choice is modelled based on random utility maximisation with systematic utility embodying loss aversion for the travel time and money expenditure attributes. Stochastic user equilibrium models found in the literature have considered exogenously given reference points. The paper proposes a model where reference points are determined consistently with the equilibrium flows and travel times. The reference-dependent stochastic user equilibrium (RDSUE) is defined as the condition where (i) no user can improve her utility by unilaterally changing path, (ii) each user has as reference point the current travel time and the money expenditure of one of the available paths, and (iii) if each user updates the reference point to her current path the observed path flows do not change. These conditions are formally equivalent to a multi-class stochastic equilibrium where each class is associated with a path and has as reference point the current state on the path, and the

> number of users in each class equals the current flow on the path. The RDSUE is formulated as a fixed point problem in the path flows. Existence of RDSUE is guaranteed under usual assumptions. A heuristic algorithm based on the method of successive averages is proposed to solve the problem. The model is illustrated by two numerical examples, one relates to a two-link network and another to the Nguyen-Dupuit network. A reference-dependent route choice model calibrated on stated preference data is used. The second example serves also to demonstrate the algorithm. The impact on the equilibrium of different assumptions on the degree of loss aversion with respect to the travel time attribute are investigated.

78. A Bayesian approach to traffic estimation in stochastic user equilibrium networks

1. Wei, Chong; Asakura, Yasuo
2. TRANSPORT RES C-EMER

> This study proposes a statistical model to estimate route traffic flows in congested networks. In the study, it is assumed that route traffic flows conform to the stochastic user equilibrium (SUE) principle while being treated as random variables in order to exploit the stochastic nature of traffic. The proposed model formulates the distribution of these random variables as the conditional distribution of route flows given the observed link flows and the SUE principle. Here, the SUE principle is accounted for through the likelihood of user behaviours rather than by using a bi-level formulation. In this study, the Bayesian theorem is applied to derive the probability density function (PDF) of the conditional distribution. Based on the PDF, characteristics such as the means and variances of route/link traffic flows are estimated using a blocked Metropolis-Hastings (M-H) algorithm. To facilitate the use of prior knowledge, a hierarchical form is designed to provide a straightforward way to integrate prior knowledge into the traffic estimation model. The performance of the proposed method is tested on the Sioux-Falls network through a series of numerical examples.

79. The posterior probability distribution of traffic flow: a new scheme for the assignment of stochastic traffic flow

1. Wei, Chong; Asakura, Yasuo; Iryo, Takamasa
2. TRANSPORTMETRICA A

> This study proposes a new scheme for assigning traffic flows that aims to capture the stochastic nature of route traffic flows. We consider the route traffic flows to be random variables. The distribution of these random variables is formulated as a conditional probability distribution for a given assumption: the traffic network is in stochastic user equilibrium. From a Bayesian perspective, we treat the conditional distribution as a posterior distribution of route traffic flows, which is obtained using Bayes' theorem. We develop a basic Metropolis-Hastings (M-H) sampling scheme, as well as a M-H within Gibbs sampling scheme, to draw samples from the posterior distribution. We estimate characteristics such as the means and variances of route traffic flows from simulated samples. The proposed model can directly output the route traffic flows, and has a highly flexible computation process.

80. Dynamic pricing, heterogeneous users and perception error: Probit-based bi-criterion dynamic stochastic user equilibrium assignment

1. Zhang, Kuilin; Mahmassani, Hani S.; Lu, Chung-Cheng
2. TRANSPORT RES C-EMER

> A probit-based bi-criterion dynamic stochastic user equilibrium (BDSUE) model is presented to capture path choice behavior of heterogeneous users with distinct values of time (VOT) and different perception of travel costs in response to pricing and congestion in a transportation network. Across the population of travelers, the VOT is represented by a continuously distributed random variable, and path travel cost perception errors are multivariate normally distributed. The BDSUE problem is formulated as a fixed point problem in the infinite dimensional space, and solved by a column generation framework which embeds (i) a parametric analysis method (PAM) to transform the continuous problem to the finite dimensional space by finding breakpoints that partition the entire range of VOT into subintervals and define a multi-class dynamic stochastic user equilibrium (MDSUE) problem; (ii) a column generation algorithm to augment a feasible path set for each user class; (iii) a probit-based stochastic path flow updating scheme to solve a restricted MDSUE problem defined by the set of feasible paths using an averaging method; and (iv) dynamic network loading using a particle-based traffic simulator to capture traffic dynamics and determine experienced travel times for a given path flow pattern. Numerical experiments on a medium size network are conducted to explore convergence of the solution algorithm and to illustrate heterogeneous user responses to dynamic tolls. (C) 2012 Published by Elsevier Ltd.

81. Distributed computing approaches for large-scale probit-based stochastic user equilibrium problems

1. Liu, Zhiyuan; Meng, Qiang
2. J ADV TRANSPORT

> Applications of probit-based stochastic user equilibrium (SUE) principle on large-scale networks have been largely limited because of the overwhelming computational burden in solving its stochastic network loading problem. A two-stage Monte Carlo simulation method is recognized to have satisfactory accuracy level when solving this stochastic network loading. This paper thus works on the acceleration of the Monte Carlo simulation method via using distributed computing system. Three distributed computing approaches are then adopted on the workload partition of the Monte Carlo simulation method. Wherein, the first approach allocates each processor in the distributed computing system to solve each trial of the simulation in parallel and in turns, and the second approach assigns all the processors to solve the shortest-path problems in one trial of the Monte Carlo simulation concurrently. The third approach is a combination of the first two, wherein both different trials of the Monte Carlo simulation as well as the shortest path problems in one trial are solved simultaneously. Performances of the three approaches are comprehensively tested by the Sioux-Falls network and then a randomly generated network example. It shows that computational time for the probit-based SUE problem can be largely reduced by any of these three approaches, and the first approach is found out to be superior to the other two. The first approach is then selected to calculate the probit-based SUE problem on a large-scale network example. Copyright (c) 2011 John Wiley & Sons, Ltd.

82. A COMPARISON OF NETWORK INEFFICIENCY BETWEEN LOGIT-BASED STOCHASTIC USER EQUILIBRIUM AND DETERMINISTIC USER EQUILIBRIUM

1. Jiao, Jing; Xie, Jinxing
2. PAC J OPTIM

> A traffic network without central authority often evolves efficiency loss issues, since its users try to minimize their own travel time. If users have perfect information about their accurate travel time, the

> traffic flow assignment becomes deterministic user equilibrium (UE), whereas the traffic flow assignment in a network whose users have incomplete information becomes logit-based stochastic user equilibrium (SUE). Results obtained from the literature provide the bounds of inefficiency of UE and SUE respectively. This study focuses on the comparison of inefficiency of UE and that of SUE. We define the relative performance ratio of a network as the ratio of its inefficiency of SUE to that of UE, and we present the lower bound and the upper bound of the relative performance ratio. Then we focus on a two-link network. We identify regions where the logit-based SUE leads to a system optimum. Furthermore, we determine a flow region in which the relative performance ratio is strictly less than one, which means SUE performs better than UE. The conditions under which the relative performance ratio reaches its lower bound are also achieved. We further extend our study of the relative performance ratio to networks with parallel routes.

83. Unconstrained weibit stochastic user equilibrium model with extensions

1. Kitthamkesorn, Songyot; Chen, Anthony
2. TRANSPORT RES B-METH

> This study provides an unconstrained minimization program as an alternative formulation for the multinomial weibit (MNW) stochastic user equilibrium (SUE) model that explicitly considers the heterogeneous perception variances with respect to different trip lengths under congested conditions. Qualitative properties of the unconstrained minimization program are given to establish the equivalency and uniqueness of the MNW-SUE solution. The advantage of the unconstrained minimization programming formulation is that it allows the development of a link-based algorithm, which obviates path storage and enumeration. The methodological contributions lie in the derivation of the expected perceived travel cost (or the satisfaction function) that enables the development of an unconstrained MNW-SUE minimization program and a link-based stochastic loading mechanism combined with recent advances in line search strategies in the link-based algorithm. Numerical examples are also provided to illustrate the features of the MNW-SUE model and the link-based algorithm along with several extensions for future research. Published by Elsevier Ltd.

84. Toll pricing framework under logit-based stochastic user equilibrium constraints

1. Liu, Zhiyuan; Wang, Shuaian; Meng, Qiang
2. J ADV TRANSPORT

> This paper addresses the toll pricing framework for the first-best pricing with logit-based stochastic user equilibrium (SUE) constraints. The first-best pricing is usually known as marginal-cost toll, which can be obtained by solving a traffic assignment problem based on the marginal cost functions. The marginal-cost toll, however, has rarely been implemented in practice, because it requires every specific link on the network to be charged. Thus, it is necessary to search for a substitute of the marginal cost pricing scheme, which can reduce the toll locations but still minimize the total travel time. The toll pricing framework is the set of all the substitute toll patterns of the marginal cost pricing. Assuming the users' route choice behavior following the logit-based SUE principle, this paper has first derived a mathematical expression for the toll pricing framework. Then, by proposing an origin-based variational inequality model for the logit-based SUE problem, another toll pricing framework is built, which avoids path enumeration/storage. Finally, the numerical test shows that many alternative pricing patterns can inherently reduce the charging locations and total toll collected, while achieving the same equilibrium link flow pattern. Copyright (c) 2013 John Wiley & Sons, Ltd.

85. Ferry service network design with stochastic demand under user equilibrium flows

1. An, Kun; Lo, Hong K.
2. TRANSPORT RES B-METH

> This paper develops a service reliability-based formulation for ferry service network design with stochastic demand under user equilibrium flows while considering two types of services, regular and ad hoc. Regular services operate with a fixed schedule; whereas ad hoc services are those subcontracted or outsourced to a third party and have a higher unit cost. Two ad hoc provision schemes are studied. Scheme A considers that the demand information is known in advance by passenger reservation, and the company makes use of this information to plan for ad hoc services. In Scheme B, the demand realization is only known as passengers arrive at the piers and the company calls upon ad hoc services in case of demand overflow. In Scheme A, we utilize the notion of service reliability (SR) to address the issue of demand uncertainty and formulate the problem as a two-phase stochastic program in which the schedule of regular services and ad hoc services are derived sequentially. The user equilibrium (UE) assignment with capacity constraint is formulated via a linear programming (LP) approach considering overflow delays. A SR-based gradient solution approach is developed to solve the model. Scheme B, as expected, requires more resources to operate, for which a SR-based non-linear model is developed. The value of reservation to the company is defined as the operating cost difference between these two schemes. We apply the methods to ferry service network design in Hong Kong, and then compare the UE (Scheme A) and system optimal (SO) solutions, in terms of service deployment and computation time, to contrast the solution quality arising from the inclusion of equilibrium flows. The value of advance reservation information between Scheme A and Scheme B is presented as well. (C) 2013 Elsevier Ltd. All rights reserved.

