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1 A GRADIENT APPROXIMATION APPROACH FOR ADJUSTING TEMPORAL ORIGIN-DESTINATION MATRICES

Ernesto CIPRIANI [a], Michael FLORIAN [b], Michael MAHUT [c] and Marialisa NIGRO [a]

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The temporal demand matrix is an essential input to both on-line and off-line applications of dynamic traffic assignment (DTA). This paper presents a new method to solve the simultaneous adjustment of a dynamic traffic demand matrix, searching for a reliable solution with acceptable computational times for off-line applications and using as an input traffic counts and speeds, prior O-D matrices and other aggregate demand data (traffic demand productions by zone).

The proposed solving procedure is a modification of the basic SPSA (Simultaneous Perturbation Stochastic Approximation) path search optimization method; it can find a good solution when the starting point (the seed matrix) is assumed to be "near" the optimal one, working with a gradient approximation based on a simultaneous perturbation of each demand variable.

2 STOCHASTIC MULTI-MODAL TRANSPORT NETWORK UNDER DEMAND UNCERTAINTIES AND ADVERSE WEATHER CONDITION

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

3 MODELING MULTIMODAL MORNING COMMUTE IN A ONE-TO-ONE CORRIDOR NETWORK

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In this paper, we address the morning commute problem with three modes: transit, diving alone and carpool. The transit mode uses its own separate guideway, but the auto modes can access two parallel routes to reach the destination --- a freeway and an arterial road (AR). Moreover, carpoolers are assumed to share their fuel costs and road tolls, if there is any, in addition to their advantage of using specially provided lanes (HOV lanes). However, there is an added cost of carpool: the cost of "gathering together". We studied the interactions among the three modes and how different factors affect their mode share and network performances. This was achieved by first deriving the departure time equilibrium for the transit mode (in the same fashion as is done for the auto modes), then establishing equilibrium within each mode. The shares among the modes, the mode split, are determined by a nested logit model.

Our analytical and numerical results indicate that carpoolers always choose the freeway when carpool offers sufficient travel cost advantage over solo-driving. When HOV lanes no longer offer carpoolers the travel advantage, they are more likely to use the AR than solo drivers. But when a uniform toll is applied, Carpoolers would use the freeway more than solo-drivers because they can share the toll, and this leads to reduced total travel cost. When traffic demand is sufficiently high, adding more HOV lanes and hence the overall capacity of the freeway can entice significantly higher auto traffic and lower transit ridership. When the total capacity of the freeway is fixed but the share of the HOV capacity increases, transit ridership would increase slightly, and carpoolers shift from the AR to the freeway, and solo drivers from freeway to the AR. In addition, these modal shifts may not necessarily reduce the total travel cost of the network. The rise of gas price may entice auto commuters to carpool first. However, as the price increases further, more of them would use transit. In addition, under heavy demand expanding freeway capacity is more effective in reducing total travel cost than expanding the capacity of the AR. Finally, a time-varying toll is shown to completely eliminate congestion on the freeway.

4 MODELING HETEROGENEOUS NETWORK USER ROUTE AND DEPARTURE TIME RESPONSES TO DYNAMIC PRICING

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The ability to realistically capture tripmakers' responses to time-varying road charges is essential for network equilibrium assignment models typically applied to predict network flows in the presence of dynamic road (congestion) pricing. User responses to pricing are governed by individual tripmakers' preferences, such as their value of time (VOT), and the cost they attach to late vs. early arrival relative to the destination. These behavioral characteristics vary across users. This paper presents a joint route and departure time network equilibrium assignment model explicitly considering heterogeneous users with different preferred arrival times at destinations, VOT, and values of early and late schedule delays (VOESD and VOLSD). The model is formulated as an infinite dimensional variational inequality and solved by a column generation-based algorithmic framework that embeds (i) an extreme non-dominated alternative-generating algorithm to obtain combinations of VOT, VOESD, and VOLSD subintervals (or breakpoints) that define multiple user classes, and the corresponding least trip cost alternative (joint departure time and path) for each user class, (ii) a traffic simulator to capture traffic flow dynamics and determine experienced travel costs; and (iii) a multi-class alternative flow updating scheme to solve the reduced multi-class simultaneous route and departure time user equilibrium problem defined by a subset of feasible alternatives. Application to an actual network illustrates the properties of the algorithm, and underscores the importance of capturing user heterogeneity and temporal shifts in the appraisal of dynamic pricing schemes.

