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Abstracts for the 2002 Transportation Science Section Dissertation Prize Competition

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The Dissertation Prize awarded by the Transportation Science Section (TSS) of INFORMS is the most prestigious award for new scholars in our field. For the most recent award, eligible dissertations were those completed between June 1, 2001, and May 31, 2002, in the general area of transportation science. A thesis must be nominated by the dissertation supervisor for it to be considered for the prize.

The competition draws entries from premier transportation programs around the world. The committee received 12 submissions, all of excellent caliber. The TSS Dissertation Prize Committee that carefully reviewed all submissions consisted of Professor Patrick Jaillet, Massachusetts Institute of Technology; Professor Oli Madsen, Technical University of Denmark; Professor Srinivas Peeta, Purdue University; Professor Michael Zhang, University of California at Davis; and myself.

Most of the entries this year were excellent. After considerable review and deliberation, both via e-mail and conference call, the committee, with difficulty, narrowed down the field to two. The committee was of the opinion that these two were of equal caliber and decided to award them both the first prize. The awardees are Dr. Alvin Lim from John Hopkins University and Dr. Iris Vis from Erasmus Universiteit Rotterdam. The awards were announced and presented at the 2002 INFORMS meeting in San Jose, California.

Below are the abstracts of the 12 submissions. The first two abstracts are of the winning dissertations, organized in alphabetical order by the authors' last names. The other 10 abstracts are of the nominated dissertations, also listed in alphabetical order by the authors' last names. The abstracts indicate the depth and diversity of the type of research being conducted by the brightest new scholars in our field.

FIRST PRIZE (shared)

Transportation Network Design Problems: An MPEC Approach

Alvin C. Lim

The process of transportation network design has become a significant part in the planning and management of such networks. Utilization of a transportation network involves the interaction of two groups of people—the network's managers, and its users—each having its own objectives. To some extent, the criteria by which network users choose their routes do not coincide with society's goal of utilizing the network efficiently. In an attempt to maximize the benefit of a network to society, the network managers are generally concerned with minimizing a design cost (i.e., an aggregate cost for construction, operation, maintenance, etc.). In contrast, each network user would select what he or she perceives as a least cost travel path leading to a state of user equilibrium. A comprehensive network design process incorporating such user behavior will generally require solving mathematical programs with equilibrium constraints (MPECs).

In this study, we develop a unified model of some important transportation network design problems by treating them as MPECs. Incorporated into this model are the capacity enhancement problem, the congestion toll pricing problem, the signal setting problem, and the origin-destination matrix adjustment problem. In place of various currently employed heuristics, we systematically apply certain MPEC algorithms to solve these problems, and we verify certain conditions essential for the algorithms' convergence. Applied to numerical examples that have appeared in the literature, these MPEC algorithms produce better solutions than those produced by previously reported methods.

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To solve large scale versions of the problems, we propose a conceptual algorithm based on delayed path generation and using the MPEC framework. This algorithm takes advantage of the promising MPEC approach to the network design problems while avoiding the need to enumerate all the paths in a network. Computational examples suggest that the resulting path-generation approach performs well.

The thesis supervisor was Jong-Shi Pang, John Hopkins University.

FIRST PRIZE (shared)

Planning and Control Concepts for Material Handling Systems

Iris F. A. Vis

Supply chains are under constant pressure to operate efficiently. Some of the slowest logistics activities in supply chains occur within the nodes of supply chains, such as warehouses and container terminals. Transshipment and internal transport of products belong to these types of activities. The objective of this thesis is to develop new planning and control concepts for internal transport equipment using techniques from operations research.

Part I of this thesis discusses automated guided vehicles (AGVs). The problem discussed is the determination of the number of vehicles required to transport a set of loads. In Chapter 3 the problem is formulated as a network problem. A minimum flow algorithm is developed to find the minimum number of directed paths (i.e., vehicles) covering each node in exactly one path in polynomial time. An extension of this problem is the case in which each load has a time window in which the transport should start. In Chapter 4 this problem is formulated as an integer linear programming model and as a set partitioning model.

Storage and retrieval machines (SRMs) take care of the storage and retrieval of unit loads, such as pallets and containers. A storage area with both storage and retrieval operations at both sides is examined. In Part II a new dynamic programming algorithm is developed to sequence storage and retrieval requests for a SRM operating in a number of parallel aisles in polynomial time. This solution method has been inspired by the algorithm of Ratliff and Rosenthal. However, due to the specific properties of this problem, it differs in many ways.

