



Massachusetts Institute of Technology
Sloan School of Management

15.879 Bringing Data into Dynamic Models Fall 2022

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I. GENERAL INFORMATION

Course Description and Objectives

In this course, we introduce the basic tools for bringing quantitative data into building and estimating System Dynamics models. We will discuss various tools related to model calibration/estimation spanning optimization methods, Maximum Likelihood, Method of Simulated Moments, Markov-Chain Monte-Carlo, Kalman filtering and state resetting, Hierarchical Bayesian methods, and the modeling and computational infrastructure needed for scaling these methods. Students will collaborate in applying these techniques to a handful of classical System Dynamics models, with the aim of developing research paper(s) jointly authored by active class participants. While having taken 15.873/2 would be valuable, this course does not have those as a required pre-requisite. That said, the course is hands-on, research focused, and most suitable for PhD students and others considering rigorous merging of SD models with data.

Grading is largely based on weekly homework assignments which also contribute to building the knowledge base for the joint publication(s) to be developed in the class.

Instructor

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Teaching Assistant

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Class Meeting Time and Place

Fridays: 9 am- 12 pm
Room E62-450 and Zoom (<https://mit.zoom.us/j/99282247283>):

Primary Textbooks

1. H. Rahmandad, Oliva, R., Osgood, N. 2015. *Analytical Methods for Dynamic Modelers*. MIT Press, Cambridge, MA. (Abbreviated as AMD)
2. Sterman, John D. (2000), *Business Dynamics: Systems Thinking and Modeling for a Complex World*, Irwin McGraw-Hill, ISBN: 0-07-231135-5. (Abbreviated as BD)

Other readings will be posted on Stellar.

Software

Vensim DSS (Decision Support System). Vensim DSS is Ventana's top-of-the-line version. Ventana generously allows the students taking this course to use the software *for academic purposes only* without charge. Use the link below for downloading the Vensim DSS:
<http://www.vensim.com/mit.html>

Hardware

Many class exercises will require the use of a computer, so please bring your own laptop, with Vensim DSS installed on it, to class. We will also require computational work for weekly assignments, some of which may be computationally intensive. We have access to some Sloan virtual machines for more intensive computational work, which we will utilize for the final analyses for our joint publications, and occasionally may benefit from those if personal computers are not sufficient for your weekly assignments. Please work with instructor and TA to utilize these resources.

Homework Assignments and Weekly Presentations

The topics we cover require hands on practice to master. The weekly homework assignments are the primary learning opportunity for students. These assignments are designed to utilize and practice various tools and methods we learn about, and to put them to work for addressing a set of concrete research questions which we plan to turn into publications. As such, completing them is central to the course. These assignments are not designed for the purpose of grading students, rather, as opportunities for learning-by-doing, learning from colleagues, and getting feedback. For the latter two purposes each student is expected to provide a brief (10-15 min) presentation of what they have done for the assigned homework for the week, what they have learned, and what questions they may have. We kick off the class with these presentation/discussions. They will go over similar questions but applied to different seminal models in the field, offering valuable comparative studies each week. Individuals should upload their presentations and any relevant file to class's shared dropbox folder, under the Assignments. Name your files as: <LastName>-S<session>.ppt, e.g. Rahmandad-S5. These files will be accessible to everybody in the class.

Based on what we learn from these exercises, we may then identify scientific contributions of broader interest to the System Dynamics community which underpin specific research papers we will work on.

Research Paper(s)

The topics we cover in this course are explored in depth in various communities focused on statistical and operations research methods, yet their applications to SD models remain sparse. Thus, we don't have clear guidance on questions such as "What optimization algorithms are best suited for calibration of SD models?"; "How much quantitative data is needed to reliably infer parameters of an SD model?"; "What features of the model determine the value of including state resetting and filtering methods in the calibration process?"; "What estimation methods provide reliable confidence/credible intervals for estimated parameters?" among others. These research gaps provide contribution opportunities for class participants. Specifically, by addressing these and similar questions in the context of a few well-known SD models in weekly assignments, the students will accumulate the knowledge base needed to systematically address these research questions. Based on the speed of progress, the novelty of emerging findings, and the team's bandwidth, the instructor will coordinate the development of one to three research papers jointly co-authored by class participants. While the primary work for the analysis going into these papers is happening during the weekly assignment work, developing and writing full research papers and shepherding them through the review process will extend beyond the duration of this course. Therefore, participants interested to be co-authors will need to remain engaged with the ongoing paper(s) beyond this semester.