5 MULTI VEHICLE-TYPE TRANSIT SCHEDULING

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The transit-operation planning process commonly includes four basic activities, usually performed in sequence: (1) network route design, (2) timetable development, (3) vehicle scheduling, and (4) crew scheduling. The purpose of this work is to address the vehicle-scheduling problem, while taking into account the association between the characteristics of each trip (urban, peripheral, inter-city, etc.) and the vehicle type required for the particular trip. The problem is based on given sets of trips and vehicle types, where the categories are arranged in decreasing order of vehicle cost. Therefore, each trip can be carried out by its vehicle type, or by other types listed in prior order. This problem can be formulated as a cost-flow network problem with an NP-hard complexity level. Thus, a heuristic algorithm is developed in this work, based on the Deficit Function theory. Two examples are used as an expository device to illustrate the procedures developed, along with a real-life example of a bus company.

6 ROUTE LAYOUT ANALYSIS FOR EXPRESS BUSES

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For a fixed bus route, the path is the fundamental parameter that determines the passenger catchment area, which, via the dispatching policy, determines the time table and fleet size. However, the path cannot be chosen independent of the other parameters; they have a symbiotic relationship, even though the planning time frames are different ranging from 'years' for the path of the route to 'days' for the crew schedule. The express route planning problem deals with the optimum selection of the sequence of passenger generators to be served by the planned route. An analytical model is developed to enable minimization of operating cost and costs of passenger access, waiting and travel times. Applications of this model have provided an insight to the relative importance of different cost components. The analytical model first selects an initial trial path for the purpose of comparison and then the optimum path is sought by considering a process of swapping, adding and removing generators or extending the route. Routes based on both grid and non-grid road networks are considered. In particular, non-grid road network based routes have a clear optimum. The cost of access is shown to be the influential parameter with respect to route selection. The insights gained from such analysis are highlighted.

7 OPTIMIZATION OF TRANSIT PRIORITY IN THE TRANSPORTATION NETWORK USING A DECOMPOSITION METHODOLOGY

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A new methodology to optimize transit priority is proposed in this paper. Having a higher passenger capacity than private cars, transit vehicles can increase the passenger throughput of roads. This is the main basis for justifying the provision of exclusive transit lanes. Although a range of studies have addressed exclusive transit lanes, all have a localized focus in nominating a transit priority alternative. This paper is aimed at finding the optimum combination of exclusive transit lanes on a network basis. Transit priority is formulated as a bi-level optimization programming which considers modal split, traffic assignment, and transit assignment. A decomposition method is adapted for solving the proposed mathematical model which converges to the optimal solution. The method is also demonstrated in an example network.

8 FROM TRAFFIC BREAKDOWN TO ENERGY FLOW ANALYSIS

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Usually a traffic breakdown is defined as a speed drop of a certain amount within a dense traffic situation. To describe these dynamics successfully a probabilistic model is chosen where the unpredictable influences are summarized by a stochastic force creating vehicular platoons out of the metastable free flow. In this way the speed drop mentioned above is translated into an overshot of the threshold given by the critical cluster size.

The vehicular flow as an open nonequilibrium system of driven or active particles has energy sources like gasoline and energy sinks like road friction. Here we investigate the flux of mechanical energy to evaluate the energy balance out of the given nonlinear dynamical system of vehicular particles.

The long-time result, either fixed point or limit cycle depending on traffic density, is characterized by a certain energy value. In order to understand the traffic breakdown as transition from free flow to congested traffic we estimate the total energy per car at low and high densities and observe the energy of jam formation. This picture of energy consumption cannot be prompted by field observations directly. Nevertheless the idea of an energy picture in traffic is quite attractive and pathbreaking.

9 HETEROGENEITY IN CAR-FOLLOWING BEHAVIOR: THEORY AND EMPIRICS

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The aim of this paper is to gain insights into the level of heterogeneity in car-following behavior in real traffic. We use a large sample of trajectory observations collected by means of a helicopter to identify differences between the car-following behaviors of: (1) passenger car drivers, (2) passenger car drivers and truck drivers and (3) passenger car drivers following a passenger car and passenger car drivers following a truck. We thereto calibrate eight car-following models making different assumptions about the way in which drivers follow their leader(s) on the same lane.