86. Braess paradox and robustness of traffic networks under stochastic user equilibrium

1. Zhao, Chunxue; Fu, Baibai; Wang, Tianming
2. TRANSPORT RES E-LOG

> The Braess paradox is an important phenomenon in the traffic network, and the robustness is a characteristic that measures the network system performance under interference. Study of traffic network paradox and its robustness is an important topic of traffic assignment. In this paper, we investigate the traffic network under elastic demand, its robustness and paradox under stochastic user equilibrium. Using the Logit model and Braess' network, we find that paradox occurs when the congestion of a newly added road meets certain criterion. Paradox severity and the ranking of the network components are both affected by the new congestion. This finding can be applied in the planning of urban traffic network. (C) 2013 Elsevier Ltd. All rights reserved.

87. Formulating the within-day dynamic stochastic traffic assignment problem from a Bayesian perspective

1. Wei, Chong; Asakura, Yasuo; Iryo, Takamasa
2. TRANSPORT RES B-METH

> This study proposes a formulation of the within-day dynamic stochastic traffic assignment problem. Considering the stochastic nature of route choice behavior, we treat the solution to the assignment problem as the conditional joint distribution of route traffic, given that the network is in dynamic stochastic user equilibrium. We acquire the conditional joint probability distribution using Bayes'

> theorem. A Metropolis-Hastings sampling scheme is developed to estimate the characteristics (e.g., mean and variance) of the route traffic. The proposed formulation has no special requirements for the traffic flow models and user behavior models, and so is easily implemented. (C) 2013 Elsevier Ltd. All rights reserved.

88. A Mean-Risk Model for the Traffic Assignment Problem with Stochastic Travel Times

1. Nikolova, E.; Stier-Moses, N. E.
2. OPER RES

> Heavy and uncertain traffic conditions exacerbate the commuting experience of millions of people across the globe. When planning important trips, commuters typically add an extra buffer to the expected trip duration to ensure on-time arrival. Motivated by this, we propose a new traffic assignment model that takes into account the stochastic nature of travel times. Our model extends the traditional model of Wardrop competition when uncertainty is present in the network. The focus is on strategic risk-averse users who capture the trade-off between travel times and their variability in a mean-standard deviation objective, defined as the mean travel time plus a risk-aversion factor times the standard deviation of travel time along a path. We consider both infinitesimal users, leading to a nonatomic game, and atomic users, leading to a discrete finite game. We establish conditions that characterize an equilibrium traffic assignment and find when it exists. The main challenge is posed by the users' risk aversion, since the mean-standard deviation objective is nonconvex and nonseparable, meaning that a path cannot be split as a sum of edge costs. As a result, even an individual user's subproblem-a stochastic shortest path problem-is a nonconvex optimization problem for which no polynomial time algorithms are known. In turn, the mathematical structure of the traffic assignment model with stochastic travel times is fundamentally different from the deterministic counterpart. In particular, an equilibrium characterization requires exponentially many variables, one for each path in the network, since an edge flow has multiple possible path-flow decompositions that are not equivalent. Because of this, characterizing the equilibrium and the socially optimal assignment, which minimizes the total user cost, is more challenging than in the traditional deterministic setting. Nevertheless, we prove that both can be encoded by a representation with just polynomially many paths. Finally, under the assumption that the standard deviations of travel times are independent from edge loads, we show that the worst-case ratio between the social cost of an equilibrium and that of an optimal solution is not higher than the analogous ratio in the deterministic setting. In other words, uncertainty does not further degrade the system performance in addition to strategic user behavior alone.

89. Asymmetric stochastic user equilibrium problem with elastic demand and link capacity constraints

1. Meng, Qiang; Liu, Zhiyuan; Wang, Shuaian
2. TRANSPORTMETRICA A

> This paper focuses on model development and algorithm design for the general stochastic user equilibrium (SUE) problem with elastic demand, asymmetric link travel time functions and link capacity constraints. It first defines the generalised SUE conditions using generalised link travel time. An equivalent variational inequality (VI) model for these generalised SUE conditions is then developed and it is rigorously proven to be monotone and uniform Lipschitz-continuous. These two properties of the proposed VI model ensure the global convergence of the self-adaptive prediction-correction algorithm

> incorporating cost averaging method as a solution algorithm. Finally, a numerical example is utilised to assess the performance of the proposed VI model and solution algorithm.

90. Computation and application of the paired combinatorial logit stochastic user equilibrium problem

1. Chen, Anthony; Ryu, Seungkyu; Xu, Xiangdong; Choi, Keechoo
2. COMPUT OPER RES

> The paired combinatorial logit (PCL) model is one of the recent extended logit models adapted to resolve the overlapping problem in the route choice problem, while keeping the analytical tractability of the logit choice probability function. However, the development of efficient algorithms for solving the PCL model under congested and realistic networks is quite challenging, since it has large-dimensional solution variables as well as a complex objective function. In this paper, we examine the computation and application of the PCL stochastic user equilibrium (SUE) problem under congested and realistic networks. Specifically, we develop an improved path-based partial linearization algorithm for solving the PCL SUE problem by incorporating recent advances in line search strategies to enhance the computational efficiency required to determine a suitable stepsize that guarantees convergence. A real network in the city of Winnipeg is applied to examine the computational efficiency of the proposed algorithm and the robustness of various line search strategies. In addition, in order to acquire the practical implications of the PCL SUE model, we investigate the effectiveness of how the PCL model handles the effects of congestion, stochasticity, and similarity in comparison with the multinomial logit stochastic traffic equilibrium problem and the deterministic traffic equilibrium problem. Published by Elsevier Ltd.

91. EFFICIENCY LOSS OF MIXED EQUILIBRIUM ASSOCIATED WITH ALTRUISTIC USERS AND LOGIT-BASED STOCHASTIC USERS IN TRANSPORTATION NETWORK

1. Yu, Xiao-Jun; Fang, Chun-Hua
2. PROMET-ZAGREB

> The efficiency loss of mixed equilibrium associated with two categories of users is investigated in this paper. The first category of users are altruistic users (AU) who have the same altruism coefficient and try to minimize their own perceived cost that assumed to be a linear combination of selfish component and altruistic component. The second category of users are Logit-based stochastic users (LSU) who choose the route according to the Logit-based stochastic user equilibrium (SUE) principle. The variational inequality (VI) model is used to formulate the mixed route choice behaviours associated with AU and LSU. The efficiency loss caused by the two categories of users is analytically derived and the relations to some network parameters are discussed. The numerical tests validate our analytical results. Our result takes the results in the existing literature as its special cases.

92. Exploring trust region method for the solution of logit-based stochastic user equilibrium problem

1. Zhou, Bojian; Li, Xuhong; He, Jie
2. EUR J OPER RES

> In this research paper, we explored using the trust region method to solve the logit-based SUE problem. We proposed a modified trust region Newton (MTRN) algorithm for this problem. When

> solving the trust region SUE subproblem, we showed that applying the well-known Steihaug-Toint method is inappropriate, since it may make the convergence rate of the major iteration very slow in the early stage of the computation. To overcome this drawback, a modified Steihaug-Toint method was proposed. We proved the convergence of our MTRN algorithm and showed its convergence rate is superlinear. For the implication of our algorithm, we proposed an important principle on how to select the basic route for each OD pair. We indicated that it is a crucial principle to accelerate the convergence rate of the minor iteration (i.e. trust region subproblem-solving iteration). In this study, other implication issues for the SUE problem are also considered, including the computation of the trial step and the strategy to ensure strict feasibility iteration point. We compared the MTRN algorithm with the Gradient Projection (GP) algorithm on the Sioux Falls network. Some results of numerical analysis are also reported. (C) 2014 Elsevier B.V. All rights reserved.

93. Modeling Demand Elasticity and Route Overlapping in Stochastic User Equilibrium Through Paired Combinatorial Logit Model

1. Ryu, Seungkyu; Chen, Anthony; Xu, Xiangdong; Choi, Keechoo
2. TRANSPORT RES REC

> In this paper an equivalent mathematical programming formulation is provided for modeling demand elasticity and route overlapping in the stochastic user equilibrium (SUE) problem. The elastic demand establishes the equilibrium between supply function and demand function on the basis of microeconomics. Because the elasticity of demand is an important factor in predicting the future demand pattern and avoiding the potential biased assessment in transportation planning, the elasticity of travel demand must be modeled endogenously. The route overlapping problem is handled by the paired combinatorial logit (PCL) model while retaining the analytical tractability of the logit choice probability function. The PCL SUE model with elastic demand (PCL-SUE-ED) explicitly models the elasticity of travel demand and the effect of route overlapping on travel choice and route choice simultaneously. A path-based partial linearization algorithm is also developed for solving the PCL-SUE-ED model. In addition, a self-regulated averaging line search strategy is incorporated into the algorithm to minimize the computational efforts required to determine a suitable step size that guarantees convergence. Numerical results are provided to examine the features of the PCL-SUE-ED model as well as the efficiency of the path-based partial linearization algorithm.

94. Variational inequality model for cordon-based congestion pricing under side constrained stochastic user equilibrium conditions

1. Liu, Zhiyuan; Meng, Qiang; Wang, Shuaian
2. TRANSPORTMETRICA A

> A major objective of the practical implemented cordon-based congestion pricing schemes is to maintain the traffic conditions within the cordon area, which is rarely considered in most of the existing studies. Thus, this paper addresses the optimal toll charge pattern that can restrict the total inbound flow of each cordon to a predetermined threshold. The toll charges on all the entry links of one cordon are required to be identical, for the ease of implementation and users' recognition. The users' route choice behaviour is assumed to follow stochastic user equilibrium (SUE) with asymmetric link travel time functions. It is shown that such an optimal toll charge pattern can be attained by solving a SUE problem with side constraints. A variational inequality (VI) model is first proposed for the optimal toll pattern, where the monotone property of this model is rigorously proved. Then, a convergent self-

> adaptive prediction and correction method can be adopted for solving the VI model. It is shown that when used in practice, the solution method only needs traffic counts on entry links of each cordon.

95. Solving the logit-based stochastic user equilibrium problem with elastic demand based on the extended traffic network model

1. Yu, Qian; Fang, Debin; Du, Wei
2. EUR J OPER RES

> This paper proposes a novel extended traffic network model to solve the logit-based stochastic user equilibrium (SUE) problem with elastic demand. In this model, an extended traffic network is established by properly adding dummy nodes and links to the original traffic network. Based on the extended traffic network, the logit-based SUE problem with elastic demand is transformed to the SUE problem with fixed demand. Such problem is then further converted to a linearly constrained convex programming and addressed by a predictor-corrector interior point algorithm with polynomial complexity. A numerical example is provided to compare the proposed model with the method of successive averages (MSA). The numerical results indicate that the proposed model is more efficient and has a better convergence than the MSA.

