Development of a Large-Scale Transportation Optimization Course

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16. Abstract

In this project, a course was developed to introduce transportation and logistics applications of large-scale optimization to graduate students. This report details what similar courses exist in other universities, and the methodology used to gather literature for course. Details about the learning objectives and structure of the course are given, as well as lessons learned from the initial offering of this course in Fall 2009. Course feedback and outcomes as well as suggestions for future offerings of the course are discussed.

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Table of Contents

1 Background and Motivation

Northwest Arkansas' central location and strong economy make it a prime location for many transportation-related companies. Many masters and PhD graduates of the industrial engineering department at the University of Arkansas accept positions in the transportation and logistics field with companies such as JB Hunt, ABF, Transplace, Walmart, and Sam's Club. The number of jobs in the trucking and warehousing industry alone is projected to grow 15 percent from 2006 through 2016, underscoring the importance of having well-trained professionals ready to help fill these positions (BLS 2009). Additionally, many students in our department complete their masters and PhD theses about some aspect of transportation or logistics.

Despite the large number of students who work in the transportation and logistics fields in graduate school and as professionals, prior to this work there was no quantitative upper-level coursework offered by the University of Arkansas in the large-scale optimization of transporation networks. Many transportation problems are large-scale due to the vast number of commodities that must be transported through large networks. While these challenges alone are can pose problems to standard optimization algorithms, additional complexities such as non-linear cost structures and timing constraints further challenge the tractability of these problems. These computational challenges have attracted the attention of a sizable body of researchers who have developed a growing number of innovative modeling approaches and solution techniques to address these problems. The goal of this project was to develop a course that would teach students about these approaches to large-scale optimization problems, with an emphasis on those arising in transportation and logistics networks.

2 Courses at Other Institutions

Prior to developing this course, a search was conducted for syllabi for related courses at other universities to determine how many courses of this type exist in industrial engineering and operations research curricula across the country, to ensure that the content developed for this course was appropriate, and that relevant aspects of the course were not omitted.

Syllabi were collected in two ways. First, a general internet search for large-scale optimization and transportation syllabi was conducted. This was only moderately successful. As a result, a second approach was taken. Coursework from the top 20 industrial engineering programs in the country was analyzed. Additionally, coursework from Massachusetts Institute of Technology was studied since their Civil Engineering department in conjunction with their Operations Research Center has a well-known transportation program. Course descriptions from each of these departments was obtained and analyzed to identify which of the courses – if any – had strong transportation and large-scale optimization content. Wherever possible, syllabi were obtained for these courses to better understand the material covered.

In general courses that were listed as supply chain courses were not included in our listing of relevant courses shown in Table 1 below, although each course was considered on a course-by-course basis. This is because these courses tended to be comprehensive, covering a wide variety of topics including forecasting, inventory models, and other production planning-type concepts. Although transportation was typically included in these courses, they tended to be a minor competent of the overall course content and were therefore excluded. Although there were courses that that covered large-scale optimization methodologies as a portion of a course (typically, an optimization course), these tended not to be the exclusive focus of the course and also tended to have no application areas mentioned. As a result, these were excluded from our analysis as well.

Table 1 below includes all relevant coursework identified through this search. Course numbers, titles, and descriptions are included in addition to the institutions at which the courses are offered.

Course Number	Course Title	Institution	Course Description
ISYE 6203	Transportation and Supply Chain Systems	Georgia Tech	A study of logistics systems, with emphasis on quantitative approaches for the design and control of freight transportation and supply chain systems. Topics include: an introduction to the components of logistics systems, such as suppliers, customers, inventory, orders, and transportation systems, and the interactions between these components; models and techniques for the design and control of logistics systems and the development of decision support systems; and case studies of applications of such techniques.
IE 480-1	Transportation Network Design and Operation	Northwestern	Interrelationship between transportation, inventory, and production costs; design and operation of physical distribution and collection systems; role of terminals and transshipments; relevant analysis and methodologies.
MS&E 296	Transportation Systems and Urban Development	Stanford	Economic analysis of transportation, supply and demand equilibrium analysis, urban transportation networks, congestion management, short and long term transportation planning, the impact of technology on transportation systems, land use and transportation, case studies of current transportation news items.
ISE 62xx	Logistics Engineering Systems	Virginia Tech	*(course description unavailable; listed in ISE graduate handbook but not in course VT course catalog)*
ISEN 603	Advanced Logistics	Texas A&M	Topics in logistics including measures of logistical systems performance, facilities location—allocation, production/distribution system design, transportation network design, vehicle routing; emphasis on mathematical modeling based on large scale integer programs and solution approaches for general network design problems.
ISE 754	Logistics Engineering	NCSU	Elements of logistics networks. Supply chain design: facility location and allocation; great-circle distances; geocoding. Multi-echelon production and inventory systems; sourcing decision systems. Vehicle routing: exact, approximation, and heuristic procedures; traveling salesman problem; basic vehicle routing problem and extensions; backhauling; mixed-mode transportation system design.

