IEOR 8100: Topics in IEOR: Stochastic Models in Service Engineering

Instructors: This course is co-taught by Professor Ward Whitt and Dr. Galit Yom-Tov

Contact Information:

Prof. Whitt: 801D Schapiro (CEPSR), ww2040@columbia.edu, and 212-854-7255

Dr. Yom-Tov: 318 S. Mudd Building, gy2185@columbia.edu, and 212-854-2987

Time and Place: The course will be given in the spring semester 2012, meeting on Wednesdays at 1:30pm for about two hours in Room 317 Mudd.

Course Description:

This course will focus on **stochastic models of service systems**. One goal is to help students learn about that application context. A second goal is to focus on a class of mathematical models and analysis techniques that have proven useful in that application context. As is almost always the case in operations research, these models and analysis techniques have many other applications, so that the course can be useful even if you are primarily interested in other applications.

This course provides an introduction to the theory behind **Service Engineering**, as applied mainly in healthcare (hospitals) and tele-services (e.g., call centers). Many topics are relevant and interesting for both applications, e.g., *staffing* of nurses in hospital and call center agents in call centers. Of special interests are topics that involve multi-disciplinary aspects such as queueing theory, statistics, game theory and psychology. There will be a focus on service system data. Students will be encouraged to become familiar with the data resources, such as available at the SEE-Laboratory at the Technion.

From the **mathematical perspective**, the course focuses on **multi-server queues**, and networks of such multi-server queues. Important customer behavior includes **balking** (deciding upon arrival not to wait), reneging or **abandoning** (leaving after waiting a while), **retrying** (coming back later after balking or reneging) and **returning** (coming back for additional service). There may be multiple types of customers and customer service representatives (agents) with different sets of skills. Automatic call distributors provide the capability of **skill-based routing**, but there remains an opportunity to improve the routing.

Consistent with the instructors' recent research, the course we will pay special attention to many-server queues. One main topic is staffing to cope with **time-varying arrival rates**. A second main topic is **many-server heavy-traffic limits**, in which both the arrival rate and the number of servers approach infinity. Three different limiting regimes emerge, depending on the way these variables approach infinity: (i) the quality-driven (**QD**) regime, (ii) the efficiency-driven (**ED**) regime and (iii) the quality-and-efficiency-driven (**QED**) regime. These limits yield useful approximations.

Target Audience:

This course is intended for **doctoral students** in IEOR and related fields. Since the course has a significant focus on stochastic models, students are expected to have completed an introductory course on stochastic models at the level of the first-year doctoral course IEOR 6711, Stochastic Models I. Yet, it is possible for students without this prerequisite to take the course after consulting with the instructors.

Student Requirements:

This course is a **research course**, giving students the opportunity to conduct independent research. That goal makes it possible for students to participate with a variety of backgrounds. The main task is a **course project**, which can be conducted individually or in small groups. The course project will culminate in both a written report and an oral presentation. The instructors will suggest possible projects, but students choose their own project within the broad domain of the course.

The students will also be asked to give one or more **lectures** about papers that students will choose or be assigned.

There will be **no exams**.

Course structure:

The course will have 3 parts: In the first part, the instructors will give lectures. In the second part, student will present various research papers. In the third part, at the end of the course, students will give project presentations. There may be visting lectures as well.

The lectures at the beginning will provide **an introduction to service engineering,** emphasizing **how data elevate research in that area, mathematical models, and mathematical analysis of those models**. To benefit from those lectures, some background is needed in the theory of probability and stochastic processes, but interesting research can be done without much background.

Students are encouraged to participate in our companion course IEOR 4615, where students will be working with call center data from Avishai's data archive iat the Technion.

Other topics include: time-dependent arrival rates, offered-load (infinite-server) models, overflow processes, skill-based routing, staffing, resource pooling, real-time congestion prediction, demand forecasting and simulation.