Reading Assignments

We largely flip the classroom, so class work relies on the assumption that you have done the readings and we can build on that basic knowledge.

Class Exercises

Readings would prepare you to apply the various techniques in simple problems. We typically spend the class time beyond project presentations addressing your questions on different methods, discussing the readings, and working on a few exercises to apply those methods. Your active participation in these activities contributes to your classroom participation component of the grade.

II. OUTLINE OF TOPICS AND READINGS

Subject to change. Please check for latest version on canvas. References at the end of syllabus.

Date	Classes	Topic	Reading, Homework Due
9/9	1	Intro; Choosing Models, Measurement and Process Noise; Model parameters; Data types	Readings: BD Appendix A Industrial Dynamics, Appendix O AMD Introduction
9/16	2	Vensim Tips and Tricks: Subscripts, Data Connections; Sensitivity Analysis; Optimization Analysis workflow	Homework 1: Identifying data and parameter types, measurement and process noise. Readings: Industrial Dynamics Appendix K; BD Appendix B
9/23	3	Model Analysis Process; Equilibrium; Synthetic Data Experiments	Readings: Gelman et al 2020
9/30	4	Functional forms, Allocation, Coflow	Homework 2: Setting up <i>two</i> python-based methods for automated simulation workflows Readings: Rios-Ocampo and Gary 2022; Vensim Allocate by Priority help
10/7	5	Optimization and Calibration	Homework 3: Exploring the modes of behavior from the model; Creating Synthetic Data Readings: Amaran et al 2016
10/14	6	Likelihood-based error terms and Bayesian introduction	Homework 4: Calibrating to synthetic data, comparing optimization algorithms Readings: Vrugt 2016
10/21	7	MCMC; HMC	Homework 5: Maximum Likelihood Estimation Readings: Betancourt 2018
10/28		No class. SIP	
11/4	8	Hierarchical Bayesian	Homework 6: MCMC and comparison with HMC Readings: Gelman et al 1996; Huang et al 2005
11/11	9	Method of Simulated Moments and Indirect Inference	Homework 7: Hierarchical Bayesian Estimation Readings: Hosseinichimeh et al 2016;
11/18	10	State resetting and Kalman filtering	Homework 8: Indirect Inference Estimation Readings: Eberlein 2015 (AMD Ch. 4)
11/25		No class. Thanksgiving	
12/2	11	Building a SD workflow; Simulation-based Calibration	Homework 9: Estimation with extended Kalman filtering Readings: Talts et al 2020
12/9	12	Hands-on: Developing papers	Homework 10: Bringing it together. Paper outlines.

IV. COURSE GRADING

Grade Distribution

% of Final Grade

Class Participation and Classroom Exercises
Assignments and Presentations

25
75

V. OTHER IMPORTANT ISSUES

Academic standards

We expect the highest standards of academic honesty and behavior from all participants in class. Our course Stellar site contains a link to an important document describing the academic and personal values we uphold at MIT Sloan. The document, Classroom Values in Practice, presents standards for individual and group work as well as those for citing the work of others (proper referencing to avoid plagiarism) and for personal conduct in the classroom and as a member of our community. Be sure to read this document. If you have any questions about standards and expectations regarding individual and team assignments, please ask us after you have read the standards and before doing the assignments.

References

- Rahmandad, H., Oliva, R., & Osgood, N. (Eds.). (2015). *Analytical Methods for Dynamic Modelers*. Cambridge, MA: MIT Press.
- Sterman, J. (2000). *Business dynamics: systems thinking and modeling for a complex world* (1 ed.). Boston: McGraw-Hill/Irwin.
- Forrester, J. W. (1961). *Industrial Dynamics* (1 ed.). Cambridge: The M.I.T. Press.
- Gelman, A., Vehtari, A., Simpson, D., Margossian, C. C., Carpenter, B., Yao, Y., . . . Modrák, M. (2020). Bayesian workflow. *arXiv preprint arXiv:2011.01808*.