Course Number	Course Title	Institution	Course Description
IEE 535	Intro to International Logistics Systems	Arizona State	Exploratory project-oriented course that addresses domestic and international logistics practices from a high-level descriptive perspective and an analytical model-based perspective.
IE5333	Logistics Transportation Systems Design	University of Texas	The design and analysis of domestic and international transportation systems of people, processes, and technology. Topics include the role of transportation in the extended enterprise, transportation modeling and optimization techniques, value-added supply chain issues, and financial performance measures. Prerequisites: IE 5317 or equivalent, IE 5301 or concurrent, and IE 5329 or concurrent, or equivalent.
1.203J / 6.281J / 15.073J / 16.76J / ESD.216J	Logistical and Transportation Planning Methods	MIT	The class will cover quantitative techniques of Operations Research with emphasis on applications in transportation systems analysis (urban, air, ocean, highway, pick-up and delivery systems) and in the planning and design of logistically oriented urban service systems (e.g., fire and police departments, emergency medical services, emergency repair services). It presents a unified study of functions of random variables, geometrical probability, multi-server queueing theory, spatial location theory, network analysis and graph theory, and relevant methods of simulation. There will be discussion focused on the difficulty of implementation, among other topics.
1.221J / 11.527J / ESD.201J	Transportation Systems	MIT	Approaching transportation as a complex, large-scale, integrated, open system (CLIOS), this course strives to be an interdisciplinary systems subject in the "open" sense. It introduces qualitative modeling ideas and various techniques and philosophies of modeling complex transportation enterprises. It also introduces conceptual frameworks for qualitative analysis, such as frameworks for regional strategic planning, institutional change analysis, and new technology development and deployment. And it covers transportation as a large-scale, integrated system that interacts directly with the social, political, and economic aspects of contemporary society. Fundamental elements and issues shaping traveler and freight transportation systems are covered, along with underlying principles governing transportation planning, investment, operations, and maintenance.

Course Number	Course Title	Institution	Course Description
1.224J / ESD.204J	Carrier Systems	MIT	Carrier systems involve the design, operation and management of transportation networks, assets, personnel, freight and passengers. In this course, we will present models and tools for analyzing, optimizing, planning, managing and controlling carrier systems.
ESD.260J / 1.260J / 15.770J	Logistics System	MIT	This subject is a survey of the fundamental analytic tools, approaches, and techniques which are useful in the design and operation of logistics systems and integrated supply chains. The material is taught from a managerial perspective, with an emphasis on where and how specific tools can be used to improve the overall performance and reduce the total cost of a supply chain. We place a strong emphasis on the development and use of fundamental models to illustrate the underlying concepts involved in both intra and inter-company logistics operations.

Table 1. Graduate Transportation and Logistics Course Offerings.

2.1 Synthesis of Course Information

In analyzing the syllabi available for the courses listed above, four main themes emerged.

1. Course content covered both strategic- and operational-level content. Topics covered ranged from long-term strategic planning problems such as facility location and network design to operational-level problems such as the dispatch of vehicles and vehicle routing.
2. Many courses included practically-motivated content. Although transportation is by its very nature an applied, practically-motivated field, many of the courses included case studies or project to encourage students to move beyond simply understanding and applying models to small textbook type problems.
3. Many course descriptions mention the large-scale nature of the problems solved in the area of transportation, and several specifically mention large-scale optimization tools and heuristics explicitly as a part of the course content.
4. Various modes of transportation are discussed in the courses. While many courses seem to concentrate primarily on freight transportation as opposed to passenger transportation, these courses typically discuss topics relating to trucking, intermodal, air, and rail.