96. On multi-objective stochastic user equilibrium

1. Ehrgott, Matthias; Wang, Judith Y. T.; Watling, David P.
2. TRANSPORT RES B-METH

> There is extensive empirical evidence that travellers consider many qualities (travel time, tolls, reliability, etc.) when choosing between alternative routes. Two main approaches exist to deal with this in network assignment models: Combine all qualities into a single (linear) utility function, or solve a multi-objective problem. The former has the advantages of a unique solution and efficient algorithms; the latter, however, is more general, but leads to many solutions and is difficult to implement in larger systems. In the present paper we present three alternative approaches for combining the principles of multi-objective decision-making with a stochastic user equilibrium model based on random utility theory. The aim is to deduce a tractable, analytic method. The three methods are compared both in terms of their theoretical principles, and in terms of the implied trade-offs, illustrated through simple numerical examples.

97. ROAD NETWORK RESERVE CAPACITY WITH STOCHASTIC USER EQUILIBRIUM

1. Wang, Jian; Deng, Wei; Zhao, Jinbao
2. TRANSPORT-VILNIUS

> To relax the strong assumption associated with User Equilibrium (UE) in the previous research of network reserve capacity conducted by Gao and Song (2002), this paper assumes that the drivers all make route choices based on Stochastic User Equilibrium (SUE) principle. Similarly, two bi-level programs are formulated to study the network reserve capacity with SUE problem. The first bi-level program is developed to maximize the network reserve capacity by optimizing signal settings while the traffic demands are reassigned by SUE model. The second program extends the research with Continuous Network Design (CND) problem to find the maximum possible increase in reserve capacity through optimizing allocation of network investment. Two methods, i.e. the sensitivity analysis-based method and Genetic Algorithm (GA), are detailed formulated to solve the bi-level reserve capacity

> problem. Application of the proposed model and its solution algorithms on two numerical examples find that the network reserve capacity does not always increase with improved quality of drivers' information. Besides, CND can not only help to increase network reserve capacity, but also can help to make more use of physical capacity of road network at Deterministic User Equilibrium (DUE) condition, thus reduces the difference of reserve capacity between the assumptions of SUE and DUE.

98. Beyond normality: A cross moment-stochastic user equilibrium model

1. Ahipasaoglu, Selin Damla; Meskarian, Rudabeh; Magnanti, Thomas L.; Natarajan, Karthik
2. TRANSPORT RES B-METH

> The Stochastic User Equilibrium (SUE) model predicts traffic equilibrium flow assuming that users choose their perceived maximum utility paths (or perceived shortest paths) while accounting for the effects of congestion that arise due to users sharing links. Inspired by recent work on distributionally robust optimization, specifically a Cross Moment (CMM) choice model, we develop a new SUE model that uses the mean and covariance information on path utilities but does not assume the particular form of the distribution. Robustness to distributional assumptions is obtained in this model by minimizing the worst-case expected cost over all distributions with fixed two moments. We show that under mild conditions, the CMM-SUE (Cross Moment-Stochastic User Equilibrium) exists and is unique. By combining a simple projected gradient ascent method to evaluate path choice probabilities with a gradient descent method to find flows, we show that the CMM-SUE is efficiently computable. CMM-SUE provides both modeling flexibility and computational advantages over approaches such as the well-known MNP-SUE (Multinomial Probit-Stochastic User Equilibrium) model that require distributional (normality) assumptions to model correlation effects from overlapping paths. In particular, it avoids the use of simulation methods employed in computations for the distribution-based MNP-SUE model. Preliminary computational results indicate that CMM-SUE provides a practical distributionally robust alternative to MNP-SUE.

99. Modeling absolute and relative cost differences in stochastic user equilibrium problem

1. Xu, Xiangdong; Chen, Anthony; Kitthamkesorn, Songyot; Yang, Hai; Lo, Hong K.
2. TRANSPORT RES B-METH

> This paper aims to develop a hybrid closed-form route choice model and the corresponding stochastic user equilibrium (SUE) to alleviate the drawbacks of both Logit and Weibit models by simultaneously considering absolute cost difference and relative cost difference in travelers' route choice decisions. The model development is based on an observation that the issues of absolute and relative cost differences are analogous to the negative exponential and power impedance functions of the trip distribution gravity model. Some theoretical properties of the hybrid model are also examined, such as the probability relationship among the three models, independence from irrelevant alternatives, and direct and indirect elasticities. To consider the congestion effect, we provide a unified modeling framework to formulate the Logit, Weibit and hybrid SUE models with the same entropy maximization objective but with different total cost constraint specifications representing the modelers' knowledge of the system. With this, there are two ways to interpret the dual variable associated with the cost constraint: shadow price representing the marginal change in the entropy level to a marginal change in the total cost, and dispersion/shape parameter representing the travelers' perceptions of travel costs. To further consider the route overlapping effect, a path-size factor is incorporated into the hybrid SUE model. Numerical examples are also provided to illustrate the capability of the hybrid model in

> handling both absolute and relative cost differences as well as the route overlapping problem in travelers' route choice decisions. Published by Elsevier Ltd.

100. Global optimization method for network design problem with stochastic user equilibrium

1. Liu, Haoxiang; Wang, David Z. W.
2. TRANSPORT RES B-METH

> In this paper, we consider the continuous road network design problem with stochastic user equilibrium constraint that aims to optimize the network performance via road capacity expansion. The network flow pattern is subject to stochastic user equilibrium, specifically, the logit route choice model. The resulting formulation, a nonlinear nonconvex programming problem, is firstly transformed into a nonlinear program with only logarithmic functions as nonlinear terms, for which a tight linear programming relaxation is derived by using an outer-approximation technique. The linear programming relaxation is then embedded within a global optimization solution algorithm based on range reduction technique, and the proposed approach is proved to converge to a global optimum. (C) 2014 Elsevier Ltd. All rights reserved.

101. Combined Gravity Model Trip Distribution and Paired Combinatorial Logit Stochastic User Equilibrium Problem

1. Karoonsoontawong, Ampol; Lin, Dung-Ying
2. NETW SPAT ECON

> The equivalent mathematical formulation of the combined doubly-constrained gravity-based trip distribution and paired-combinatorial-logit stochastic user equilibrium assignment problem (CDA-PCL-SUE) is proposed. Its first order conditions are shown to be equal to the gravity equations and PCL formula. The proposed solution method is a path-based partial linearization algorithm to approximately solve the restricted CDA-PCL-SUE. The proposed algorithm is a three-phase iterative process. Phase 1 is an entropy maximization problem on O-D flow space that can be solved by Bregman's balancing algorithm. Phase 2 is a PCL SUE problem that can be solved by PCL formula. Phase 3 is line search. CDA-PCL-SUE is solved on a small network and a real network, the city of Winnipeg network. The proposed algorithms with the six line search methods, namely, golden section (GS), bisection (BS), Armijo's rule (AR), method of successive averages (MSA), self-regulated averaging (SRA) scheme, and quadratic interpolation (QI) scheme, are compared in terms of various convergence characteristics: root mean square error, step size, KKT-based mean square error and objective function. In terms of computational efficiency, under different path set sizes, dispersion parameters, impedance parameters and demand levels, the following line search methods are ordered from best to worst: SRA, GS, AR, QI, BS and MSA. The performances of Armijo's rule and QI have greater variances. The performance of QI is worse with the increase of the path set size. Given all other factors being the same, the increase of dispersion parameter, path set size or demand level yields the increase of CPU time, whereas the change of impedance parameter does not influence CPU time. In addition, CDA-PCL-SUE is compared with its multinomial-logit counterpart (CDA-MNL-SUE).

102. Multiclass Stochastic User Equilibrium Model with Elastic Demand Considering Systematic and Accidental Delays

1. Sun, Chao; Cheng, Lin; Zhu, Senlai; Chu, Zhaoming
2. TRANSPORT RES REC

> This paper proposes a multiclass, multidelay stochastic user equilibrium model with elastic demand (MC-MDSUE-ED) that explicitly considers both systematic delay and accidental delay in the route choice decision process. This new model hypothesizes that for each user class and each origin destination (O-D) pair, no traveler can reduce his or her multi-delay travel time,defined as the systematic delay plus accidental delay, by unilaterally changing paths. The actual travel demand for each user class between each O-D pair satisfies its elastic demand function. Travel time budget and robust optimization theory are used to compute the systematic delay and accidental delay, respectively. The MC-MDSUE-ED conditions compose a cobweb model. A self-adaptive bisection algorithm that converts the problem with elastic demand to a series of problems with fixed demand was developed for solving the cobweb model. A path-based quasi method of successive averages was used to solve the MC-MDSUE model with fixed demand. Numerical examples illustrate the essential ideas of the proposed model and the applicability of the proposed solution algorithm.

103. Stochastic user equilibrium with equilibrated choice sets: Part I - Model formulations under alternative distributions and restrictions

1. Watling, David Paul; Rasmussen, Thomas Kjaer; Prato, Carlo Giacomo; Nielsen, Otto Anker
2. TRANSPORT RES B-METH

> The aim of this paper is to remove the known limitations of Deterministic and Stochastic User Equilibrium (DUE and SUE), namely that only routes with the minimum cost are used in DUE, and that all permitted routes are used in SUE regardless of their costs. We achieve this by combining the advantages of the two principles, namely the definition of unused routes in DUE and of mis-perception in SUE, such that the resulting choice sets of used routes are equilibrated. Two model families are formulated to address this issue: the first is a general version of SUE permitting bounded and discrete error distributions; the second is a Restricted SUE model with an additional constraint that must be satisfied for unused paths. The overall advantage of these model families consists in their ability to combine the unused routes with the use of random utility models for used routes, without the need to pre-specify the choice set. We present model specifications within these families, show illustrative examples, evaluate their relative merits, and identify key directions for further research. (C) 2015 Elsevier Ltd. All rights reserved.

104. Elastic demand with weibit stochastic user equilibrium flows and application in a motorised and non-motorised network

1. Kitthamkesorn, Songyot; Chen, Anthony; Xu, Xiangdong
2. TRANSPORTMETRICA A

> In this paper, we propose a new elastic demand (ED) stochastic user equilibrium (SUE) model with an application to the combined modal split and traffic assignment (CMSTA) problem. This new model, called the path-size weibit (PSW) SUE model with ED, is derived based on the Weibull distribution, which does not require the identically distributed assumption typically imposed in the multinomial logit (MNL) model with the Gumbel distribution. In addition, a path-size factor is included to correct the choice probabilities of routes that are not truly independent (i.e. another assumption typically required in the MNL model). Equivalent mathematical programming (MP) formulation of the PSW-SUE-ED model is developed to simultaneously consider both travel choice and route choice. The travel choice is determined based on the ED function that explicitly considers the network level of service based on the logarithmic expected perceived cost of the Weibull distribution to determine the travel

> demand, while the route choice accounts for both route overlapping and non-identical perception variance with respect to different trip lengths. Qualitative properties of the proposed MP formulation are rigorously proved. A path-based partial linearisation algorithm combined with a self-regulated averaging line search strategy is developed for solving the PSW-SUE-ED model and its application to the CMSTA problem. Numerical examples are also provided to demonstrate the features of the proposed PSW-SUE-ED model as well as a real-case study in a bi-modal network with motorised and non-motorised mode choices.