We show that considerable behavioral differences exist between passenger car drivers. Different passenger car drivers do not only consider different stimuli (like speed difference(s) with the leading car(s) and distance headway(s) to leading car(s)) but also the extents to which these stimuli influence their behavior differ. Truck drivers turn furthermore out to adopt in general a more robust car-following behavior than passenger car drivers. Their speeds show, for example, less variation over time. We also find indications that the desired headways of passenger car drivers are lower when following a truck than when following a passenger car.

10 A DISCRETE TRAFFIC KINETIC MODEL - INTEGRATING LAGGED CELL TRANSMISSION MODEL WITH CONTINUOUS TRAFFIC KINETIC MODEL

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Continuous traffic kinetic models are difficult to solve because of the occurrence of integro-differential equations in the models. In this paper, we formulate a discrete traffic kinetic model through extending the cell transmission mechanism, which can capture not only the number of vehicles, but also velocity probability distribution. The variation of velocity probability distribution is modeled on the basis of the idea of cell transmission to avoid integro-differential terms. An example with discontinuous initial density condition is analysed to demonstrate the validity of the proposed discrete traffic kinetic model. From the evolution curve of velocity probability distribution, we can see that the proposed model can be used to describe the diffusion process of vehicles from high density section to low density section.

11 COMPARISON OF TRAFFIC STATE ESTIMATION METHODS FOR LAGRANGIAN DATA

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Most of today's freeways are monitored using systems based on loop detectors embedded in the pavement, which collect data used to estimate the state of the traffic. However, these sensors are expensive, need maintenance and their reliability varies. When traveling on-board vehicles, cellular devices equipped with a Global Positioning System (GPS) chipset are able to accurately provide position and velocity of the vehicle, and therefore can be used as probe traffic sensors. Several ways of using this source of data (speed or travel times) for estimation purposes can be found in the literature. However, the field of highway traffic flow estimation from probe data is still in its infancy. Moreover, methods to estimate traffic state using probe data have not been compared to each other and have not been assessed against loop detector based methods. The present article addresses this problem. For this purpose, it first presents two traffic state estimation methods to incorporate mobile probe measurements into highway flow models. Both techniques are used to reconstruct the state of traffic (density). The first method is an extension of a technique used in oceanography called Newtonian relaxation. The second method is based on Kalman filtering. Using loop detector data and GPS data collected from a field experiment performed in California, the state estimation performed with both methods is compared. The experiment was carried out on a stretch of highway I880 in the San Francisco Bay Area, California, and involved 100 vehicles carrying GPS-enabled cellular phones driving repeated loops of six to ten miles in length continuously for eight hours. The results are promising, showing that the methods successfully incorporate the GPS data in the estimation of traffic. It is found that for high loop detector density (more than two per mile) the estimates are comparable with the ones obtained when less than 5% of the vehicles are equipped with GPS at the rate of one observation every 3 minutes. This confirms that GPS-enabled cell phones are a feasible alternative for traffic monitoring and traffic state estimation.

12 ANALYSIS AND MODELLING OF TRAFFIC FLOW UNDER VARIABLE SPEED LIMITS

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We investigate the relationship between speed and density that is used to formulate models of traffic flow, and consider how it can be used to analyse traffic under the operation of variable speed limits. By statistical analysis of traffic data from the UK motorway network, we find that the functional form preferred for this does not have an explicit jam density that will induce zero speed in traffic. We deduce that it is zero speed that induces jam density in traffic rather than vice versa, so that the direction of causality between speed and density differs according to circumstances. We develop an approach to modelling traffic in light of this. We apply this to analyse speed control as a traffic management measure and show how it can be used to estimate the effect of speed management on road capacity.