Another observation from the analysis is that logistics and transportation education is far from pervasive in industrial engineering course offerings. Of the 20 programs analyzed, less than half had graduate courses focused on logistics and transportation. Further analysis reveals that, in general, programs that offer transportation and logistics courses have a concentration of faculty who work on transportation research. Many of the universities who offer these courses also have University Transportation Centers as well (Georgia Tech, Northwestern, Texas A&M, NCSU, MIT).

2.2 Integrating this Knowledge into the Proposed Course

One of the major objectives of this course as outlined in the proposal was expose students to large-scale optimization via articles in prominent journals. The analysis of courses offered at other institutions reiterated that transportation problems are large-scale, typically requiring specialized algorithms and solution techniques to solve them. Additionally this analysis revealed that it is critical to integrate a practical component of the course (vs. straight theory), and to highlight transportation applications that arise in various modes of transportation.

3 Literature Review

3.1 Methodology

A critical component of the course developed as outlined in the proposal was to expose students to seminal works that are foundational in this the area of large-scale optimization in transportation and logistics as well as contemporary, cutting edge research in this area. A thorough literature review was conducted to ensure that all articles from 2000-2009 that highlighted applications of large-scale optimization tools in logistics were identified. Various combinations of the following search terms were used: logistics, transportation, airlines, crew pairing, crew scheduling, fleet assignment, rail, railroad, blocking, routing, column generation, Bender's decomposition, decomposition, intermodal, container terminal, branch and price, branch and cut, Lagrangian relaxation. Additionally, all issues of *Operations Research* and *Transportation Science* from 2000-2009 were examined to identify all articles whose content was relevant to the course. Articles that were not published in high-quality journals were examined but, for the most part, not considered for the class if they did not adhere to quality standards. Additionally, for modes of transportation with limited large-scale optimization research, survey papers were identified to introduce students to research in these modes of transportation.

After conducting the literature review as described above, all papers were checked for quality. Those that were deemed of insufficient quality were not included in the list of papers for the course to ensure that the content of the course represented the highest-quality contemporary research.

3.2 Papers for the Course

A listing of papers considered for this course is given in Table 2.

Title	Authors	Journal	Issue	Topics and Keywords
Ship Scheduling and Network Design for Cargo Routing in Liner Shipping	Agarwal, R.; Ergun, Ö.	Transportation Science	Vol. 42, No. 2, May 2008, pp. 175-196	shipping, Langrangian relaxation, Benders decomposition
Solving Real-Life Railroad Blocking Problems	Ahuja, R.; Jha, K.; Liu, J.	Interfaces	Vol. 37, No. 5, September–October 2007, pp. 404–419	networks; network design; multicommodity flows; flow algorithms; heuristics; transportation; freight; railroad; blocking; integer programming; neighborhood search
Composite Variable Formulations for Express Shipment Service Network Design	Armacost, A.; Barnhart, C.; Ware, K.	Transportation Science	Vol. 36, No. 1, February 2002, pp.1–20	air cargo, express shipment, composite variable modeling
Optimizing Military Airlift	Baker, S.; Morton, D.; Rosenthal, R.; Williams, L.	Operations Research	Vol. 50, No. 4, July-August 2002, pp. 582-602	planning, military, aircraft fleet utilization
Optimizing military airlift	Baker, S.; Morton, D.; Rosenthal, R.; Williams, M.	Operations Research	Vol. 50, No. 4, July-August 2002, pg. 582-603	strategic airlift, large-scale linear programming, multi-period air transportation model for cargo and passengers
An exact method for the car pooling problem based on Lagrangian column generation	Baldacci,R.;Maniezzo, V.; Mingozzi, A.	Operations Research	Vol. 52, No. 3, May-June 2004, pp. 422-439	carpooling, Langrangian column generation
Air network design for express shipment service	Barnhart, C., Schneur, R.	Operations Research	Vol. 44, No. 6, November-December 1996, pp. 852-863	express shipment design, column generation
Applications of Operations Research in the Air Transport Industry	Barnhart, C.; Belobaba, P.; Odoni, A.	Transportation Science	Vol. 37, No. 4, November 2003, pp. 368-391	airlines overview
Airline Schedule Planning: Accomplishments and Opportunities	Barnhart, C.; Cohn, A.	Manufacturing & Service Operations Management	Vol. 6, No. 1, Winter 2004, pp. 3-22	airlines overview