Background Reading: (No required textbook)

Textbooks on Services:

- R. W. Hall, *Queueing Methods for Service and Manufacturing*, Prentice Hall, 1991.
- Hall, Randolph W. (Ed.), *Patient Flow: Reducing Delay in Healthcare Delivery*, Series: International Series in Operations Research & Management Science, Vol. 91, 91 pages, Springer 2006.
- Fitzsimmons, J.A. and M.J., "Service Management: Operations, Strategy, and Information Technology", McGraw Hill, 4th Edition, 2004 (or previous editions, which are also OK).
- Lovelock. C.G., "Managing Services: Marketing, Operations and Human Resources", Prentice-Hall, 1992.),
- Brad Cleveland and Julia Mayben, *Call Center Management On Fast Forward, Succeeding in Today's Dynamic Inbound Environment*, Published in 1997 by Call Center Press, A division of ICMI, Inc., P.O. Box 6177, Annapolis, Maryland 21401, 281 pages, ISBN 0-9659093-0-1

Overview Papers:

- N. Gans, G. Koole and A. Mandelbaum, "Telephone call centers: tutorial, review and research prospects," Manufacturing and Service Operations Management, vol. 5, 2003, 79-141. PDF
- W. Whitt, "Stochastic models for the design and management of customer contact centers: some research directions," March 2002. Postscipt PDF
- Z. Arkin, M. Armony and V. Mehrotra, "The modern call center: a multidisciplinary perspective on operations management," *Production and Operations Management*, vol. 16, 2007, 665-688.

Background Introductory Queueing Textbooks

- R. B. Cooper, *Introduction to Queueing Theory*, second edition, North Holland, 1981. On reserve. Out of print, but available in .pdf format (about 13mb zipped) from Michael Taaffe at VPI, with approval from the author.
- S. Asmussen, *Applied Probability and Queues*, Second Edition, Springer, 2003. (introductory, but at a high mathematical level; concise, but difficult for beginners)
- L. Kleinrock, *Queueing Systems*, vols. I and II, Wiley, New York, 1975-6. (introductory with computer science and networking perspective)
- R. Wolff, *Stochastic Modeling and the Theory of Queues*, Prentice-Hall, Englewood Cliffs, NJ, 1989. (truly introductory)

Background on Stochastic-Process Limits

W. Whitt, *Stochastic-Process Limits*, Springer, 2002.

- G. Pang, R. Talreja and W. Whitt, "Martingale Proofs of Many-Server Heavy-Traffic Limits for Markovian Queues." *Probability Surveys*, vol. 4, 2007, 193-267. [PDF].

Initial Lecture Topics:

1. Introduction to service engineering
2. The Importance of Queueing Models
3. Fitting Queueing Models To Data
4. Predicting Queueing Delays
5. Time-varying arrivals: stabilizing performance over time. Offered load and Erlang-R.
6. Priority queues, Skill-based routing, Fairness.

Possible Project Topics:

For the research topics, there are many options. Please discuss your ideas with one of the instructors. The research may be original research, reading some research papers or part of a book and reporting on that, or some combination of those.

The research topic could be theoretical or practical.

Here are some suggested topics, with one or two candidate references. These are only intended to be illustrative. There are many other good topics.

Possible Papers for Students Lectures:

Queueing in healthcare

1. Providing Timely Access to Medical Care: A Queueing Model, by Linda Green and Sergei Savin, Columbia University. Under review for *Operations Research.* ???
2. O.B. Jennings and F. de Vericourt. Nurse-to-patient ratios in hospital staffing: a queueing perspective. Working Paper, Duke University, 2007
3. Services Research in Hospitals, or the multi-disciplinary science of patients care, The OCR Project (IBM, Rambom, Technion), invited for *The Journal of Service Research*, June 2009. by Avi Mandelbaum and others.
4. Modeling the Emergency Cardiac In-Patient Flow: An Application of Queueing Theory, by Arnoud de Bruin, Ger Koole, Bert van Rossum, and Marieke Visser. *Health Care Management Science* 10 (2007) 125-137.
5. Time-Dependent Analysis for Refused Admissions in Clinical Wards. by R. Bekker and A.M. de Bruin. *Annals of Operations Research*, June 2009.
6. Dimensioning Hospital Wards Using the Erlang Loss Model. by A.M. de Bruin, R. Bekker, G. Koole and L. van Zanten. *Annals of Operations Research,*, forthcoming.