In Part III simulation studies are performed to test the concepts developed in Parts I and II in the context of container terminals. It is demonstrated that the results of these studies can be helpful in the design of container terminals.

The thesis supervisors were Rene de Koster and Rommert Dekker, Erasmus University, Rotterdam.

Load Plan Selection for Package Express Fleets

David E. Benson

A loader serves two roles during the loading process for package delivery. First, given a load plan, which is an assignment of regions to delivery vehicles, the loader takes each package to be delivered and one-by-one reads the address and assigns it to the proper vehicle, according to the load plan. Second, the loader can decide whether or not to change the load plan during the loading process. Changing a load plan involves the reassignment of regions to vehicles and, when appropriate, removing packages from one vehicle and placing them on another vehicle. Moving already assigned packages takes time, delays fleet departure, and hence generates additional cost. However, load plan adjustment can better balance delivery workload, which reduces cost. The objective of the research presented is to aid the loader during the loading process in deciding whether or not the current load plan should be continued, and if not, identify a better load plan, assuming that the current package load of each delivery vehicle is known. The load plan selection process is modeled as a Markov decision process (MDP) and analyzed in Chapter 2. We present structured results for the expected cost-to-go function that lead to an improved algorithm for computing an optimal load plan policy. We describe the improved algorithm and compare it to traditional dynamic programming methods in Chapter 3. We present a heuristic, based on conditions for action elimination, that is computationally superior to the exact methods. In Chapter 4, we present a prototype decision support system (DSS) for load plan selection in package express. We develop a statistical model to reflect a more complex information state and describe the implementation of the statistical model in an actual operation. We model the load plan selection process for air packages and suggest a solution technique. Conclusions are presented in Chapter 5.

The thesis supervisor was Chelsea C. White, III, Michigan University (currently at the Georgia Institute of Technology).

Generalized Real-Time Route Guidance Strategies in Urban Networks

Yi-Chang Chiu

Considered as critical components in the ATMIS architecture, the dynamic traffic assignment (DTA) problems have been extensively studied in the last decade. Researchers have proposed various DTA problem classes and formulations and have gained basic understanding of the solution characteristics. Although a vast amount of intellectual effort has been invested in characterizing and solving DTA problems, the current state-of-the-art falls short of providing DTA solutions that are guaranteed to be effective and robust in real-world operation. This dissertation is motivated by the need for a DTA framework that offers significant potential for successful real-world operation. The objective of this dissertation is to develop a generalized DTA framework that combines the advantages of both centralized and decentralized paradigms and circumvents the respective disadvantages, so as to provide efficient and robust dynamic traffic assignment solutions under various network conditions in the real-time operational environment.

To achieve the generalization of the DTA framework, this dissertation presents a hybrid DTA (HDTA) framework. The HDTA approach envisions a Stackelberg game-theoretic routing decision process achieved through the careful interplay between a centralized DTA model (CDTA) and a decentralized DTA (DDTA) capability. The CDTA model supplies anticipatory a priori routing decisions, taking into account DDTA's possible reactions to CDTA anticipatory routing policies, while the DDTA model generates locally reactive solutions online, given CDTA's anticipatory solutions.

To further improve online operating performance and robustness of the HDTA, an online routing profile updating automaton (ORPUA) model is proposed. The ORPUA dynamically adjusts the routing profile based on the online performance competitiveness measures of CDTA- and DDTA-guided vehicles. If one of the two classes of vehicles is detected to underperform the counterpart class, certain vehicles in this class will be assigned with guidance from the counterpart class for the remaining portion of the trip. The ORPUA constantly monitors and maintains the competitiveness between CDTA- and DDTA-class vehicles in the HDTA framework. It allows HDTA to adaptively maintain online operating performance vis-à-vis general demand or supply scenarios. Numerical experiments demonstrate the effectiveness of ORPUA under the scenarios in which CDTA's inputs are of varying accuracy levels.

The thesis supervisor was Hani S. Mahmassani, University of Texas at Austin (currently at the University of Maryland).