Title	Authors	Journal	Issue	Topics and Keywords
Airline Fleet Assignment with Enhanced Revenue Modeling	Barnhart, C.; Farahat, A.; Lohatepanont, M.	Operations Research	Vol. 57 , No. 1, January 2009, 231-244	airlines, decomposition
Railroad Blocking: A Network Design Application	Barnhart, C.;Jin, H.; Vance, P.	Operations Research	Vol. 48 , No. 4, July 2000, 603 - 614, 2009	column generation, railroad, network design
Real-time control of freight forwarder transportation networks by integrating multimodal transport chains	Bock, S.	European Journal of Operational Research	Vol. 200, 2010, pp. 733–746	real time control, freight forwarder, transshipment
Is a New Applied Transportation Field Emerging? - A Review of Intermodal Rail-Truck Transport Literature	Bontekoning, Y.M.; Macharis, C.; Trip, J.J.	Transportation Research Part A	Vol. 38, 2008, pp. 1-34	literature review, intermodal
A column-generation approach to line planning in public transport	Borndorfer, R.; Grotschel, M.; Pfetsch, M.E.;	Transportation Science	Vol. 41 , No. 1, February 2007, 123-132	rail, column generation
A Decomposition Approach for the Inventory-Routing Problem	Campbel, A.; Savelsbergh, M.	Transportation Science	Vol. 38, No. 4, November 2004, pp. 488–502	integrated planning, decomposition
Exploiting the Opportunities of Collaborative Decision Making: A Model and Efficient Solution Algorithm for Airline Use	Carlson, P.M.	Transportation Science	Vol. 34, No. 4, November 2000, pp. 381-393	airlines, real time, industry/practice
Optimizing the Cargo Express Service of Swiss Federal Railways	Ceselli A.;Gatto, M.; Lübbecke, M.E.; Nunkesser, M.	Transportation Science	Vol. 42 , No. 4 (November 2008) 450-465	branch and cut, branch and price, rail
Strategic service network design for DHL Hong Kong	Cheung, W.; Leung, L.; Wong, Y.	Interfaces	Vol. 31, No. 4, July-August 2001, pp. 1-14	small package, network design, equipment planning
Ship Routing and Scheduling: Status and Perspectives	Christiansen, M.; Fagerholt, K.; Ronan, D.	Transportation Science	Vol. 38, No. 1, February 2004, pp. 1–18	maritime transportation; ship scheduling; fleet size and mix

Title	Authors	Journal	Issue	Topics and Keywords
Service network design in freight transportation	Crainic, T.	European Journal of Operational Research	Vol. 122, 2000, pp. 272-288	service network design; freight transportation; tactical planning; modeling
A genetic algorithm for the problem of configuring a hub-and-spoke network for a LTL trucking company in Brazil	Cunha, C.; Silva, M.	European Journal of Operational Research	Vol. 179, 2007, pp. 747–758	LTL, metaheuristic, hub and spoke network design
Robust Optimization for Empty Repositioning Problems	Erera, A.; Morales, J.; Savelsbergh, M.	Operations Research	Vol. 57, No. 2, March-April 2009, pp. 468-483	operations, empty containers
Reducing Truckload Transportation Costs Through Collaboration	Ergun, E.; Kuyzu, G.; Savelsbergh, M.	Transportation Science	Vol. 41, No. 2, May 2007, pp. 206-221	collaboration, trucks, freight
Scheduling Locomotive and Freight Car Transfers in Freight Transport	Fuegenschuh, A.; Homfeld, H.; Huck, A.; Martin, A.; Yuan, Z.	Transportation Science	Vol. 42, No. 4, November 2008, pp. 478-491	rail, cyclic scheduling, time window, heuristics, cutting planes
Integrated Airline Fleet and Crew Robust Planning	Gao, C.; Johnson, E.; and Smith, B.	Transportation Science	Vol. 43, No. 1, 2009, pp. 2 - 16.	airlines, integrated planning
Vehicle Scheduling and Routing with Drivers' Working Hours	Goel, A.	Transportation Science	Vol. 43, No. 1, February 2009, pp. 17-26	vehicle routing, real world, VNS
Planning models for long-haul operations of postal and express shipment companies	Gruenert, T.; Sebastian, H.	European Journal of Operational Research	Vol. 122, 2000, pp. 289-309	network design, LTL
A Branch-and-Price-and-Cut Method for Ship Scheduling with Limited Risk	Hwang, H.S.; Visoldilokpun, S.; Rosenberger, J.M.	Transportation Science	Vol. 42 , No. 3, August 2008	ship, risk, uncertainty
Large-Scale, Less-than-Truckload Service Network Design	Jarrah, A.; Johnson, E.; Neubert, L.	Operations Research	Vol. 57, No. 3, May-June 2009, pp. 609-625	network design

