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TSS Dissertation Abstracts

Abstracts for the 1999 Transportation Science Section Dissertation Prize Competition

GARRETT J. VAN RYZIN

Columbia University, Chair, 1999 TSS Dissertation Prize Committee

The TSS Dissertation Prize is the most prestigious award a young scholar in our field can receive. Eligible doctoral dissertations are those completed and submitted between June 1, 1998 and May 31, 1999 in the general area of transportation science. To be considered, the thesis supervisor must nominate the dissertation.

The competition draws entries from the top transportation programs around the world and, typically, many excellent submissions are received. I am pleased to report that this year was no exception. The committee received eight submissions in total, each of which was carefully reviewed by the prize committee.

The members of this year's committee were:

- Professor Ismail Chabini, Massachusetts Institute of Technology
- Professor Anton Kleywegt, Georgia Institute of Technology
- Professor Sarah Stock Patterson, Duke University
- Professor Paolo Toth, University of Bologna, Italy

The committee provided thoughtful and timely reviews of all the submissions and was a very collegial group; it was a delight to work with them. I sincerely thank each of the members for the time and effort they so unselfishly devoted to the task.

There were many strong entries in this year's competition, and, as always, it was difficult to narrow the list down to only a small number of awardees. However, the committee felt that three entries were especially deserving of prizes. The First Prize was awarded to Padma Ramanujam of the University of Massachusetts, Amherst. Two honorable mentions were awarded as well, one to William Hall of MIT and the other to Nicola Secomandi of the University of Houston. The awards were announced at the INFORMS meeting in Philadelphia.

Abstracts for the eight submissions are provided below, with the winners listed first and the remaining submission in alphabetical order. Each provides a glimpse of transportation research as viewed through the eyes of our next generation of scholars.

FIRST PRIZE

Transportation Network Policy Modeling for Congestion and Pollution Control: A Variational Inequality Approach.

PADMA RAMANUJAM

Transportation planners around the world face the question: cleaner air and/or faster commutes? Although individual vehicles can be made more environmentally friendly, the sheer scale of growth in worldwide vehicle numbers is projected to cause significant environmental degradation in the longer run, and in the absence of newer and stricter polices. It is a challenge for governments to find policies that ensure congestion-free metropolitan areas while guaranteeing both critical environmental quality levels and a sufficient infrastructure access to all groups involved.

The objective of the dissertation is to provide a

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mathematical framework to study transportation policy models for the purpose of controlling congestion and pollution. Toward this objective, a series of transportation policy models is developed and the theory of variational inequalities has been adopted to study travel behavior and to quantify the reductions in congestion and automobile emissions.

The dissertation begins with a brief historical overview of some of the pioneering works in urban transportation economics, and later presents the theoretical foundation for the transportation policy models developed. The dissertation introduces single modal and multimodal transportation network policy models that accomplish road pricing with the imposition of goal targets on link loads, as well as integrated traffic equilibrium models with marketable mobile emission permits. Furthermore, the issue of noncompliance has been analyzed. Moreover, equilibrium conditions are derived for each model, and both qualitative analysis and computational procedures are studied. Finally, the dissertation concludes with a comparative study of the relationship between regulatory pricing models and marketable emission permit transportation models and a discussion on key factors that influence implementation of the proposed policy models.

With a constant rise in the pressures of increased transport, this research aims to equip transportation planners with additional knowledge of economic instruments in environmental policy to confront the twofold problems of congestion and pollution.

The thesis supervisor was Professor Anna Nagurney.

HONORABLE MENTION

Efficient Capacity Allocation in a Collaborative Air Transport System

WILLIAM HALL

This thesis proposes methods of allocating airport capacity to the users of the National Airspace System (NAS) during periods in which demand for the resources exceeds capacity. A metric by which the proposed methods are judged is the value that the users of the NAS are able to realize through the allocation. Maximization of this metric produces notably different results from minimization of flight-minutes of delay and similar objectives used in related works.

The heart of this approach is the treatment of the Federal Aviation Administration (FAA) and the NAS users as solvers of subproblems in a decomposition of the overall problem of determining how to operate the system. The best possible capacity allocation method would allow the users to achieve the same result collectively that a single omniscient entity in control of all decisions in the system could achieve.

The typical approach to decomposition used in optimization, that of modifying the subproblem objectives through a penalty function determined by a master "dual" problem, is used in the Objective-Based Allocation Method (OBAM). It is shown that the proper choice of penalty function results in a method that performs well dynamically and, assuming each user operates to maximize its operating objectives through the allocation, achieves the optimal solution that an omniscient single controller would achieve.