Empirical/Statistical studies in queueing

1. Statistical Analysis of a Telephone Call Center: A Queueing-Science Perspective, by Larry Brown, Noah Gans, Avishai Mandelbaum, A. Sakov, Sergei Zeltyn, Linda Zhao and Haipeng Shen. *Journal of the American Statistical Association,* 100 (2005) 36-50.
2. Forecasting Time Series of Inhomogeneous Poisson Processes with Applications to Call Center Workforce Management, by Haipeng Shen and Jianhua Z. Huang. *The Annals of Applied Statistics,* 2 (2008) 601-623.
3. Asymptotic Inference for Waiting Times and Patiences in Queues with Abandonment, by Anders Gorst-Rasmussen and Martin B. Hansen, *Communications in Statistics - Simulation and Computation,* 38 (2009) 318 - 334. article online
4. Forecast Errors in Service Systems, by S. Steckley, S. Henderson and V. Mehrotra, *Probability in the Engineering and Information Science,* 23 (2009) 305-332.
5. Patient Flow in Hospitals: A Data-Based Queueing-Science Perspective, By Mor Armony, Avishai Mandelbaum, Yariv Marmor, Yulia Tseytlin, and Galit Yom-Tov. Working paper, 2011.

Behavioral or psychological issues in queueing

6. Adaptive Behavior of Impatient Customers in Tele-Queues: Theory and Empirical Support. by E. Zohar, Avishai Mandelbaum and Nahum Shimkin. *Management Science,* 48 (2002) 566-583.
7. The Impact of Delay Announcements in Many-Server Queues with Abandonment., by Mor Armony, Nahum Shimkin and Ward Whitt. *Operations Research,* 57 (2009) 66-81.
8. Value-Based Routing and Preference-Based Routing in Customer Contact Centers, by Michael Sisselman and Ward Whitt. *Production and Operations Management,* 16 (2007) 277-291.
9. Perspectives on Queues: Combining Queues is Not Always Beneficial, by Michael Rothkopf and Paul Rech. *Operations Research,* 35 (1987) 906-909.
10. Service Times in Call Centers: Agent Heterogeneity and Learning with some Operational Consequences, By Noah Gans, Nan Liu, Avishai Mandelbaum, Haipeng Shen, Han Ye (2011).
11. pnina

Delay announcements queueing systems

1. Real-Time Delay Estimation Based on Delay History, by Rouba Ibrahim and Ward Whitt, *Manufacturing and Service Operations Management,* 11 (2009) 397-415.
2. The Impact of Delaying Delay Announcements, by Gad Alon and Achal Bassamboo, kellogg, Northwestern, 2008.

Queues with time-varying arrival rates.

3. What You Should Know About Queueing Models to Set Staffing Requirements in Service Systems. *Naval Research Logistics,* by Ward Whitt, 54 (2007) 476-484.
4. Coping with Time-Varying Demand when Setting Staffing Requirements for a Service System, by Linda V. Green, Peter Kolesar and Ward Whitt, *Production and Operations Management* (POMS), 16 (2007) 13-39.
5. Stabilizing Customer Abandonment in Many-Server Queues with Time-Varying Arrivals, by Yunan Liu and Ward Whitt, 2009. Submitted to *Operations Research*.

6. Erlang-R: A Time-Varying Queue with ReEntrant Customers, in Support of Healthcare Staffing, by Galit Yom-tov and Avishai Mandelbaum, 2011. Submitted to *M&SOM*.