Title	Authors	Journal	Issue	Topics and Keywords
Economies of Scale in Empty Freight Car Distribution in Scheduled Railways	Joborn, M.; Crainic, T.; Gendreau, M.; Holmberg, K.; Lundgren, J.	Transportation Science	Vol. 38, No. 2, May 2004, pp. 121–134	empty freight car distribution; time-dependent capacitated network design; tabu search
Multimodal Express Package Delivery: A Service Network Design Application	Kim, D.; Barnhart, C.; Ware, K.; Reinhardt, G.	Transportation Science	Vol. 33, No. 4, November 1999, pp. 391-407	air, network design, express package
The New Dutch Timetable: The OR Revolution	Kroon, L.; Huisman, D.; Abbink, E.; Fioole, P.; Fischetti, M.; Maróti, G.; Schrijver, A.; Steenbeek, A.; Ybema, R.	Interfaces	Vol. 39, No. 1, January–February 2009, pp. 6–17	rail, scheduling, vehicles, crew; programming: large-scale systems, integer; network graphs: multicommodity
A Fictitious Play Approach to Large-Scale Optimization	Lambert, T.; Epelman, M.; Smith, R.	Operations Research	Vol. 53, No. 3, May-June 2005, pp. 477-489	methods, traffic planning
Simplicial Decomposition with Disaggregated Representation for the Traffic Assignment Problem	Larsson, R.; Patriksson, M.	Transportation Science	Vol. 26, No. 1, February 1992, pp. 4-17	theoretical, traffic assignment, decomposition
Real-time vehicle rerouting problems with time windows	Li, J.; Mirchandani, P.; Borenstein, D.	European Journal of Operational Research	Vol. 194, 2009, pp. 711–727	vehicle routing; rerouting; schedule recovery; Lagrangian heuristic
Opportunities for OR in intermodal freight transport research: A review	Macharis, C.; Bontekoning, Y.M.	European Journal of Operational Research	Vol. 153, 2004, pp. 400–416	intermodal transportation, literature review
Optimal Real-Time Traffic Control in Metro Stations	Mannino, C.; Mascis, A.	Transportation Science	Vol. 57, No. 4, July–August 2009, pp. 1026–1039	real time, passenger transportation, public transportation, rail
Tactical design of rail freight networks. Part I: Exact and heuristic methods	Marin, A.; Salmeron, J.	European Journal of Operational Research	Vol. 90, 1996, pp. 26-44	network design; rail freight transportation; local search;
Scheduling Direct and Indirect Trains and Containers in an Intermodal Setting	Newman, A.; Yano, C.	Transportation Science	Vol. 34, No. 3, August 2000, pp. 256-270	rail containers, intermodal, decomposition