105. Optimal location of wireless charging facilities for electric vehicles: Flow-capturing location model with stochastic user equilibrium

1. Riemann, Raffaela; Wang, David Z. W.; Busch, Fritz
2. TRANSPORT RES C-EMER

> In this study, the optimal locations of a specific type of charging facilities for electric vehicles (EVs), wireless power transfer facilities, are investigated. A mathematical model has been developed to address this problem. The objective of the model is to locate a given number of wireless charging facilities for EVs out of a set of candidate facility locations for capturing the maximum traffic flow on a network. The interaction between traffic flow patterns and the location of the charging facilities is incorporated explicitly by applying the stochastic user equilibrium principle to describe electric vehicle drivers' routing choice behavior. Firstly, the problem is formulated into a mixed-integer nonlinear program, secondly a solution method is developed to obtain the global optimal solution of the linearized program. Numerical experiments are presented to demonstrate the model validity.

106. Stochastic user equilibrium with equilibrated choice sets: Part II - Solving the restricted SUE for the logit family

1. Rasmussen, Thomas Kjaer; Watling, David Paul; Prato, Carlo Giacomo; Nielsen, Otto Anker
2. TRANSPORT RES B-METH

> We propose a new class of path-based solution algorithms to solve the Restricted Stochastic User Equilibrium (RSUE), as introduced in Wading et al. (2015). The class allows a flexible specification of how the choice sets are systematically grown by considering congestion effects and how the flows are allocated among routes. The specification allows adapting traditional path-based stochastic user equilibrium flow allocation methods (originally designed for pre-specified choice sets) to the generic solution algorithm. We also propose a cost transformation function and show that by using this we can, for certain Logit-type choice models, modify existing path-based Deterministic User Equilibrium solution methods to compute RSUE solutions. The transformation function also leads to a two-part relative gap measure for consistently monitoring convergence to a RSUE solution. Numerical tests are reported on two real-life cases, in which we explore convergence patterns and choice set composition and size, for alternative specifications of the RSUE model and solution algorithm.

107. A nonlinear equation system approach to the dynamic stochastic user equilibrium simultaneous route and departure time choice problem

1. Long, Jiancheng; Szeto, W. Y.; Shi, Qin; Gao, Ziyou; Huang, Hai-Jun
2. TRANSPORTMETRICA A

> In dynamic stochastic user equilibrium simultaneous route and departure time choice (DSUE-SRDTC) problems, route travel costs can be non-monotone even if route travel times are monotone with respect to route flows. As a result, the mapping function of the variational inequality (VI) problems for the DSUE-SRDTC problems can be non-monotone, and many existing solution algorithms developed for the DSUE-SRDTC problems do not guarantee convergence under this non-monotone condition. This paper formulates the DSUE-SRDTC problem with fixed demand as a system of nonlinear equations. The mapping function of the proposed system of nonlinear equations is defined by a dynamic route choice problem, which can also be formulated as a VI problem with a strictly monotone mapping function under some assumptions. This property enables that the solution algorithm for the DSUE-SRDTC problem can avoid the requirement of the monotonicity of the route travel cost functions for the convergence of the solution procedure. A backtracking inexact Broyden-Fletcher-Goldfarb-Shanno (BFGS) method is adopted to solve the system of nonlinear equations, and iterative methods are developed to generate an initial solution for the BFGS method and solve the dynamic route choice problem. Finally, numerical examples are set up to show that the proposed method outperforms many existing algorithms for solving the DSUE-SRDTC problem in terms of guaranteeing solution convergence.

108. Modeling and solving discrete network design problem with stochastic user equilibrium

1. Liu, Haoxiang; Wang, David Z. W.
2. J ADV TRANSPORT

> In this paper, we address the discrete network design problem, which determines the addition of new roads to existing transportation network to optimize the transportation system performance. Road users are assumed to follow the traffic assignment principle of stochastic user equilibrium. A mixed-integer nonlinear nonconvex problem is developed to model this discrete network design problem with stochastic user equilibrium. The original problem is relaxed into a convex mixed-integer nonlinear program, whose solution provides a lower bound of the original problem. The relaxed problem is then embedded into two proposed global optimization solution algorithms to obtain the global optimal solution of the problem. Copyright (c) 2016 John Wiley & Sons, Ltd.

109. A route-swapping dynamical system and Lyapunov function for stochastic user equilibrium

1. Smith, Michael J.; Watling, David P.
2. TRANSPORT RES B-METH

> An analysis of the continuous-time dynamics of a route-swap adjustment process is presented, which is a natural adaptation of that presented in Smith (1984) for deterministic choice problems, for a case in which drivers are assumed to make perceptual errors in their evaluations of travel cost according to a Random Utility Model. We show that stationary points of this system are stochastic user equilibria. A Lyapnuov function is developed for this system under the assumption of monotone, continuously differentiable and bounded cost-flow functions and a logit-based decision rule, establishing convergence and stability of trajectories of such a dynamical system with respect to a stochastic user equilibrium solution. (C) 2016 Elsevier Ltd. All rights reserved.

110. Two New Methods for Solving the Path-Based Stochastic User Equilibrium Problem

1. Zhou, Bojian; Bliemer, Michiel C. J.; Bell, Michael G. H.; He, Jie

2. COMPUT-AIDED CIV INF

> In this article, we present two new methods for the path-based logit stochastic user equilibrium problem, and investigate their convergence properties. First, a two-level partial linearization method is proposed. Second, a dual method is developed. Both of these two methods use second-order approximation of the objective function. Our novel methods are compared to Damberg's partial linearization method (Damberg, 1996), which is known to be one of the best performing methods. Numerical results on the different networks show that, if properly scaled, our new methods compare favorably to Damberg's method.

111. Solving the stochastic multi-class traffic assignment problem with asymmetric interactions, route overlapping, and vehicle restrictions

1. Ryu, Seungkyu; Chen, Anthony; Choi, Keechoo
2. J ADV TRANSPORT

> In this paper, we develop a customized path-based algorithm for solving the stochastic multi-class traffic assignment problem with asymmetric interactions, route overlapping, and vehicle restrictions. The algorithm consists of an iterative balancing scheme to find the search direction, a self-regulated averaging line search scheme to determine a suitable stepsize, and a column generation scheme to generate a universal path set for multiple vehicle classes. These three schemes work together in the customized path-based algorithm to solve the stochastic multi-class traffic assignment problem. The solution algorithm simultaneously considers the asymmetric interactions among different vehicle types through the link travel time functions, various vehicle restrictions in a transportation network, and route overlapping using the path-size logit model for accounting random perceptions of network conditions in a stochastic user equilibrium framework. A real network in the city of Winnipeg, Canada, is used to examine the computational performance of the customized path-based algorithm. In addition, sensitivity analyses are conducted to test the algorithmic effectiveness with respect to several model parameters and percentages of trucks in the transportation network. Numerical results reveal that the path-based algorithm with the self-regulated averaging line search scheme is computationally effective in solving the stochastic multi-class traffic assignment problem with different modeling considerations. The algorithm is also computationally robust against various model parameters in the sensitivity analyses. Copyright (c) 2015 John Wiley & Sons, Ltd.

112. A general stochastic process for day-to-day dynamic traffic assignment: Formulation, asymptotic behaviour, and stability analysis

1. Cantarella, Giulio E.; Watling, David P.
2. TRANSPORT RES B-METH

> This paper presents a general modelling approach to day-to-day dynamic assignment to a congested network through discrete-time stochastic and deterministic process models including an explicit modelling of users' habit as a part of route choice behaviour, through an exponential smoothing filter, and of their memory of network conditions on past days, through a moving average or an exponentially smoothing filter. An asymptotic analysis of the mean process is carried out to provide a better insight. Results of such analyses are also used for deriving conditions, about values of the system parameters, assuring that the mean process is dissipative and/or converges to some kind of

> attractor. Numerical small examples are also provided in order to illustrate the theoretical results obtained. (C) 2016 Elsevier Ltd. All rights reserved.

113. Stochastic user equilibrium traffic assignment with equilibrated parking search routes

1. Pel, Adam J.; Chaniotakis, Emmanouil
2. TRANSPORT RES B-METH

> In this paper we define and formulate the concept of parking search routes (PSR) where a driver visits a sequence of parking locations until the first vacant parking spot is found and in doing so may account for (expected) parking probabilities. From there we define and formulate the stochastic user equilibrium (SUE) traffic assignment in which no driver, by unilaterally changing its PSR, can lower its perceived expected generalized costs. Recognizing the interdependency between PSR flows, travel times and parking probabilities, we propose a queuing model in order to compute endogenous parking probabilities accounting for these factors as well as maximum admissible search times. To solve the SUE assignment with equilibrated PSR we propose a solution algorithm, including a method for PSR choice set generation. The model is implemented and applied both to a number of experimental cases to verify its properties and to a real-life setting to illustrate its usefulness in parking-related studies. (C) 2017 Elsevier Ltd. All rights reserved.

114. Direct formulation and algorithms for the probit-based stochastic user equilibrium traffic assignment problem

1. Chen, Qun; Pan, Shuangli
2. TRANSPORT PLAN TECHN

> This paper proposes simple and direct formulation and algorithms for the probit-based stochastic user equilibrium traffic assignment problem. It is only necessary to account for random variables independent of link flows by performing a simple transformation of the perceived link travel time with a normal distribution. At every iteration of a Monte-Carlo simulation procedure, the values of the random variables are sampled based on their probability distributions, and then a regular deterministic user equilibrium assignment is carried out to produce link flows. The link flows produced at each iteration of the Monte-Carlo simulation are averaged to yield the final flow pattern. Two test networks demonstrate that the proposed algorithms and the traditional algorithm (the Method of Successive Averages) produce similar results and that the proposed algorithms can be extended to the computation of the case in which the random error term depends on measured travel time.