OBAM requires complete communication of user objectives and constraints to achieve optimality. It also requires that the penalty functions used to coordinate the subproblem solutions be added to the user objective functions through assessment of fees. The second part of this thesis addresses the improvement of the decomposition by changing the nature of the allocation without these requirements. Rather than allocate airport arrival capacity alone, a more general notion of airport capacity that captures the interactions between arrival and departure processes at an airport is allocated. This allows the users the flexibility to adjust the operations mix of the airport according to their objectives and improves the ability of the system to match demand to forecast airport capacity. Through simulation, it is shown that this approach could improve significantly on the primary metric of achieving user value. In addition, the approach facilitates side benefits, such as the reduction of fuel consumption, the reduction of harmful emissions into the environment, and the improvement of service reliability for the flying public.

The thesis supervisor was Professor Amedeo Odoni.

HONORABLE MENTION

Exact and Heuristic Dynamic Programming Algorithms for the Vehicle Routing Problem with Stochastic Demands

NICOLA SECOMANDI

The deterministic vehicle routing problem (VRP) is well studied in the operations research literature.

A set of geographically dispersed customers each showing a positive demand has to be served by one or more vehicles of limited capacity located at a central depot. The objective is to route the vehicles through the customers' locations such that all customers' demands are satisfied and the distance traveled is minimized. This thesis deals with a VRP variation, the stochastic VRP (SVRP), where customers' demands are assumed to follow given probability distributions. For SVRP, the objective consists of generating a routing policy that minimizes the expected distance traveled to serve all customers' demands. Two distinct approaches for SVRP have been proposed: the a priori optimization and the reoptimization approach. Mainly because of the computational difficulty of the reoptimization approach, most researchers have focused on the a priori approach. Although it is recognized in the literature that the reoptimization approach yields routing policies of shorter expected distances, the approach has been deemed impractical because of its computational burden. The objective of the thesis is to derive computationally viable ways of generating a reoptimization-type routing policy for the single-vehicle SVRP. The thesis makes the following contributions:

- It models SVRP as a stochastic shortest-path problem and develops and analyzes different stochastic dynamic programming formulations. Structural properties of an optimal policy for one of these formulations are derived that shed light on the structural behavior of an optimal reoptimization-type routing policy.
- It develops rollout algorithms for both the a priori and reoptimization versions of SVRP. Properties of the proposed algorithms are discussed, and an extension of the theory of rollout algorithms to the case of stochastic shortest-path problems is derived.
- It derives a new algorithm to compute the expected distance of a given a priori tour. The result is important because it allows a more efficient implementation of the rollout algorithm. The thesis also provides a formal proof of the validity of a dynamic programming algorithm already available in the literature for optimally scheduling replenishment trips within a given a priori tour. Structural properties of the optimal replenishment policy for a given a priori tour are also derived. These properties are relevant because they establish a similarity between the structure of an optimal reoptimization policy and that of an optimal replenishment policy for a given a priori tour.
- It uses an exact stochastic dynamic programming algorithm within a heuristic problem decomposition scheme to generate a piecewise reoptimization-type routing policy.

The significance of the thesis relies on its novelty: it proposes computationally viable algorithms for computing approximate piecewise and full reoptimization-type routing policies for a version of the vehicle routing problem that has been so far considered intractable. To the best of our knowledge, these are the first heuristics ever proposed for approximately solving SVRP under the reoptimization approach.

The thesis supervisor was Professor Edward P. C. Kao.

Modeling Drivers' Acceleration and Lane Changing Behavior

KAZI IFTEKHAR AHMED

This thesis contributes to the development of microscopic traffic performance models, which includes the acceleration and lane changing models. It enhances the existing models and develops new ones. Another major contribution of this thesis is the empirical work, i.e., estimating the models using statistically rigorous methods and microscopic data collected from real traffic.

The acceleration model defines two regimes of traffic flow: the car-following regime and the free-flow regime. In the car-following regime, a driver is assumed to follow his/her leader, whereas in the free-flow regime, a driver is assumed to try to attain his/her desired speed. A probabilistic model, based on a time–headway threshold, is used to determine the regime the driver belongs to. Heterogeneity across drivers is captured through the headway threshold and reaction time distributions. The parameters of the car-following and free-flow acceleration models, along with the headway threshold and reaction time distributions, are jointly estimated using the maximum likelihood estimation method.