Title	Authors	Journal	Issue	Topics and Keywords
Dynamic control of logistics queueing networks for large-scale fleet management	Powell, W.; Carvalho, T.	Transportation Science	May98, Vol. 32 No. 2, p90	fleet, approximate dynamic programming
Real-Time Optimization of Containers and Flatcars for Intermodal Operations	Powell, W.; Carvalho, T.	Transportation Science	Vol. 32, No. 2, May 1998, pp. 110-126	rail, real time, intermodal
Implementing Real-Time Optimization Models: A Case Application from the Motor Carrier Industry	Powell, W.; Marar, A.; Gelfand, J.; Bowers, S.	Operations Research	Vol. 50, No. 4, July-August 2002, pp. 571-581	real time, TL transportation, implementation issues
Advances in the Optimization of Airline Fleet Assignment	Rushmeier, R.; Kontogiorgis, S.	Transportation Science	Vol. 31, No. 2, May 1997, pp. 159-169	airlines, fleet assignment
Integrated Airline Fleeting and Crew-Pairing Decisions	Sandhu, R.; Klabjan, D.	Operations Research	Vol. 55, No. 3, May-June 2007, pp. 439-456	airlines, integrated planning, Lagrangian relaxation, column generation, Bender's decomposition
Benders Decomposition for Hub Location Problems with Economies of Scale	Saraiva de Camargo, R.; de Miranda, Jr., G.; Pacca L. Luna, H.	Transportation Science	Vol. 43, No. 1, February 2009, pp. 86-97	Bender's decomposition, network design
The General Pickup and Delivery Problem	Savelsbergh, M.; Sol, M.	Transportation Science	Vol. 29, No. 1, February 1995, pp. 17-29	literature review, overview of pickup delivery problems
Intramarket Optimization for Express Package Carriers	Schenk, L.; Klabjan, D.	Transportation Science	Vol. 42, No. 4, November 2008, pp. 530-545	approximate dynamic programming, express package
Robust Airline Crew Pairing: Move-up Crews	Shebalov, S.; Klabjan, D.	Transportation Science	Vol. 40, No. 3, August 2006, pp. 300-312	robust, airline, operational, lagrangian relaxation, column generation
Scheduling Transportation of Live Animals to Avoid the Spread of Diseases	Sigurd, M.; Pisinger, M.; Sig, M.	Transportation Science	Vol. 38, No. 2, May 2004, pp. 197-209	Dantzig-Wolfe decomposition, VRP, column generation

Title	Authors	Journal	Issue	Topics and Keywords
Multi-resource routing with flexible tasks: an application in drayage operations	Smilowitz, K.	IIE Transactions	Vol. 38, 2006, pp. 555-568	drayage, routing choice, column generation, branch and bound
Continuum Approximation Techniques for the Design of Integrated Package Distribution Systems	Smilowitz, K.; Daganzo, C.	Networks	Vol. 50, No. 3, 2007, pp. 183-196	network design problem, approximation
Cost Modeling and Design Techniques for Integrated Package Distribution Systems	Smilowitz, K.R.; Daganzo, C.F.	Networks	Forthcoming	design, decomposition
Robust Airline Fleet Assignment: Imposing Station Purity Using Station Decomposition	Smith, B.; Johnson, E.	Transportation Science	Vol. 40, No. 4, November 2006, pp. 497-516	robust scheduling, airline, column generation
Yield Management at American Airlines	Smith, B.; Leimkuhler, J.; Darrow, R.	Interfaces	Vol. 22, January-February 1992, pp. 8-31	yield management, airlines, policy
Operations research at container terminals: a literature update	Stahlbock, R.; Voß, Stefan	OR Spektrum	Vol. 30, 2008, pp. 1–52	container terminal, logistics, planning, optimization
Revenue Management Without Forecasting or Optimization: An Adaptive Algorithm for Determining Airline Seat Protection Levels	van Ryzin, G.; McGill, J.	Management Science	Vol. 46, No. 6, June 2000 pp. 760–775	yield Management, revenue management, airlines; forecasting;, optimization, adaptive algorithms
Transshipment of containers at a container terminal: An overview	Vis, I.; Koster, R.	European Journal of Operational Research	Vol. 147, 2003, pp. 1–16	Logistics, container terminal, literature overview, material handling equipment
Service network design for freight transportation: a review	Wieberneit, N.	OR Spektrum	Vol 30, 2008, 77–112	service network design, freight transportation, integer programming

Title	Authors	Journal	Issue	Topics and Keywords
Designing Multimodal Freight Transport Networks: A Heuristic Approach and Applications	Yamada, T.; Russ, B.; Castro; Taniguchi, E.	Transportation Science	Vol. 43, No. 2, May 2009, pp. 129-143	multimodal, master and subproblem, network design
Territory Planning and Vehicle Dispatching with Driver Learning	Zhong, H.; Hall, R.; Dessouky, M.	Transportation Science	Vol. 41, No. 1, February 2007, pp. 74-89	vehicle routing, medium term planning, express package

Table 2. Survey of Articles on Transportation and Large-Scale Optimization.