13 A RELIABILITY-BASED LAND USE AND TRANSPORTATION OPTIMIZATION MODEL

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We consider a transportation network with a set of origins and a set of destinations. Given a set of budgets for the residential and employment developments, and network enhancement, the problem is one of allocating the resources within the system, so that the probability of overloading the links in the network is minimized. For the improved transportation system with new household and employment distribution patterns, a combined distribution and assignment model is used to map the land-use pattern to the link-loading pattern in the network. Assuming that the actual demand of each origin-destination (O-D) pair follows a certain distribution, the road users choose their destination and route in accordance with the user equilibrium principle that is based on the long-run perceived travel cost. Moreover, it is assumed that despite the short-term demand fluctuation, the O-D-link choice proportion remains unchanged for the choices of destination and route, and the stochastic demand of all O-D pairs are independent. Explicit formulae for the mean and variance of the traffic volume on each link are derived. Using the central limit theorem, the probability that the traffic volume does not exceed the link capacity can be estimated, from which we can calculate a network reliability index. This index represents the probability that all links in the network are within the respective capacities. The problem can be formulated as a bi-level program, in which the upper-level sub-program maximizes the network reliability index with respect to the residential and employment allocations and network enhancements, whereas the lower-level sub-program is the combined distribution and assignment model with long-run travel cost functions. The problem is solved by a genetic algorithm. A numerical example is used to demonstrate the effectiveness of the methodology.

14 COOPERATIVE GAME APPROACHES TO MEASURING NETWORK RELIABILITY CONSIDERING PARADOXES

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Traditionally, game-theoretic approaches to measuring transport network reliability have relied on the outcome of a game played between on the one hand users who seek minimum cost routes, and on the other hand, one or more evil entities or demons that seek to maximize the total expected network cost to the users by damaging links in the network. As the demons are assumed to be non-cooperative, this approach has been criticized that it cannot produce the worst-case solution for reliability analysis, contradicting the original purpose of adopting game-theoretic approaches. In this paper, two cooperative game formulations, Stackelberg-Nash formulation and partial-cooperative Nash formulation, are proposed to determine travel cost reliability. Their relationships are analyzed and their properties are examined. This paper also investigates under what condition(s) the classical non-cooperative demon behavior can lead to the worst-case solution. Numerical studies are provided to demonstrate (i) the effects of the number of coalitions formed by demons on total network expected cost and network/Origin-Destination (OD) travel cost reliability; (ii) the paradoxical phenomena that if one adds a road to a network then all the travelers may be worse off in terms of expected network travel cost and network travel cost reliability respectively, and iii) the possibility of the classical game-theoretic approach of overestimating network/OD travel cost reliability.

15 QUALITY OF TRAFFIC PERFORMANCE ASSESSMENT FOR PRIORITY TYPE INTERSECTION WITH NON-STATIONARY TRAFFIC FLOW DEMANDS

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Non-stationary traffic processes on controlled by traffic signs priority type intersections generate variable traffic conditions. Random traffic data can cause inaccurate or even incorrect assessment of an intersection performance. The paper presents the results of traffic performance analyses on a priority type intersection based on several realizations of real demand processes (time series of traffic flows). It has been demonstrated that key to intersection efficiency assessment is characteristics is traffic variability and its formal description and method of analysis. While commonly used in practice, the simplified analysis of intersection capacity and traffic performance in a peak quarter of an hour does not take account of the actual hourly traffic variability. If suitable capacity reserves ($X \leq 0{,}70$) are made at the design stage, the negative effects of demand variability and the uncertainty of predicted traffic volumes may well be reduced.

16 A DECISION-MAKING RULE IN TRAVELER'S ROUTE CHOICE BEHAVIOR BASED ON CUMULATIVE PROSPECT THEORY

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To make practical use of traveler's behavior study in route-choice modeling, a link is required to connect the objective travel scene to the subjective decisions made by travelers. Cumulative Prospect Theory (CPT) proposes an alternative framework in route-choice behavior to the conventional EUT-based model. This paper conduct an investigation to set up a general travel decision-making rule by utilizing the CPT. The conducted investigation illustrates traveler's behavior mechanism, examines the probability of applying CPT for commute utility measure, and establishes a general utility measure system which is demonstrated to be more consistent with the experimental data than EUT-based route-choice models. In addition, an approach to confirm the reference point value is suggested. The main techniques adopted in this study are demonstration analysis, questionnaire survey and some statistical approaches.

17 A DYNAMIC MODEL OF ACTIVITY GENERATION: DEVELOPMENT AND EMPIRICAL DERIVATION

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In this paper we develop and explore a method to estimate dynamic models of activity generation on one-day travel diary data. Dynamic models predict longitudinal activity patterns of individuals taking into account dynamic needs as well as day-varying preferences and time-budgets. We show how one-day observation probabilities can be derived from proposed dynamic models as a function of a model's parameters and, with that, how parameters can be estimated using standard loglikelihood estimation. The results of an application on data from a national travel survey are well interpretable. Moreover longitudinal activity patterns predicted by the model have approximately the same statistical characteristics as the one-day sample data from the survey. We conclude therefore that the proposed method opens up a way to develop a next generation of dynamic activity-based models of travel demand.