The lane-changing decision process is modeled as a sequence of three steps: decision to consider a lane change, choice of a target lane, and gap acceptance. Because acceptable gaps are hard to find in a heavily congested traffic, a forced merging model that captures forced lane changing behavior and courtesy yielding is developed. A discrete choice model framework is used to model the impact of the surrounding traffic environment and lane configuration on drivers' lane-changing decision process.

The models are estimated using actual traffic data collected from Interstate 93 at the Central Artery, located in downtown Boston, MA, USA. In addition to assessing the model parameters from statistical and behavioral standpoints, the models are validated using a microscopic traffic simulator. Overall, the empirical results are encouraging, and demonstrate the effectiveness of the modeling framework.

The thesis supervisor was Moshe Ben-Akiva.

A Multi-Objective Integrated Large-Scale Optimized Ramp Metering Control System for Freeway/Surface-Street Traffic Management

DOUGLAS M. GETTMAN

This research develops MILOS (Multi-objective Integrated Large-scale Optimized ramp metering System), a hierarchical control system for freeway management. MILOS decomposes the freeway control problem into subproblems along temporal–spatial boundaries and is composed of three primary components: (1) anomaly detection and optimization scheduling based on statistical process control, (2) area-wide metering rate coordination, and (3) predictive–cooperative real-time (PC-RT) metering rate regulation.

The area-wide coordination component of the hierarchical control system considers the impact of queue growth at the interchanges using a quadratic programming model with a multi-criterion objective function. The formulation of the area-wide optimization problem is augmented with overflow variables to guarantee a feasible solution. The nominal solution of this problem is then modified in real time by the locally traffic-reactive PC-RT rate regulation algorithm based on a linear program (LP) using a linearized dynamic difference equation implementation of the macroscopic FREFLO model. The PC-RT formulation proactively utilizes opportunities to disperse queues or hold back additional vehicles on ramps when freeway- and ramp-demand conditions are appropriate. The solution runs of the area-wide coordination and the PC-RT rate regulation problems at each ramp are scheduled by a demand/flow monitoring system based on statistical process control.

A simulation experiment was conducted to evaluate the MILOS hierarchical system against "no control," a locally traffic-responsive metering policy (currently under consideration by Arizona Department of Transportation), and an area-wide LP optimization policy re-solved at 5-minute intervals on a small freeway network in metropolitan Phoenix, Arizona. Three test cases were evaluated: a short "burst" of heavy-volume flows to all ramps, a 3-hour commuting peak, and a 3-hour commuting peak with a 30-minute incident occurring in the middle of the corridor. Simulation results indicate that MILOS is able to reduce freeway travel time, increase freeway average speed, and improve recovery performance when flow conditions become congested.

The thesis supervisor was Professor K. Larry Head.

Optimizing Highway Alignments with Genetic Algorithms

JYH-CHERNG JONG

In highway design, we should try to select an economic alignment based on topography, soil conditions, socioeconomic considerations, and other factors, while subject to a set of design constraints. This task is a very complex and laborious process with an astronomical number of alternatives, and has been recognized as a very difficult optimization problem. Over the past three decades, the optimization of highway alignments has attracted considerable research interest, and several mathematical models have been developed. However, due to the rigorous geometric specifications of alignments and the complexity of the problem, none of the existing models can yield satisfactory results, especially for simultaneously optimizing 3-dimensional alignments.

This dissertation starts by investigating the major cost components and important constraints in highway designs. Existing models for optimizing highway alignments are reviewed, and the advantages and disadvantages of different approaches are identified. The necessary conditions of an ideal model for optimizing highway alignments are then defined. Each condition suggests a possible improvement in modeling alignment optimization problems and helps guide this research. The properties of the problems are also scrutinized, and several definitions and theorems are developed, which provide insight into the problems from a mathematical viewpoint.

Four computable models are developed for optimizing highway alignments under different conditions. Models 1 and 2 are designed for optimizing horizontal alignments, whereas Models 3 and 4 are designed for simultaneously optimizing 3-dimensional alignments. Both Models 2 and 4 are capable of handling backtracking alignments, which may be more suitable in environments with complex topography and/or land use. The objective functions embedded in the proposed models combine various cost components and are relatively comprehensive when compared with previous works. The alignments generated by the proposed models are smooth and satisfy the geometric specifications of highway designs. Four evolution programs based on the concept of genetic algorithms (GAs) are also developed for solving these models. Several modifications have been made to classic GAs, and some problem-specific genetic operators are designed to facilitate the search. The case studies show that the proposed models and solution algorithms can efficiently find good highway alignments in complex geographic and topographic environments.