Improving Crew Scheduling by Incorporating Key Maintenance Routing Decisions

Amy E. M. Cohn

Numerous important real-world problems are found in the areas of transportation and logistics. Many of these problems pose tremendous challenges because of characteristics such as complex networks, tightly constrained resources, and very large numbers of heavily interconnected decisions. As a result, mathematical models can be critical in solving these problems. These models, however, can be computationally challenging or even intractable. In this thesis we discuss how greater tractability can sometimes be achieved with *composite-variable models*—models in which individual binary variables encompass multiple decisions.

In Part I, we discuss common challenges found in solving large-scale transportation and logistics problems. We introduce the idea of composite variables and discuss the potential benefits of composite-variable models. We also note some of the drawbacks of these models and discuss approaches to addressing these drawbacks. In Parts II and III, we demonstrate these ideas using two real-world examples, one from airline planning and the other from service parts logistics. We build on our experience from these two applications in Part IV, providing some broader insights for composite-variable modeling. We focus in particular on the dominance property seen in the service parts logistics example and on the fact that we can relax the integrality of the composite variables in the airline planning example. In both cases, we introduce broader classes of problems in which these properties can also be found. We offer conclusions in Part V.

The contributions of the thesis are three-fold. First, we provide a new model and solution approach for an important real-world problem from the airline industry. Second, we provide a framework for addressing challenging problems in service parts logistics. Third, we provide insights into how to construct composite-variable models for greater tractability. These insights can be useful not only in solving large-scale problems, but also in integrating multiple stages within a planning environment, developing better heuristics for solving large problems in real time, and providing users with greater control in trading off solution time and quality.

The thesis supervisor was Cynthia Barnhart, Massachusetts Institute of Technology.

Dynamic Travel Time Models for Pricing and Route Guidance: A Fluid Dynamics Approach

Soulaymane Kachani

This thesis investigates dynamic phenomena that arise in a variety of systems that share similar characteristics. A common characteristic of particular interest in this work is travel time. We wish to address questions of the type: *How long does it take a driver to traverse a route in a transportation network? How long does a unit of product remain in inventory before being sold?*

To address these issues, we develop general models for travel times. To make these models more accessible, we describe them as they apply to transportation systems. We propose first-order and second-order fluid models. We enhance these models to account for spillback and bottleneck phenomena. Based on piecewise linear and piecewise quadratic approximations of the departure or exit flows, we propose several classes of travel time functions.

In the area of supply chain, we propose and study a fluid model of pricing and inventory management for make-to-stock manufacturing systems. This model is based on how price and level of inventory affect the time a unit of product remains in inventory. Our motivation is based on the observation that in inventory systems, a unit of product incurs a delay before being sold. This delay depends on the level of inventory of this product, its unit price, and prices of competitors. The model includes joint pricing, production and inventory decisions in a competitive, capacitated, multiproduct dynamic environment.

Finally, we consider the anticipatory route guidance problem, an extension of the dynamic user-equilibrium problem. This problem consists of providing messages to drivers, based on forecasts of traffic conditions, to assist them in their path-choice decisions. We propose two equivalent formulations that are the first general analytical formulations of this problem. We establish, under weak assumptions, the existence of a solution to this problem.

The thesis supervisor was Georgia Perakis, Massachusetts Institute of Technology.

Airline Fleet Assignment and Schedule Design: Integrated Models and Algorithms

Manoj Lohatepanont

In scheduled passenger air transportation, airline profitability is critically influenced by the airline's ability to construct flight schedules containing flights at desirable times in profitable markets. In this dissertation, we study two elements of the schedule generation process: schedule design and fleet assignment. The *schedule design problem* involves selecting an optimal set of flight legs to be included in the schedule, while the *fleet assignment problem* involves assigning aircraft types (or fleets) to flight legs to maximize revenues and minimize operating costs simultaneously.

With the fleet assignment problem, we investigate the issues of *network effects*, *spill*, and *recapture*. On a constrained flight leg in which demand exceeds capacity, some passengers are not accommodated, or *spilled*. When passengers travel on two or more constrained legs, *flight leg interdependencies* or *network effects* arise because spill can occur on any of these legs. In most basic fleet assignment models, simplistic modeling of network effects and recapture leads to sometimes severe miscalculations of revenues. *Recapture* occurs when some of the spilled passengers are reaccommodated on alternate itineraries in the system. In this dissertation, we develop new fleet assignment models that capture network effects, spill, and recapture. Another benefit of one of our models is its tractability and potential for integration with other schedule planning steps. Our study shows that the benefits of modeling these elements exceed $100 million annually for a major U.S. airline.