115. Subjective-utility travel time budget modeling in the stochastic traffic network assignment

1. Ji, Xiangfeng; Ban, Xuegang (Jeff); Zhang, Jian; Ran, Bin
2. J INTELL TRANSPORT S

> In this article, we propose a new model called subjective-utility travel time budget (SU-TTB) model to capture travelers' risk-averse route choices. In the travel time budget (TTB) and mean-excess travel time (METT) model, a predefined confidence level is needed to capture the risk-aversion in route choice. Due to the day-to-day route travel time variations, the exact confidence level is hard to be predicted. With the SU-TTB model, we assume travelers' confidence level belongs to an interval that they may comply with in the route choice. The two main components of SU-TTB are the utility function

> and the TTB model. We can show that the SU-TTB can be reduced to the TTB and METT model with proper utility function for the confidence levels. We can also prove its equivalence with our recently proposed nonlinear-expectation route travel time (NERTT) model in some cases and give some new interpretation on the NERTT with this equivalence. Finally, we formulate the SU-TTB model as a variational inequality (VI) problem to model the risk-averse user equilibrium (RAUE), termed as generalized RAUE (GRAUE). The GRAUE is solved via a heuristic gradient projection algorithm, and the model and solution algorithm are demonstrated with the Braess's traffic network and the Nguyen and Dupuis's traffic network.

116. Path-constrained traffic assignment: Modeling and computing network impacts of stochastic range anxietye

1. Xie, Chi; Wang, Tong-Gen; Pu, Xiaoting; Karoonsoontawong, Ampol
2. TRANSPORT RES B-METH

> It is notoriously known that range anxiety is one of the major barriers that hinder a wide adoption of plug-in electric vehicles, especially battery electric vehicles. Recent studies suggested that if the caused driving range limit makes any impact on travel behaviors, it more likely occurs on the tour or trip chain level than the trip level. To properly assess its impacts on travel choices and traffic congestion, this research is devoted to studying a new network equilibrium problem that implies activity location and travel path choices on the trip chain level subject to stochastic driving ranges. Convex optimization and variational inequality models are respectively constructed for characterizing the equilibrium conditions under both discretely and continuously distributed driving ranges. For deriving the equilibrium flow solutions for these problem cases, we suggested different adaptations of a well-known path-based algorithm the projected gradient method. While the problem instance with a discrete number of driving ranges can be simply treated as a multi-class version of its deterministic counterpart, the one with continuous driving ranges poses a much more complicated situation. To overcome this arising modeling and algorithmic complication, we introduce a couple of newly defined variables, namely, path-indexed travel subdemand rate and traffic subflow rate, by which the demand and flow rates as well as their corresponding feasible path sets can be dynamically indexed in the solution process with reference to path lengths. An illustrative example with various types and forms of driving range distributions demonstrates the applicability of the proposed modeling and solution methods and various impacts of the heterogeneity of range anxiety on network flows and computational costs. The numerical analysis results from this example show that stochastic driving ranges confine network flows in a different way from deterministic or no driving ranges and the projected gradient procedure relying on dynamically indexed subdemand and subflow rates is generally preferable to its counterpart on pre-indexed ones for both the discrete and continuous driving range cases. 2017 Elsevier Ltd. All rights reserved.

117. The Restricted Stochastic User Equilibrium with Threshold model: Large-scale application and parameter testing

1. Rasmussen, Thomas Kjaer; Nielsen, Otto Anker; Watling, David P.; Prato, Carlo Giacomo
2. EUR J TRANSP INFRAST

> This paper presents the application and calibration of the recently proposed Restricted Stochastic User Equilibrium with Threshold model (RSUET) to a large-scale case-study. The RSUET model avoids the limitations of the well-known Stochastic User Equilibrium model (SUE) and the Deterministic User

> Equilibrium model (DUE), by combining the strengths of the Boundedly Rational User Equilibrium model and the Restricted Stochastic User Equilibrium model (RSUE). Thereby, the RSUET model reaches an equilibrated solution in which the flow is distributed according to Random Utility Theory among a consistently equilibrated set of paths which all are within a threshold relative to the cost on the cheapest path and which do not leave any attractive paths unused. Several variants of a generic RSUET solution algorithm are tested and calibrated on a large-scale case network with 18,708 arcs and about 20 million OD-pairs, and comparisons are performed with respect to a previously proposed RSUE model as well as an existing link-based mixed Multinomial Probit (MNP) SUE model. The results show that the RSUET has very attractive computation times for large-scale applications and demonstrate that the threshold addition to the RSUE model improves the behavioural realism, especially for high congestion cases. Also, fast and well-behaved convergence to equilibrated solutions among non-universal choice sets is observed across different congestion levels, choice model scale parameters, and algorithm step sizes. Clearly, the results highlight that the RSUET outperforms the MNP SUE in terms of convergence, calculation time and behavioural realism. The choice set composition is validated by using 16,618 observed route choices collected by GPS devices in the same network and observing their reproduction within the equilibrated choice sets generated by the RSUET model. Relevantly, the RSUET model is very successful in reproducing observed link.

118. Location Design of Electric Vehicle Charging Facilities: A Path-Distance Constrained Stochastic User Equilibrium Approach

1. Jing, Wentao; An, Kun; Ramezani, Mohsen; Kim, Inhi
2. J ADV TRANSPORT

> Location of public charging stations, range limit, and long battery-charging time inevitably affect drivers' path choice behavior and equilibrium flows of battery electric vehicles (BEVs) in a transportation network. This study investigates the effect of the location of BEVs public charging facilities on a network with mixed conventional gasoline vehicles (GVs) and BEVs. These two types of vehicles are distinguished from each other in terms of travel cost composition and distance limit. A bilevel model is developed to address this problem. In the upper level, the objective is to maximize coverage of BEV flows by locating a given number of charging stations on road segments considering budget constraints. A mixed-integer nonlinear program is proposed to formulate this model. A simple equilibrium-based heuristic algorithm is developed to obtain the solution. Finally, two numerical tests are presented to demonstrate applicability of the proposedmodel and feasibility and effectiveness of the solution algorithm. The results demonstrate that the equilibrium traffic flows are affected by charging speed, range limit, and charging facilities' utility and that BEV drivers incline to choose the route with charging stations and less charging time.

119. Stochastic user equilibrium model with a tradable credit scheme and application in maximizing network reserve capacity

1. Han, Fei; Cheng, Lin
2. ENG OPTIMIZ

> The tradable credit scheme (TCS) outperforms congestion pricing in terms of social equity and revenue neutrality, apart from the same perfect performance on congestion mitigation. This article investigates the effectiveness and efficiency of TCS on enhancing transportation network capacity in a stochastic user equilibrium (SUE) modelling framework. First, the SUE and credit market equilibrium conditions

> are presented; then an equivalent general SUE model with TCS is established by virtue of two constructed functions, which can be further simplified under a specific probability distribution. To enhance the network capacity by utilizing TCS, a bi-level mathematical programming model is established for the optimal TCS design problem, with the upper level optimization objective maximizing network reserve capacity and lower level being the proposed SUE model. The heuristic sensitivity analysis-based algorithm is developed to solve the bi-level model. Three numerical examples are provided to illustrate the improvement effect of TCS on the network in different scenarios.

120. An informed user equilibrium dynamic traffic assignment problem in a multiple origin-destination stochastic network

1. Hoang, Nam H.; Vu, Hai L.; Lo, Hong K.
2. TRANSPORT RES B-METH

> We develop in this paper a comprehensive linear mathematical framework to study the benefit of real-time information and the impact of resulting user adaptive route choice behaviours on network performance. The framework formulates the information-based stochastic user equilibrium (ISUE) dynamic traffic assignment (DTA) problem for a multiple origin-destination (OD) network. Using the framework, we prove the linkage between the user equilibrium (UE) and system optimal (SO) solutions underpinned by the first-in-first out (FIFO) principle. This important property then enables us to develop an incremental loading method to obtain the ISUE solutions efficiently by solving a sequence of linear programs. Moreover, the proposed method is more scalable that avoids a huge enumeration of paths in large-scale networks as done in path-based methods of the existing literature on this topic. We show via numerical examples the impact of information on both route choices and network performance, and demonstrate the significant improvements in the obtained ISUE solution both in terms of accuracy and computational complexity.

121. A stochastic process traffic assignment model considering stochastic traffic demand

1. Han, Linghui; Sun, Huijun; Wang, David Z. W.; Zhu, Chengjuan
2. TRANSPORTMETRICA B

> In real traffic network, both link capacity and traffic demand are subject to stochastic fluctuations. These random fluctuations are major sources of travel time uncertainty. All existing stochastic process traffic assignment model models considering the uncertainty of travel time are presented with fixed traffic demand. In this study, a stochastic process traffic assignment model is presented to consider stochastic traffic demand. The traffic demand is assumed to be comprised of two groups of travelers: commuters with fixed traffic demand and irregular travelers with discrete random demand. With mild conditions, it is proved that our stochastic process traffic assignment model is ergodic and has a unique stable distribution. An algorithm is given to describe the stochastic process model. By conducting numerical test, we analyze the effect of commuters' memory length, irregular travelers' demand and commuters' perception error on the stable distribution of our model.

122. Stochastic user equilibrium with a bounded choice model

1. Watling, David Paul; Rasmussen, Thomas Kjaer; Prato, Carlo Giacomo; Nielsen, Otto Anker
2. TRANSPORT RES B-METH

> Stochastic User Equilibrium (SUE) models allow the representation of the perceptual and preferential differences that exist when drivers compare alternative routes through a transportation network. However, as an effect of the used choice models, conventional applications of SUE are based on the assumption that all available routes have a positive probability of being chosen, however unattractive. In this paper, a novel choice model, the Bounded Choice Model (BCM), is presented along with network conditions for a corresponding Bounded SUE. The model integrates an exogenously-defined bound on the random utility of the set of paths that are used at equilibrium, within a Random Utility Theory (RUT) framework. The model predicts which routes are used and unused (the choice sets are equilibrated), while still ensuring that the distribution of flows on used routes accords to a Discrete Choice Model. Importantly, conditions to guarantee existence and uniqueness of the Bounded SUE are shown. Also, a corresponding solution algorithm is proposed and numerical results are reported by applying this to the Sioux Falls network. (C) 2018 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license. (http://creativecommons.orgflicenses/by/4.0/)

123. Maximizing Network Throughput under Stochastic User Equilibrium with Elastic Demand

1. Wang, Jian; Du, Muqing; Lu, Lili; He, Xiaozheng
2. NETW SPAT ECON

> Most of the existing studies adopt the fixed-demand equilibrium formulation to model drivers' route choice when studying network throughput maximization problem. Travelers' reactions to the increased origin-destination (O-D) travel cost and network congestion level are less considered in the problem. Note that travelers can cancel the trip or use other modes to travel if the road network is congested. This study aims to address this gap by analyzing the maximum network throughput problem using the formulation of Logit-based SUE with elastic demand (SUEED). The Logit-based SUEED problem not only models the drivers' route choice according to the SUE principle, but also estimates the equilibrium O-D demand by factoring the effect of expected perceived O-D travel time on O-D demand. A bi-level programming problem is proposed to characterize the maximum network throughput based on the Logit-based SUEED problem. The sensitivity analysis for the Logit-based SUEED problem is presented and incorporated into the solution algorithm for the proposed problem. A numerical example demonstrates the effectiveness of the proposed sensitivity-based solution algorithm. This study finds that under the SUEED condition, the maximum network throughput decreases monotonically when travelers' knowledge level of traffic conditions increases (less travel time perception error). It implies that promoting advanced traveler information system ATIS may not serve to foster more number of trips by travelers and make more use of physical network capacity.