4 Course Format

After synthesizing both the syllabi of transportation related courses and the literature about transportation and large-scale optimization, I determined that the course would be run in a seminar fashion. Although a few course periods were dedicated to discussing methodological topics such as column generation, Danzig-Wolfe decomposition, and Lagrangian relaxation, the majority of the time was spent reading and analyzing journal articles. Prior to designing the course in detail, I established the following learning objectives. Note that the audience of the course is PhD students; as a result, emphasis was placed on research skills and students' ability to read and analyze articles in the literature.

i. ***Students will learn about large-scale optimization modeling and solution techniques***. An important goal of this course is to teach students what is considered large-scale optimization, and why traditional optimization solution approaches must be adapted to handle these large-scale problems. In addition, students will learn about techniques such as composite variable modeling that have been developed to handle many of the complexities associated with transportation and logistics problems arising in practice. They will also learn about algorithms (e.g., delayed column generation, branch and price, etc.) and solution techniques (e.g., decomposition approaches, Lagrangian relaxation, etc.) to solve these problems. An important goal of the course will be not only to teach students what these algorithms and solution techniques are and how to use them, but also ***when*** and ***why*** different solution techniques are effective by understanding and exploiting a problem's underlying structure. These skills will serve the students well in their research and careers.

ii. ***Students will practice reading and analyzing technical journal articles, particularly those focused on transportation-related research***. As large-scale optimization and transportation-related operations research are vibrant areas of research, many algorithmic and computational advances are relatively recent. As a class, we will read and analyze many journal articles selected to highlight a variety of application domains as well as algorithmic and modeling techniques.

This will serve a number of purposes. First, it will serve as a vehicle to expose students to a breadth of topics. These articles will highlight many of the challenges of applying optimization algorithms to transportation and logistics systems, and motivate why specialized approaches are necessary to solve many of these problems. Second, it will help students to practice reading, understanding, and analyzing technical journal articles. This is an important student for graduate students to have to help them in their own research. In addition by gaining experience and confidence in reading such articles, students who take this course will be able to more easily teach themselves about advances in the large-scale optimization community after they graduate. This is a skill that is likely to serve them well throughout the remainder of their careers.

iii. ***This course will highlight many of the challenges of modeling and solving real-world optimization problems.*** Although many courses in academic curricula are quite successful in exposing students about a variety of topics and teaching them to solve small (sometimes almost trivial) examples, we often fail at teaching students about the subtle challenges that can make applying the course material in the real world. For example, where will the data we need come from? What assumptions will we need to make to enhance the tractability of this problem? Will these assumptions compromise the applicability of our solution to the real world? Through the use of journal articles, these topics will be highlighted and discussed with students.

iv. ***Students will be exposed to a broad set of transportation-related research- and career-opportunities.*** In developing this course, experts in the fields of trucking, airlines, and railroads will be consulted to ensure that an appropriate breadth of topics are being introduced to the students. In addition to covering the topics suggested by these experts in class via journal articles, a number of guest speakers will be invited in class to interact directly with the students. These experts will be asked to present not only technical content, but also to share with the students about various career opportunities in the field of transportation.

The majority of the class periods were devoted to reading and analyzing journal articles. For the first two-thirds of the course, I selected the articles we read to ensure breadth in both the methodologies and transportation topics covered. I also facilitated in class discussions on each of the articles. Although we did briefly discuss the content of each article (e.g. "What did the authors do, how did they do it, and what were the results?"), the majority of the class period was spent critically analyzing these articles – How does this article make a contribution to the existing body of literature? Why did they select the modeling and solution approaches they did? What limitations does this approach have?

To help facilitate the discussion, students were required to complete "reading summaries" to ensure that they had read and critically analyzed each article. It also helped the students to come prepared with questions that we discussed as we analyzed the articles. Each reading summary was to be 1-2 pages in length, and contain the following information.

- A very brief summary the article; this should be about one paragraph in length.
- An explicit statement about what you believe the article's contribution to the literature was.
- List 3-5 things you liked about the article.
- Suggestions for future work (preferred). If your suggestions do not differ from the those of the authors, please do not restate what the authors have explained. Instead, explain which of the avenues of future research you believe to be the most promising and why.

