CEE 471-1: Transportation Network Analysis
Winter 2024

Course:

Lecture:	Monday/Wednesday 8:00 - 9:50 am
Classroom:	M120, Technological Institute
Instructor:	Marco Nie
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Office Hours:	Monday/Wednesday 1:00–1:50 pm, and by appointment

Description: This course introduces students to network analysis tools that form an important branch of transportation science. The course covers fundamental concepts and principles that guide urban travel forecasting and transportation system management/operations, with a focus on underlying optimization models and solution techniques. All problems concerned in this course are "static", meaning that travel occurring during the analysis period is considered to be in the form of constant or static flows. "Dynamic" counterparts of these problems will be introduced in the sequel of this course.
The course is designed to help students achieve the following learning objectives:

- understanding the concept of *equilibrium* and its role in transportation systems analysis;
- becoming familiar with formulations, analytical properties and solution algorithms of classical network models that arise from transportation applications;
- being able to formulate, analyze and solve real-world transportation problems using the network analysis tools learned in this course; and
- developing basic computer programming skills that serve a foundation for students who wish to pursue more advanced courses and/or conduct independent research in related fields.

Prerequisites: Basic knowledge on mathematical programming is preferred, although the subject will be reviewed. Students should also know how to write basic computer programs in MATLAB or any equivalent or lower level languages (such as Java, C++, FORTRAN, C etc.)

Recommended Text:
Yosef Sheffi (1985) Urban Transportation Networks: Equilibrium Analysis with Mathematical Programming Methods. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. Available on-line at http://web.mit.edu/sheffi/www/urbanTransportation.html.

Other References Texts:
David Boyce (2006) Urban Travel Forecasting, Class Notes (available on Canvas).
Michael Patricksson (1994) The Traffic Assignment Problem: Models and Methods. Utrecht, The Netherlands (available on Canvas).

Course requirements:

- *Three homework assignments*, of which two involve substantial computer programming work.
- *One take-home mid-term exam*.
- *Term paper, final presentation and peer review*. Each student will be required to write a term paper that reviews a topic related to transportation network analysis. Several sample topics will be provided. However, students are encouraged to define their own topics with the help of the instructor. Students will make a final presentation based on the term paper. They will also be asked to read three to five term papers (depending on the class size) and provide a written review report for each paper. 40% of the project grade will come from these peer review reports. These peer review reports are themselves part of the assignments, and will be graded by the instructor. The term paper can be completed individually or in groups of two students.

Grading: The final grade will be assigned on the following basis:

Homework	45%
Mid term exam	25%
Term paper	20%
Presentation	5%
Peer review report	5%

Late submissions: Students are expected to submit their homework and project reports in time. For late submissions, 5% credits will be deducted for every 24 hour delay - the maximum deduction is 15% per homework.

Working Together: Working together on homework is accepted. However, students are expected to write up their own versions of solutions. Depending on the class size, students may be asked to form teams to do the course project. A team may not have more than two members. Working together on exams, of course, is forbidden.

Subject area and learning objectives

Introduction: transportation systems analysis; sequential travel forecasting procedure; brief history of travel forecasting

- Objectives: This portion of the class provides general background information, basic assumptions and concepts on transportation systems analysis in general, and urban travel forecasting in particular.
- Reference: Chapter 1 (Sheffi's book) and supplementary materials.

Basics of equilibrium analysis: Demand-performance equilibrium, Wardrop's first and second principles; graphic solution of user equilibrium (UE) and system optimum (SO); Braess's paradox

- Objectives: This lecture aims to (1) give students a basic understanding of route choice equilibria and their behavioral and economical implications, and (2) prepare students for understanding general formulations of equilibrium problems by analyzing the intuitive, graphical solution.
- Reference: Chapter 1 (Sheffi's book) and supplementary materials

Preliminaries of optimization: basics of linear programming (standard primal and dual formulations, simplex method); shortest path problem; KKT conditions for nonlinear programs with linear constraints; basics of nonlinear complementarity problem (NCP) and variational inequality (VI) problem

- Objectives: This lecture reviews basic optimization theory that provides the foundation for understanding network models. The focus is on the KKT conditions and the relationship between mathematical programs, NCP, and VI problems. After this lecture, students should be able to implement a reasonably efficient shortest path algorithm.
- Reference: Chapter 2 and 4 (Sheffi's book), and supplementary materials.

Basic formulation of the traffic assignment problem (TAP) and solution algorithms: link-path TAP formulation; equivalence between KKT and UE conditions; properties of the TAP formulation; Beckmann's formulation; basic structure of iterative algorithms; Frank-Wolfe algorithm

- Objectives: As a core of the entire course, this lecture introduces basic TAP formulations and solution techniques. The main objective is to facilitate the understanding of the equivalence between the KKT conditions of the formulation and the UE conditions, and to reveal how the special network structure can be utilized to design efficient solution procedures. After this lecture, students should be able to write a reasonably efficient Frank-Wolfe code to solve the basic TAP model.

- Reference: Chapter 5 (Sheffi's book)

Extensions of the basic TAP model TAP with side constraints; TAP with symmetric and asymmetric link interactions; elastic demand TAP; multiple-class TAP

- Objectives: Through this lecture students are expected to learn several important TAP extensions. These more complicated TAP models help students see the patterns and principles through which a basic model can be extended to become more "realistic" and to address special needs.

- Reference: Chapter 6 and 7 (Sheffi's book) and supplementary materials.

Stochastic traffic assignment: Concept of stochastic user equilibrium (SUE); basics of random utility theory; logit and probit models for route choice; stochastic network loading; SUE formulations and solution algorithms

- Objectives: This lecture introduces a class of stochastic traffic assignment models in which users' perception errors are explicitly considered using random utility theory. The lecture aims to help students appreciate the importance of the uncertainty issue in the real-world problems and learn how a compromised yet useful solution can be achieved.

- Reference: Chapter 11-13 (Sheffi's book)

Combined models: combined mode choice/traffic assignment models; combined trip distribution/traffic assignment models; a grand model that integrate model choice, trip distribution and traffic assignment

- Objectives: This lecture introduces various models that integrates traffic assignment with mode choice and/or trip distributions, which aims to resolve the inconsistency inherent in the conventional four-step models. Through the analysis of these larger and more complicated models, students are expected to improve the skills of building equivalent mathematical programs from equilibrium conditions.

- Reference: Chapter 8-10 (Sheffi's book)

Table 1: Tentative course schedule

Date	Week	Topic	Assignment	Due
1-Jan	1-1			
3-Jan	1-2	Introduction	Term paper	
8-Jan	2-1	TRB week (makeup tbd)	HW1	
10-Jan	2-2	TRB week (makeup tbd)		
15-Jan	3-1	MLK day		
17-Jan	3-2	Route choice		
22-Jan	4-1	Route choice (Zoom)	HW-2	HW-1, Project topic
24-Jan	4-2	Optimization primer (Zoom)		
29-Jan	5-1	Optimization primer		
31-Jan	5-2	Basic formulation		
5-Feb	6-1	Basic formulation	HW-3	HW-2
7-Feb	6-2	Alternative formulation		Term paper abstract
12-Feb	7-1	Alternative formulation		
14-Feb	7-2	Model extension	Mid-term (take home)	
19-Feb	8-1	Model extension		
21-Feb	8-2	Model extension		
26-Feb	9-1	Stochastic UE		HW-3
28-Feb	9-2	Stochastic UE	HW-4	
4-Mar	10-1	Stochastic UE		
6-Mar	10-2	Combined model	Peer review report	Term paper
		Combined model		
13-Mar		Final presentation (tentative)		HW-4, peer review reports