124. TURNING DELAY STOCHASTIC USER EQUILIBRIUM MODEL BASED ON THE WEIBULL DISTRIBUTION

1. Chen, Jing; Xu, Wenqiang; Peng, Weimin; Xing, Baixi; Xu, Haitao
2. PROMET-ZAGREB

> With the continuous expansion of urban scales and the constant growth of traffic demands, it has become important to accurately predict the distribution of traffic flow so as to relieve the traffic jams and lower the energy consumption. This research mainly focuses on the distribution problem of traffic flow in the urban traffic network. A minimization program has been provided as an alternative formulation for the turning delay stochastic user equilibrium problem. The paper derives the Weibull distribution-based node-link random loading mechanism of turning delay for direct calculation of link

> and turning flows that are consistent with the path flow, thus avoiding the enumeration of turning paths. Numerical examples are provided to illustrate the turning delay stochastic user equilibrium (SUE) model and the node-link-based algorithm. The experiment demonstrates that the present method can reflect the relative performance of link and turning costs well, while presenting its advantages in the simulation of large-scale turning delay flow assignment.

125. A Generalized Single-Level Formulation for Origin-Destination Estimation under Stochastic User Equilibrium

1. Ma, Wei; Qian, Zhen (Sean)
2. TRANSPORT RES REC

> Origin-destination (OD) demand is an indispensable component for modeling transportation networks, and the prevailing approach to estimating OD demand using traffic data is through bi-level optimization. A bi-level optimization approach considering equilibrium constraints is computationally challenging for large-scale networks, which prevents the OD estimation (ODE) being scalable. To solve for ODE in large-scale networks, this paper develops a generalized single-level formulation for ODE incorporating stochastic user equilibrium (SUE) constraints. Two single-level ODE models are specifically discussed and tested. One employs a SUE based on the satisfaction function, and the other is based on the Logit model. Analytical properties of the new formulation are analyzed. The estimation methods are proven to be unbiased. Gradient-based algorithms are proposed to solve for this formulation. Numerical experiments are conducted on a small network and a large network, along with sensitivity analysis on sensor locations, historical OD information and measurement error. Results indicate that the new single-level formulation, in conjunction with the proposed solution algorithms, can achieve accuracy comparable with the bi-level formulation, while being much more computationally efficient for large networks.

126. New Formulations of the Stochastic User Equilibrium with Logit Route Choice as an Extension of the Deterministic Model

1. Gentile, Guido
2. TRANSPORT SCI

> This paper addresses the stochastic user equilibrium (SUE) in the case where the route choice is the multinomial logit model (MNL). Our main finding is that MNL SUE can be formulated and solved as an immediate extension of the deterministic user equilibrium (DUE) through a particular application of Wardrop's first principle. The latter states, in general, that at equilibrium, the cost of all used routes is equal and not higher than those of unused routes. The extension is achieved by applying this statement to the perceived cost of a choice alternative, which is defined here as its generalized cost plus the logarithm of its choice probability multiplied by the logit parameter. Thus, substituting in DUE models the generalized costs with the perceived costs allows to easily adapt to MNL SUE the existing formulations and algorithms for DUE, as well as to manage a smooth transition of the route choice model from stochastic to deterministic by reducing the logit parameter down to zero. Particular consideration is devoted to the interpretation of the numerical solution as a restricted logit model, where only sufficiently good alternatives receive a positive probability. A family of MNL SUE models is then presented ranging from nonlinear optimization to variational inequalities and fixed-point problems, with both explicit and implicit path enumeration. A range of numerical tests is presented with the aim of assessing the continuity of the model results for decreasing logit parameter and

> proving the applicability of the proposed approach to real size networks, with particular emphasis on the performance and convergence of the methods.

127. Stochastic Ridesharing User Equilibrium in Transport Networks

1. Yan, Chen-Yang; Hu, Mao-Bin; Jiang, Rui; Long, Jiancheng; Chen, Jin-Yong; Liu, Hao-Xiang
2. NETW SPAT ECON

> With the development of the Internet and mobile phone technology, it is much easier to access ridesharing information via mobile applications. In this paper, the relationship between the demand of ridesharing passengers (RPs), ridesharing drivers (RDs) and solo drivers (SDs) in a ridesharing compensation scheme is studied by a stochastic ridesharing user equilibrium (SRUE), which contains a mode choice model and a route choice model. The mode choice model and the route choice model influence each other. The SRUE is first expressed as a fixed-point problem mathematically. Six possible states of OD pairs are discussed. Then the existence of SRUE is proved. The method of successive weighted averages is adopted to solve the problem. It is found that there will be a higher demand of ridesharing passengers for journeys with longer travel time. Moreover, with the increase of the ridesharing compensation, the demand of ridesharing passengers is not always decreasing, and the demand of ridesharing drivers is not always increasing.

128. Traffic assignment paradox incorporating congestion and stochastic perceived error simultaneously

1. Yao, Jia; Cheng, Zhanhong; Dai, Jingtong; Chen, Anthony; An, Shi
2. TRANSPORTMETRICA A

> This paper analyses the effects of congestion and stochastic perceived error in stochastic traffic assignment paradox, by the measure of both actual and perceived travel cost. Two different circumstances are studied: improving an existing link and adding a new link. It is found that different congestion cost functions and perceived error levels will significantly affect the road condition and the demand level under which paradox happens. Moreover, how the interaction between traffic demands of different O-D pairs affects the occurrence of traffic paradox is illustrated by a two O-D pairs' network. Besides, a counter-intuitive phenomenon when less stochastic perceived error yet increases the average travel cost (information paradox) is also discussed. The results of this paper help to understand the interactional impact of congestion and stochastic perceived error, and give some new insights to traffic paradox.

129. Stochastic user equilibrium in the presence of state dependence

1. Castaldi, Claudia; Delle Site, Paolo; Filippi, Francesco
2. EURO J TRANSP LOGIST

> We consider the following two state-dependent effects at the level of route choice: inertia to change and, as a consequence of experience, lower perception variance for the currently used route. A heteroscedastic extreme value model embodying heterogeneity across alternatives in the mean of the random terms is used. Estimations based on stated preference data confirm the presence of both state-dependent effects. We introduce a new class of stochastic user equilibrium (SUE) models that take state-dependent effects into account. The class includes conventional SUE as special case. The equilibrium conditions are formulated as fixed-point states of deterministic day-to-day assignment

> processes. At the equilibrium (1) no user can improve her/his utility by unilaterally changing route, and (2) if each user shifts from her/his current route to her/his newly chosen route the observed route flows do not change. The existence of the equilibrium is guaranteed under usually satisfied conditions. A modified method of successive averages is proposed for solution. Examples related to a two arc network and to the Nguyen-Dupuis network illustrate the model.

130. Toll Choice and Stochastic User Equilibrium: Ticking All the Boxes

1. Zill, Jan C.; Camargo, Pedro; Daisy, Naznin Sultana; Veitch, Tim
2. TRANSPORT RES REC

> Stochastic user equilibrium is a behaviorally realistic framework for strategic demand modeling and forecasting in cities/ regions where there are multiple tolled facilities, especially when it comes to patronage forecasting for existing or planned tolled facilities. However, there is currently no algorithm available in the literature or in commercial software that provides a comprehensive approach for stochastic user equilibrium assignment that addresses the generation of route choice sets for tolled roads, path overlap, and high levels of convergence. This paper presents a novel choice set generation algorithm combined with the path-size logit model and the bi-conjugate Frank-Wolfe equilibrium assignment in a comprehensive algorithm for forecasting tolled road patronage, along with the results of its application to a real-life model in Brisbane, Australia.

131. An Alternative Stochastic User Equilibrium Formulation Based on Regret Theory

1. Rassafi, Amir Abbas; Barzegar-Ganji, Mehdi
2. INT J CIV ENG

> Traffic assignment is the last stage of the classical transportation planning process in which, the travel demand of each O-D pair is allocated to the network links, and links' flows are estimated. To solve such a problem, some assumptions should be made about travellers' decision-making behavior. One of the most popular approaches in this regard is the deterministic assignment that assumes all drivers are fully informed about the condition of the network and they always select the best (usually the shortest) route. These assumptions do not thoroughly match to the reality. To deal with this problem, the concept of stochastic user equilibrium has been introduced. The conventional stochastic user equilibrium assignments models are typically based on random utility theory. In this paper an alternative approach for stochastic user equilibrium assignment called random regret theory has been used in which a random regret-minimization (RRM) model is developed. RRM considers the regret of an option just with respect to outperformed options and furthermore does not lead to a closed-form stochastic user equilibrium (SUE) model, though based on that a formulation of SUE is proposed in a variational inequality form. In this study the definition of regret is modified and based on that a closed form SUE model is developed. This model is examined by two network examples.

132. Apples versus oranges? Comparing deterministic and stochastic day-to-day traffic assignment models

1. Mahmoodjanlou, Ahmad; Hazelton, Martin L.; Parry, Katharina
2. TRANSPORTMETRICA B

> Both stochastic and deterministic models can be used to describe the day-to-day evolution of traffic flow across a network, and applied for a raft of transport planning and control purposes. We might

> hope that these two types of models would give qualitatively similar results, so that forecasts based on either type of model will lead to broadly similar conclusions. This will be the case when the mean of the stochastic model behaves in a similar fashion to the deterministic model. In this paper we explore this issue in detail, using examples involving some simple networks. We find that for systems with multiple deterministic equilibria, stochastic and deterministic models can appear comparable for extended periods and yet have very different long-term properties. We conclude that care is required when handling deterministic and stochastic day-to-day models if we are to avoid comparing apples with oranges, as the saying goes.