We develop two models for schedule design, one assuming that the market share of an airline remains

constant with schedule changes, and the other assuming that market share varies with schedule changes. The constant market share model, while less precise in its modeling, is much easier to solve than the variable market share model. We estimate that the potential benefits of these models range from $100 to $350 million annually.

The thesis supervisor was Cynthia Barnhart, Massachusetts Institute of Technology.

Models for the Design and Analysis of a Large Package Sort Facility

Major Paul W. McAree, United States Air Force

In a *hub-and-spoke* system that represents a large package, overnight delivery operation, packages are loaded onto aircraft at origin airports, moved to a sort facility, unloaded and sorted using a forklift, and loaded onto aircraft for delivery to destination airports. The sort facility represents the *hub* of this operation, and the *spokes* are the package movements between the airports and hub. In this operation, a forklift movement can take several minutes and there can be congestion. The large package sort facility operation of Federal Express is the motivation for this research. The objective of the analysis is to determine the minimum cost design of the sort facility.

In the dissertation several integer programming models are described and analyzed; these models include the bin and rack assignment model (BRAM), the bin assignment model (BAM), and the rack assignment model (RAM). Because real problem instances could not be solved directly using BRAM, the BAM and RAM models were developed and embedded into a heuristic called the BAM and RAM algorithm for generating feasible solutions to the BRAM.

The BAM determines the assignment of inbound ULDs to bins for a fixed assignment of outbound ULDs to racks. The RAM determines the assignment of outbound ULDs to racks for a fixed assignment of inbound ULDs to bins. The *BAM and RAM algorithm* iteratively solves the BAM and RAM where the RAM's optimal solution is a feasible solution to the BAM, the BAM's optimal solution is a feasible solution to RAM, and the overall solution is continuously improving. Computational experiments show that this approach represents an effective heuristic.

The dissertation reports on results of a comprehensive set of computational experiments. These results provide an analysis of the effectiveness of the solution strategy and of potential sort facility architectures. The second set of experiments produced substantial improvements in the current sort facility layout and provided a definitive recommendation on a future architecture.

The thesis supervisors were Michael Ball and Lawrence Bodin, University of Maryland.

Design and Operation of Multimode, Multiservice Logistics Systems

Karen R. Smilowitz

This thesis introduces design strategies and operational plans for multimode, multiservice package delivery networks where service levels are defined by guaranteed delivery times (i.e., overnight, two-day delivery). Large-scale network design problems are typically challenging because of the number of interdependent decision variables and constraints. These problems are even more complex with multiple service levels. Conventional design and routing models cannot sufficiently capture the complexity of multimode, multiservice networks. This thesis discusses two principal design and routing approaches, and shows how the two can be integrated. In one approach, detailed mixed-integer programming formulations and numerical methods are utilized. In the other, less detailed models based on continuous approximations are used. While the former provide a higher level of detail, the latter are more revealing of "the big picture." Numerical methods are well suited for operational control, while continuous approximation methods are particularly effective for strategic planning and design, especially under uncertainty. A novel approach is developed based on the complementary use of the two methods to develop, test, and evaluate integrated strategies. This is the first application of hybrid continuous approximation/numerical optimization to design and operate large-scale integrated networks with shipment choice. As such, advancements in continuous approximation and numerical optimization techniques, and in the integration of the two, are required. The cost functions developed are capable of modeling complex systems, and their accuracy is demonstrated using independent cost validation. With creative solution techniques, these complex models are reduced to a series

of subproblems that are solvable using spreadsheet technology. Results suggest that integration benefits are greater when deferred demand exceeds express demand. This insight helps to explain the different business strategies of package delivery firms today. This research shows how integration strategies can reduce operating costs and how hybrid modeling approaches can be used to better understand and better plan distribution strategies.

The thesis supervisor was Carlos F. Daganzo, University of California, Berkeley.

The Capacitated Arc Routing Problem with Vehicle/Site Dependencies: An Application of Arc Routing and Partitioning

John S. Sniezek

The capacitated arc routing problem (CARP) is a class of vehicle routing problems in which service requirements are associated with network arcs. In the capacitated arc routing problem with vehicle/site dependencies (CARP-VSD), there are restrictions on the types of vehicles that can service or traverse each network arc. In general, vehicles may vary in other characteristics as well, including their cost parameters and capacities. The scheduling of residential solid waste collection vehicle motivated the study of the CARP-VSD. Real instances of these problems can have several thousand network elements.