18 TOUR-BASED ENTROPY MAXIMIZATION FORMULATIONS OF URBAN COMMERCIAL VEHICLE MOVEMENTS

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One of the major obstacles to urban freight demand forecasting is the lack of aggregate-level models that consider commercial vehicle tours. To bridge the gap, this paper describes two variants of entropy maximization formulations that are aimed to estimate the tour flows of commercial vehicles given the number of trips produced by or attracted to each node, and the impedance to travel. The first and second order conditions were derived to gain insight from the entropy maximization formulations. The first-order conditions show that the flow of commercial vehicles traveling along a given tour is a function of the Lagrange multiplier associated with the number of trips produced by each node along that tour, and the tour impedance. The second-order conditions indicate the convexity of the formulations. A case study in the Denver metropolitan area shows the efficiency of this approach: the estimated tour flows closely match the observations with the mean absolute percentage error as 6.71% and 6.61% for the two formulations respectively. Based on the findings, the paper discusses two possible ways of applying this approach to model urban freight movements.

19 FREEWAY SERVICE PATROL DEPLOYMENT PLANNING FOR INCIDENT MANAGEMENT AND CONGESTION MITIGATION

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This paper investigates the problem of deploying freeway service patrols to detect, respond to and clear traffic incidents in two settings, deterministic and stochastic. The deterministic setting assumes that there is only one scenario of incident occurrence and, in the stochastic counterpart, there are many scenarios, each of which occurs with a probability. The main objective of both problems is to minimize the total incident response time. Instead of minimizing the expected total response time, the stochastic model minimizes the expected total response time over the high-consequence scenarios instead. In both settings, the deployment problem can be formulated as a mixed-integer nonlinear optimization problem, a hard class of problem to solve. To obtain solutions in a reasonable amount of time, three heuristic algorithms are proposed. In particular, one makes use of the dual information, another employs a neighborhood search technique and the third uses simulated annealing, a meta-heuristic algorithm. Numerical experiments based on data from Sioux Falls demonstrate that all three algorithms provide solutions with a significant reduction in total response time without using an excessive amount of CPU time.

20 REAL-TIME ESTIMATION OF ARTERIAL TRAVEL TIME UNDER CONGESTED CONDITIONS

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Estimation of arterial travel time on signalized arterials is a challenging task due to the nature of interrupted traffic flow. It becomes particularly difficult when the arterial links are congested with long queues (long queue is defined in the paper as the queue length is longer than distance from stop-bar to advance loop detector) because under such situations the queue length cannot be estimated using the traditional cumulative input-output curves. In this paper, we extend the virtual probe model previously proposed by the authors to estimate arterial travel time with congested links. Specifically, we propose a queue length estimation model that can handle long queues under both under-saturated and over-saturated conditions. Using the "event" data (including both time-stamped signal phase changes and vehicle-detector actuations) collected from traffic signal systems, time-dependent queue length can be derived by examining the changes in signal detector's occupancy profile within a cycle. Field studies at a 11-intersection arterial corridor along France Avenue in Minneapolis, Minnesota, demonstrate that the proposed model can generate accurate estimation of queue length and arterial travel time under congested conditions.

21 QUANTIFYING PERCEIVED QUALITY OF TRAFFIC SERVICE AND ITS AGGREGATION STRUCTURE

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This paper proposes a methodology for measuring the perceived quality of service (QOS) of a driver. The proposed method characterizes a driver's perception of the quality of traffic service as based on not the macroscopic or average traffic conditions but on the microscopic traffic conditions that the driver faces. To ascertain this, three methods are developed in this study. The first one is to estimate the driver's perceived QOS of traffic service on a point-basis that is formulated based on revealed preference data and a discrete choice model. Existence of order effect is, then, examined and the relationship between point-basis utility and point-basis perceived utility is clarified. The second method is to relate the point-basis perceived QOS with the section-basis perceived QOS. The third one is a method to select appropriate macroscopic traffic condition variables for describing estimated QOS index in the section-basis. Through a data analysis, the existence of some formation structures for the QOS perception has been confirmed.