133. Dynamic traffic assignment in degradable networks: paradoxes and formulations with stochastic link transmission model

1. Long, Jiancheng; Szeto, W. Y.; Ding, Jianxun
2. TRANSPORTMETRICA B

> This paper proposes a simultaneous route and departure time choice (SRDTC) problem with fixed demand in a degradable transport network. In this network, travelers face with stochastic travel times. Their selection of routes and departure times follows the UE principle in terms of the mean generalized route cost, which is defined as the probabilistic dynamic user optimal (PDUO) principle. The proposed PDUO-SRDTC problem is formulated as a variational inequality (VI) problem. As a special case of PDUO-SRDTC problem, the PDUO route choice (PDUO-RC) problem is also proposed and formulated as a VI problem. Network degradation is defined on the degradation of the outflow capacity of each link. A Monte Carlo-based stochastic link transmission model (MC-SLTM) is developed to capture the effect of physical queues and the random evolution of traffic states during flow propagation to estimate mean generalized route costs. Both the extragradient algorithm and the route-swapping method with a variable sample size scheme are developed to solve the proposed VI problems. Numerical examples are developed to illustrate the paradoxical phenomena of the problems and the effectiveness of the solution methods. Numerical results show that constructing a new road, enhancing link outflow capacity, or reducing outflow capacity degradation can lead to poor network performance and it is important to consider both network degradation and queue spillback when making transportation policies aimed at improving network performance. The results also demonstrate that the variable sample size scheme can give a quicker and better solution than the traditional fixed sample size scheme.

134. Stochastic stability of dynamic user equilibrium in unidirectional networks: Weakly acyclic game approach

1. Satsukawa, Koki; Wada, Kentaro; Iryo, Takamasa
2. TRANSPORT RES B-METH

> The aim of this study is to analyze the stability of dynamic user equilibrium (DUE) with fixed departure times in unidirectional networks. Specifically, stochastic stability, which is the concept of stability in evolutionary dynamics subjected to stochastic effects, is herein considered. To achieve this, a new approach is developed by synthesizing the three concepts: the decomposition technique of DUE assignments, the weakly acyclic game, and the asymptotic analysis of the stationary distribution of perturbed dynamics. Specifically, we first formulate a DUE assignment as a strategic game (DUE game) that deals with atomic users. We then prove that there exists an appropriate order of assigning users for ensuring equilibrium in a unidirectional network. With this property, we establish the relationship

> between DUE games in unidirectional networks and weakly acyclic games. The convergence and stochastic stability of better response dynamics in the DUE games are then proved based on the theory of weakly acyclic games. Finally, we observe the properties of the convergence and stability from numerical experiments. The results show that the strict improvement of users' travel times by the applied evolutionary dynamics is important for ensuring the existence of a stochastically stable equilibrium in DUE games. (C) 2019 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license. (http://creativecommons.org/licenses/by-nc-nd/4.0/)

135. Day-to-Day Flow Dynamics for Stochastic User Equilibrium and a General Lyapunov Function

1. Xiao, Feng; Shen, Minyu; Xu, Zhengtian; Li, Ruijie; Yang, Hai; Yin, Yafeng
2. TRANSPORT SCI

> This study establishes a general framework for continuous day-to-day models to capture the perceptual errors in travelers' day-to-day route choice behavior. As the counterpart of the Beckmann transformation, which has been widely used as a candidate Lyapunov function to prove the stability of continuous day-to-day traffic evolution models that converge to deterministic user equilibrium, Fisk's formulation is utilized in our study as a general Lyapunov function for the day-to-day models that converge to stochastic user equilibrium (SUE), so far as the path flow growth rates and the potentials of the paths satisfy the condition of negative correlation. A sufficient condition that guarantees the nonnegativity of the path flow is also provided. The logit dynamic, the logit-based Smith dynamic, and the logit-based Brown-von Neumann-Nash (BNN) dynamic are given as three examples under this framework. Moreover, we extend the second-order day-to-day model proposed by Xiao et al. [Xiao F, Yang H, Ye H (2016) Physics of day-to-day network flow dynamics. Transportation Res. Part B: Methodological 86:86-103.] for SUE. Some properties of the new model, such as fixed point and stability, are investigated. Interestingly, we find that even when the model converges to SUE, the path flows could still go negative during the oscillation under extreme situations. A numerical experiment is conducted to demonstrate the existence of negative path flow for the second-order model.

136. Privacy Implication of Location-Based Service: Multi-Class Stochastic User Equilibrium and Incentive Mechanism

1. Hu, Haitao; Sun, Zhanbo; Liu, Runzhe; Yang, Xia
2. TRANSPORT RES REC

> As a tool to assist traffic guidance and improve service quality, location-based service (LBS) platforms such as route navigation apps rely heavily on the collection and analysis of users' location/trajectory information, which may evoke privacy concerns. Because of such privacy concerns, users may choose not to provide their information. In certain cases, this may lead to the problem of insufficient data for LBS applications (e.g., travel time estimation). To address this issue, the paper develops a modeling framework to quantify the levels of privacy for mixed user groups and proposes an incentive mechanism to encourage users to provide their location/trajectory information. It is assumed that LBS users have smaller travel time perception error but experience some extra privacy costs compared with the non-LBS users. A bi-level optimal incentive model with stochastic user equilibrium and elastic demand is developed to capture the mixed behavior of multi-class network users. The problem is solved using a meta-heuristic approach combined of genetic algorithm, successive average algorithm, and multiple behavior equilibrium assignment algorithm. The results reveal that the modeling

> framework can capture the mixed behavior of groups with different privacy levels. The proposed incentive mechanism is able to ensure sufficient data, and simultaneously minimize the required incentive.

137. User equilibrium with a policy-based link transmission model for stochastic time-dependent traffic networks

1. Gehlot, Hemant; Ukkusuri, Satish V.
2. TRANSPORTMETRICA B

> Non-recurrent congestion is a major problem in traffic networks that causes unexpected delays during travels. In such a scenario, it is preferable to use adaptive paths or policies where next link decisions on reaching junctions are continuously adapted based on the information gained with time. In this paper, we study a traffic assignment problem in stochastic time-dependent networks. The problem is modeled as a fixed-point problem and existence of the equilibrium solution is discussed. We iteratively solve the problem using the method of successive averages (MSA). A novel network loading model inspired from Link transmission model is developed that accepts policies as inputs for solving the problem. This network loading model is different from the existing network loading models that take predefined paths for input flows. We demonstrate through numerical tests that solving traffic assignment problem with the proposed loading modeling scheme is more efficient as compared to solving the problem using path-based network loading models.

138. SOLVING THE LOGIT-BASED STOCHASTIC USER EQUILIBRIUM USING MODIFIED PROJECTED CONJUGATE GRADIENT METHOD VIA CONVEX MODEL

1. Zhang, Chao; Zhang, Qian; Xiu, Naihua
2. PAC J OPTIM

> In this paper, we convert the classic stochastic user equilibrium (SUE) into a convex model and propose the modified projected conjugate gradient (mPCG) method to solve the logit-based SUE. We show that the mPCG method converges to the unique global minimizer of the convex model. Numerical experiments on Sioux Falls network of moderate size are done to compare the mPCG method solving the proposed convex model, with the projected gradient (PG) method for the convex model and the method of the successive averages (MSA) for the nonconvex model. The numerical results indicate that the proposed mPCG method for the convex model outperforms the MSA and the PG method.

139. Routing in a Stochastic Network with Nonrecurrent Incidents: Behavioral Interpretation of Dynamic Traffic Assignment

1. Chan, Yupo; Fowe, James A.; Arani, Mohammad
2. ASCE-ASME J RISK U A

> In an advanced traveler information system (ATIS), this study examines how to map a driver's time constraints and risk-taking behavior to real-time routing in a probabilistic time-dependent network (or stochastic network). Accounting for en route delays and alternate routings, ATIS networks are shown to exhibit other than the first-in first-out property (FIFO) behavior: drivers who depart earlier may not arrive ahead of those who depart later. In this paper, the term FIFO is used well beyond the traditional connotation of a single queue or a single path; it applies toward multiple routes. It is used to describe a well-recognized phenomenon in dynamic traffic assignment, wherein a commuter who delays their

> departure time may arrive at work earlier than one who takes off earlier. Given a network with full spatiotemporal information, a wait-time search algorithm is employed to account for the best-planned delays at the origin or en route. The algorithm elicits the bottlenecks in the network and obtains the optimal wait times a driver needs to avoid these bottlenecks, given their tolerance for risk. The herein defined routing policy makes decision at every network node-based on the current states-to determine the optimal wait time (if any) and the next-hop node. The model also valuates a driver's risk tolerance by imputing the worth of safety as a cost metric. Empirical results were obtained from a central Arkansas highway network based on incident reports obtained from the state police between the years 2000 to 2003. Solidly founded on Bellman's optimality condition, the fundamental diagram of traffic flow, and multiattribute utility theory, the algorithm is shown to be operationally feasible for real-time applications. (C) 2020 American Society of Civil Engineers.

140. Travel cost budget based user equilibrium in a bottleneck model with stochastic capacity

1. Liu, Qiumin; Jiang, Rui; Liu, Ronghui; Zhao, Hui; Gao, Ziyou
2. TRANSPORT RES B-METH

> This paper studies a bottleneck model in which the capacity of the bottleneck is constant within a day but changes stochastically from day-to-day between a designed value (good condition) and a degraded one (bad condition). The study relates the travel cost variability due to stochastic capacity with commuters' departure time choice behaviors. We postulate that commuters acquire the variability of travel cost based on past experiences and factor such variability into their departure time choice consideration by minimizing their travel cost budget (TCB), defined as a weighted average of mean travel cost and standard deviation of travel cost. We show that the consideration of TCB yields seven possible equilibrium patterns. Closed form solutions to all possible equilibrium patterns and their corresponding parameter ranges are derived. The rationality of the patterns has been investigated. Dependence of travel cost and the duration of peak hours on the commuters' risk attitude has also been derived in each equilibrium pattern. Finally, numerical studies have been conducted to illustrate the properties. (C) 2020 Elsevier Ltd. All rights reserved.

141. Regret-based multi-objective route choice models and stochastic user equilibrium: a non-compensatory approach

1. Xu, Yuan; Zhou, Jing; Xu, Wei
2. TRANSPORTMETRICA A

> Since regret theory has been introduced to model travellers' route choices, various random regret minimization (RRM) models have been developed for the choice situation of multiple alternatives and multiple attributes. There are two approaches dealing with multi-objective optimisations: one is to combine different attributes into a single additive one and the other is to consider each attribute separately. The existing RRM models adopt the first approach to measure regret. However, travellers might not always trade off attributes in such a compensatory way. In this paper, under the assumption that travellers might consider attributes separately, we develop two new regret-based stochastic user equilibrium (SUE) models by incorporating the RRM model and the hybrid RUM-RRM model into a non-compensatory multi-objective framework. The majority of the second approaches dealing with multiple objectives generally provide a feasible solution set caused by conflicts among objectives. Different from that, the two new models provide probabilistic choice to each route, based on which a single SUE path flow pattern would be attained. Meanwhile, the compromise effect which is widely

> seen in consumer behaviour can be explained by the two new models. The equivalent variational inequality problems for the proposed models and a path-based algorithm using the method of successive averages have been given. Numerical examples are further conducted to illustrate the properties of the proposed models and the effectiveness of the algorithm.