In this dissertation, the composite approach for solving CARP-VSD is described and analyzed. The *composite approach* is composed of the vehicle decomposition algorithm (VDA), a mathematical program (MPP), and a cost model. The VDA determines an initial vehicle fleet mix, partitions the arcs requiring service into partitions, forms a minimum deadhead time travel path over each partition, and uses between-route arc exchanges to improve the solution. In a test region in Philadelphia, the VDA saved 5 of 23 vehicles.

The MPP is primarily used as a route-improvement procedure. As a route-improvement procedure, *the MPP can alter the fleet mix in a solution*. In most prior vehicle routing research, between-route improvement procedures do not change the fleet mix.

The cost model considers capital and operating costs and is used to compare or generate solutions. While the objective functions in classical vehicle routing models generally minimize total travel time or travel distance, the CARP-VSD models developed in this dissertation consider a complex set of cost components related to the nonhomogeneous nature of the vehicle fleet, route compactness, and other factors.

Extensive computational experiments are presented, including many based on real problem instances.

The thesis supervisor was Lawrence Bodin, University of Maryland.

The Dynamic Assignment Problem

Michael Z. Spivey

In this thesis we introduce the dynamic assignment problem, which involves the solution of assignment problems over time with evolving information on the availability of resources and tasks, contributions for assigning them and restrictions on the ability to assign them. This thesis is the first major work on extending the classic assignment problem to a dynamic setting. Because the dynamic assignment problem consists of solving sequences of assignment problems over time, it lies at an intersection of both linear and dynamic programming. This thesis is one of the first to work at the confluence of these two fundamental areas of operations research.

We provide a formal model of the dynamic assignment problem. Our model explicitly includes both the physical process (the actual arrivals of resources and tasks to the system) and the information process (knowledge about these arrivals and of properties of resources and tasks). We also derive a number of structural properties of the classic assignment problem and certain types of dynamic assignment problems. These properties help provide insight into the problem class and are used in the design of approximation strategies.

We then introduce an approximation strategy for the value function that produces a computationally tractable algorithm that significantly outperforms simple myopic heuristics. Our algorithmic strategy avoids the state space problems of classical dynamic programming. Techniques from stochastic programming (which use scenarios or cuts based on nested-Benders decomposition) lose the natural integrality properties of the assignment problem. Our approach involves solving sequences of assignment problems based on sample realizations.

We also examine the effects of aggregation of resources and tasks on the dynamic assignment problem. Aggregation allows us to use the values of resources and tasks that we already know to help approximate values of resources and tasks that are new to the system. This in turn allows us to apply our value function approximation algorithm to even larger problems. We also develop a version of our algorithm that dynamically chooses an appropriate level of aggregation, and we show that this algorithm outperforms our algorithm in which the level of aggregation is static.

The thesis supervisor was Warren Powell, Princeton University.

Territory Planning and Vehicle Dispatching with Stochastic Customers and Demand

Hongsheng Zhong

This paper investigates the construction of routes for local delivery of packages. The primary objective of this research is to provide realistic models to optimize vehicle dispatching when customer locations and demand vary from day to day, while maintaining driver familiarity with their service territories and dispatch consistency. The objective of increasing driver familiarity tends to make routes or service territories fixed. On the other hand, to serve varying demand, it is advantageous to reassign vehicles/drivers and service territories each day. To balance the trade-offs between these two objectives, we developed concepts of "cell," "core area," "flex-zone," and a two-stage vehicle routing model—the strategic core area design model and operational cell routing model—and explicitly considered the value of driver familiarity by introducing a driver learning with forgetting model.

The testing results showed that the tabu search meta-heuristic for solving the strategic model is capable of finding near-optimal solutions, as evidenced by the lower bounds constructed for the nonlinear generalized assignment problem. Moreover, the core areas and flex-zone identified on the strategic level provides a good framework for building low cost yet consistent dispatch plans over certain period, as evidenced by the favorable comparison to the no-core-area method as well as by the lower bound constructed on the operational level for the learning-incorporated vehicle routing problems.

The thesis advisor was Randolph W. Hall, University of Southern California.