The thesis supervisor was Professor Paul Schonfeld.

Analysis and Optimization of Transit Network Design with Integrated Routing and Scheduling

YOUNG-JAE LEE

This study presents a methodology for transit network design with integrated routing and scheduling, which minimizes total user travel time, including in-vehicle travel time, waiting time, transfer time, and transfer penalties.

An iterative approach was used to deal with interdependency between in-vehicle travel time resulting from routing and waiting time resulting from scheduling. The algorithm starts from the minimum in-vehicle travel time network, and then improves the network with increasing in-vehicle travel time, while decreasing waiting time. To execute this methodology, TRANED (TRAnsit NEtwork Designer) was programmed. As results of the algorithm, major travel flows have direct connections, whereas minor travel flows have shorter waiting times with circuitous travel paths. This methodology consists of three major steps: generation of an initial network, assignment, and network improvement. They are followed by a supporting step, network analysis, which calculates the results of the previous three steps. All these steps are iterated until the optimal transit network is generated. A simple example was used to illustrate the procedure of the methodology, and its results were generated and compared with those reached by previous researchers.

Input elements for the model are demand volume, transit operating speed, transfer penalties, and vehicle capacity. Ranges of these elements were applied to TRANED to analyze sensitivity of the generated transit network to each one of them. Networks obtained through this analysis were classified by geometric and operational features into three types: transfer-oriented, transfer-avoidance, and directly-connected transit network.

This methodology, using an iterative approach, offers greater flexibility than most previous studies, which used simplified combinatorial approaches. So, the TRANED model can take into account various constraints and conditions, such as variable transit demand, operator's constraints, express service, given schedule information, and integrated service with an existing network. Applications of these factors and the resulting transit networks were also presented.

The thesis supervisor was Professor Vukan R. Vuchic.

A Framework for Representing and Solving Dynamic Resource Transformation Problem

JOEL SHAPIRO

In this thesis, we present a framework for modeling, solving, and coding complex operational problems we call dynamic resource transformation problems (DRTPs). A DRTP involves the control of a system of discrete resources over discrete time, subject to a guiding objective on cost or profit. Our framework combines a mathematical paradigm, a solution meta-strategy, and an object-oriented software representation to solve even the most complex DRTP.

We begin by defining a mathematical paradigm with which to represent DRTPs. Each discrete entity in a system is modeled as a resource with a generic vector of attributes to describe its state at any point in time. There are several key advantages to this paradigm:

System Dynamics: The paradigm models system dynamics in a general and flexible way. This proves particularly advantageous to models of transportation systems, where information on travel times, customer demands and fleet state is stochastic and highly dynamic.

Resource Layering: The paradigm also makes explicit provisions for what we call resource layering. Resource layering allows the modeler to segregate resources into primitive layers based on their attributes and behavior. At the same time, he can later couple resources, within and across layers, to construct more useful composite resources that can be handled with the same ease as primitive resources.

Decomposition with Hierarchical Control: Resources can be subjected to a hierarchical control structure, suitable for decomposition, that subjects them to a sequence of control decisions.

A Modify Function: The impact of each decision is modeled by a generic modify function that can efficiently update primitive and composite resource attribute vectors in response.

At an abstract level, defining a mathematical paradigm for the DRTP helps to recognize and describe similar problems from different fields (even subdisciplines of transportation) using domain-neutral language. This may stem the current profusion of industry-specific models. To solve the models produced within our paradigm, we develop a general solution meta-strategy. The meta-strategy works by first decomposing a large, complex problem into many smaller, simpler subproblems. The subproblems partition the original problem into decision blocks, which may be solved using easy, locally-optimal heuristics. Near-global optimality can be achieved by formulating the decomposed problem recursively using the notion of dynamic programming value functions to communicate dual information between subproblems. To accommodate large-scale transportation problems, we approximate the exact value function through a series of iterative slope estimates, obtained from dual estimates in each subproblem.

Advantages of this meta-strategy include no reduction in realism, low computational overhead, iterative improvement, combined simulation and optimization, extensive use of design patterns, and a novel representation of uncertainty. Extensive qualitative and quantitative software engineering analysis shows our software framework to be more extensible and maintainable than existing representations.

The thesis supervisor was Professor Warren B. Powell.