142. A multiple-path gradient projection method for solving the logit-based stochastic user equilibrium model

1. Tan, Heqing; Du, Muqing; Yu, Chun-bin
2. J TRANSP LAND USE

> This paper proposes a path-based algorithm for solving the well-known logit-based stochastic user equilibrium (SUE) problem in transportation planning and management. Based on the gradient projection (GP) method, the new algorithm incorporates a novel multiple-path gradient approach to generate the descent direction in consideration of many paths existing in every single origin-destination (O-D) pair. To apply the path-based algorithm, the SUE problem is reformulated as a variational inequality (VI), and a working path set is predetermined. The numerical experiments are conducted on the Winnipeg network where a large number of paths are provided. The results show the multiple-path gradient projection algorithm outperforms the original GP method. Three different step size strategies, including the fixed step size, self-regulated averaging and self-adaptive Armijo's strategies, are involved to draw a more general conclusion. Also, the effects of the path number on computational performance are analyzed. The multiple-path gradient projection (MGP) method converges much faster than the GP method when the path set size gets large.

143. Comparing Dynamic User Equilibrium and Noniterative Stochastic Route Choice in a Simulation-Based Dynamic Traffic Assignment Model: Practical Considerations for Large-Scale Networks

1. Ashfaq, Mudabber; Gu, Ziyuan; Waller, S. Travis; Saberi, Meead
2. J ADV TRANSPORT

> Simulation-based dynamic traffic assignment (DTA) models play a vital role in transportation planning and operations. While the widely studied equilibrium-seeking DTA including dynamic user equilibrium (DUE) often provides robust and consistent outcomes, their expensive computational cost for large-scale network applications has been a burden in practice. The noniterative stochastic route choice (SRC) model, as a nonequilibrium seeking DTA model, provides an alternative for specific transportation operations applications that may not require equilibrium results after all (e.g., evacuation and major network disruptions) and thus tend to be computationally less expensive, yet may suffer from inconsistent outcomes. While DUE is a widely accepted approach for many strategic planning applications, SRC has been increasingly used in practice for traffic operations purposes. This paper aims to provide a comparative and quantitative analysis of the two modeling approaches. Specifically, a comparison has been made at two levels: link-level flows and network-level congestion patterns. Results suggest that adaptive driving improves the quality of the SRC solution, but its difference from DUE still remains significant at the link level. Results have practical implications for the application of large-scale simulation-based DTA models for planning and operations purposes.

144. Multi-class stochastic user equilibrium assignment model with ridesharing: Formulation and policy implications

1. Sun, S.; Szeto, W. Y.
2. TRANSPORT RES A-POL

> This paper proposes a logit-based multi-class ridesharing user equilibrium assignment framework that can incorporate different policy measures such as car restrictions, cordon tolling, and subsidization. The framework is formulated as a mixed complementarity problem (MCP). Numerical studies are conducted to illustrate model properties and compare the effects of these measures under different circumstances. The results show that the effectiveness of different policy measures can be greatly influenced by the performance of the transit mode compared with that of the driving mode and the users' preference for traveling by car. The cordon toll policy can be better than the car restriction policy in terms of the improvement in social surplus when the performance of the competing transit system is poor. Subsidizing ridesharing (transit fares) using the toll income is the most effective when the performance of the competing transit system is poor (good). It is also found that the implementation of the cordon toll policy cannot effectively promote ridesharing when the performance of the transit system is good.

145. Integrating transit systems with ride-sourcing services: A study on the system users' stochastic equilibrium problem

1. Zhang, Yufeng; Khani, Alireza
2. TRANSPORT RES A-POL

> Ride-sourcing services are continuously gaining popularity among urban travelers. Due to their flexibility and responsiveness, transit agencies spot chances of collaborating with Transportation Network Companies (TNCs) in order to improve service quality, promote transit usage, and meanwhile lower their operational cost. In this paper, we studied an integrated transit system where ride-sourcing services complement the transit service as an efficient and economical access mode. The users of the integrated system consist of not only transit riders but also drivers for TNCs. Riders maximize their utilities by choosing whether and how to use the integrated system, and drivers maximize their payoffs by deciding how to serve riders. More importantly, in this twosided system, their decisions are unfolded to each other and mutually influence one another such that an equilibrium is reached where no one can improve their outcome. We modeled the stochastic mode choice of riders and zone choice of drivers and captured the interactive attributes in a fixed-point problem. The existence of such an equilibrium was proved, and an iterative solution algorithm that utilizes network algorithms was proposed to find an equilibrium pattern of the stochastic demand-supply problem. A real-world case study using the Twin Cities' data was carried out, and insights into the mechanism of the integrated transit system were developed. Various aspects of the system including user perception, demand estimation, pricing strategy, and subsidy strategy were investigated through the proposed model. These research outcomes contribute to a better comprehension of this promising mobility system and provide valuable knowledge on the planning and design of such systems.

146. A MULTICLASS CUMULATIVE PROSPECT THEORY-BASED STOCHASTIC USER EQUILIBRIUM MODEL WITH PATH CONSTRAINTS IN DEGRADABLE TRANSPORT NETWORKS

1. Yan, Dongmei; Guo, Jianhua
2. PROMET-ZAGREB

> The limited driving range and the unavailability or insufficiency of battery charging/swapping stations cause the so-called range anxiety issue for traffic assignment involving battery electric vehicle (BEV) users. In addition, expected utility theory-based stochastic user equilibrium (EUT-SUE) model generates the perfectly rational issue when the travellers make route choice decisions. To tackle these two problems, this article improves the cumulative prospect theory-based stochastic user equilibrium (CPT-SUE) model in a degradable transport network through incorporating the constraints of multiple user classes and distance limit. In this degradable network, the travellers experience stochastic travel times due to network link capacity degradations. For this improved CPT-SUE model, the equivalent variational inequality (VI) model and associated method of successive averages (MSA) based solution are provided. The improved CPT-SUE model is tested and compared with the EUT-SUE model with distance limit, with results showing that the improved CPT-SUE model can handle jointly the range anxiety issue and the perfectly rational issue.

147. On Stochastic-User-Equilibrium-Based Day-to-Day Dynamics

1. Ye, Hongbo
2. TRANSPORT SCI

> Researchers have proposed many different concepts and models to study day-to-day dynamics. Some models explicitly model travelers' perceiving and learning on travel costs, and some other models do not explicitly consider the travel cost perception but instead formulate the dynamics of flows as the functions of flows and measured travel costs (which are determined by flows). This paper investigates the interconnection between these two types of day-to-day models, in particular, those models whose fixed points are a stochastic user equilibrium. Specifically, a widely used day-to-day model that combines exponential-smoothing learning and logit stochastic network loading (called the logit-ESL model in this paper) is proved to be equivalent to a model based purely on flows, which is the logit-based extension of the first-in-first-out dynamic of Jin [Jin W (2007) A dynamical system model of the traffic assignment problem. Transportation Res. Part B Methodological 41(1):32-48]. Via this equivalent form, the logit-ESL model is proved to be globally stable under nonseparable and monotone travel cost functions. Moreover, the model of Cantarella and Cascetta is shown to be equivalent to a second-order dynamic incorporating purely flows and is proved to be globally stable under separable link cost functions [Cantarella GE, Cascetta E (1995) Dynamic processes and equilibrium in transportation networks: Towards a unifying theory. Transportation Sci. 29(4):305-329]. Further, other discrete choice models, such as C-logit, path-size logit, and weibit, are introduced into the logit-ESL model, leading to several new day-to-day models, which are also proved to be globally stable under different conditions.

148. A Revised Logit Model for Stochastic Traffic Assignment With a Relatively Stable Dispersion Parameter

1. Wang, Wei; Wang, Jian; Zhao, De; Jin, Kun
2. IEEE INTEL TRANSP SY

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149. Risk-Based Optimal Life-Cycle Maintenance Strategy for Bridge Networks Considering Stochastic User Equilibrium

1. Han, Xu; Frangopol, Dan M.
2. ASCE-ASME J RISK U A

> The risk-based approach is a powerful tool to assess the impact of hazards on bridge networks. The results of risk analysis of a bridge network can be integrated into an optimization process to obtain the optimal maintenance strategy for the network under investigation. In the process of risk analysis, the time-variant probability of failure profile of each bridge in the network can be obtained through reliability analysis, while network analysis needs to be carried out to determine the failure consequences of each bridge. The deterministic user equilibrium approach, which assumes that each driver has the perfect information on the traffic status and will adopt the path that maximizes his/her own benefit, is widely adopted to calculate traffic flows on each link in the network. Given that the assumption behind the deterministic user equilibrium can be highly unrealistic, this paper adopts a stochastic user equilibrium approach to analyze the traffic flow on each link, thereby producing a more accurate estimation of failure consequences associated with bridge failure. The failure consequences associated with both deterministic user equilibrium and stochastic user equilibrium are used in the optimization process to determine the influence of user equilibrium calculation on the optimal maintenance strategy for a bridge network subjected to corrosion. In addition, A709-50CR, a corrosion-resistant steel, is adopted as a material for the new girders to replace the corroded carbon steel girders. Comparison is made on the optimal maintenance strategies associated with using A709-50CR and carbon steel for replacement. The results show that the user equilibrium calculation has a profound influence on the optimization results. In addition, A709-50CR is economically beneficial at achieving low life-cycle risk compared with carbon steel. (C) 2022 American Society of Civil Engineers.

150. A Stochastic Dynamic Traffic Assignment Model for Emergency Evacuations That Considers Background Traffic

1. Zhang, Tao; Ren, Gang; Cheng, Gang; Yang, Yang; Jin, Minjie
2. IEEE INTEL TRANSP SY

> nan

151. Consistent iterative algorithm for stochastic dynamic traffic assignment with a stable route set

1. Verstraete, Jeroen; Tampere, Chris M. J.
2. COMPUT-AIDED CIV INF

> In stochastic (dynamic) traffic assignment (DTA), route choice (RC) formulations with implicit route set require less memory than their explicit counterparts. To compute turn probabilities, however, a topological ordering of the nodes is needed, which negatively impacts the stability of convergence and consistency of equilibrium. This paper formulates a general framework for the RC module of the efficient stochastic DTA (ESDTA) without topological ordering; we demonstrate how its full fixed route yields smooth and consistent convergence. The theoretical framework requires a series of computational modifications to ensure that numerical errors remain limited and to make the formulation more efficient for use in practice. The resulting ESDTA's computation time to reach equilibrium scales linearly with respect to all relevant complexity dimensions (network size, demand zones, time resolution, and congestion level).