After the students had more experience in reading and analyzing journal articles, the students were responsible for selecting the articles that we read and discussed. This allowed students to tailor the material covered in the class to a small degree by selecting application and methodological areas that appealed to them. Each student took turns with this responsibility, and was responsible for facilitating the discussion on the article he/she selected. When students facilitated discussions, they were responsible for turning in 3-5 thought provoking questions that helped to lead the students in the discussion.

I asked that these discussion questions be higher-level questions that required synthesis of the course materials rather than simply reading-comprehension questions. For example, the question "What type of algorithm was developed to solve this problem?" is straightforward, and students should be able to answer this question simply by reading the article; this is not the type of questions that students were encouraged to prepare. A question such as "The authors used genetic algorithms to solve address this problem, but did not use tabu search. Given what we read in last week's article, do you think this is the best choice? Why or why not?" would require students to think about how the material in the paper covered related to other concepts in the course and their optimization background. Students were encouraged to ask these types of questions, and were provided with several examples of more vs. less desirable questions to help them. Additionally, students were provided feedback on the questions that they prepared for the course.

In addition to reading and analyzing the articles for class, students were required to complete two projects. The first was related to transportation-related careers for engineers and operations research professionals. Students were required to select an area of transportation that hired operations research professionals, and to consult trade publications, professional organizations, and government sources to research the industry of their choice. In addition students were required to identify the major players in the industry that they studied, and the major trends and challenges faced by that industry. Students were also required to consult past job postings, current job postings, trade publication articles, and information from the INFORMS website to identify currently-existing OR opportunities in this field. Students completed products on the third party logistics, rail, truckload, and intermodal transportation industries.

The second projects students were to complete was a research project that applied the materials they had learned to a problem of their choice. In particular, they were to prepare a miniature proposal that detailed a research topic that they would like to pursue. The proposal needed to clearly articulate the research problem they wanted to address, position it well in the existing literature, clearly articulate the contribution of the proposed research, and give a preliminary model. Additionally, students needed to present a carefully-crafted plan for the research including next steps, data sources, and a proposed and well-justified solution methodology. Students prepared both oral and written reports that were graded. Three of the four projects were very good, and I encouraged the students to continue working on these projects. The outcome of these projects will be discussed further in Section 5.

A final component of the course was the inclusion of industry speakers who were implementing operations research solutions at their respective places of employment. These speakers represented both the trucking and rail industries, and were helpful in supplementing the research-related material we covered in class through the project and journal articles with practical experience from their careers.

5 Course Feedback and Outcomes

This course was offered in the Fall 2009 to four PhD students in the department of industrial engineering under a special topics designator (INEG 514V – Transportation Models and Algorithms). Course evaluations indicate that the course was well-received. Students indicated that that their technical skills were improved as a result of the course (4.5), the lecture information was highly relevant to course objectives (5.0), and that the course challenged them to think (5.0). Additionally, Tershia Pinder-Grover – an instructional consultant from the University of Michigan's Center for Research on learning and teaching – and I analyzed students' reading summaries over the course of the semester. Analysis revealed that students' ability to synthesize information and identify future research directions improved significantly. We are hopeful that this means that they are better read and analyze journal articles as a result of this course, and that this will be helpful both in their graduate work and professional careers.

Recall that the main semester project for this course required students to propose a large-scale transportation optimization project that they would like to pursue. Half of the students in the course have pursued their research topics after the conclusion of the course. One student is in fact completing his doctoral studies on his proposed project to model and solve the truckload relay design problem using a composite variable modeling formulation. A second student has pursued her interest in drayage operations for intermodal transit, specifically those applications that arise in congested urban areas.

This has resulted in a submission of her research to to Transportation Science ("Routing and Scheduling of Cross-Town Drayage Operations").

Due to the positive reception of the course, it will continued to be offered every other year. Due to the seminar style of instruction, it will be imperative to continue to identify the latest research in the field for each offering of the course. This will require a careful balancing act to ensure that all topics – methodological and transportation modes – remain covered in sufficient depth. Speakers will remain an integral part of the course, as they offer a practical perspective about the materials students are learning. Additionally, the course project will likely be modified to require students not only to propose a draft of a research topic but also to begin to implement their models and projects. It is hoped that this will encourage students to pursue their large-scale optimization-related research interests after the conclusion of the course.