System Dynamics: Selected Doctoral Theses

"Essays on Dynamic Supply Chains and Service Delivery Systems"
Author: James Paine (2023)
Committee: Hazhir Rahmandad (chair), John Sterman, Rogelio Oliva (Mays Business School, Texas A&M University)
Abstract:
The field of Operations Management, and closely related fields of Operations Research and Industrial Engineering, focus intensely on addressing real-world problems associated with the design and management of product and service delivery systems in a human context. System Dynamics is a framework to understand, design for, and manage change emerging from both structural and behavioral features, and is uniquely suited to address policy questions in sociotechnical supply chain contexts. Using System Dynamics, Operations Management, and Supply Chain Research methods this work expands on existing toolsets and theory and provides policy insights in dynamic supply chain and service delivery systems.

Chapter 1 presents a methodological contribution to the System Dynamics and Supply Chain Research communities by developing a novel framework for supply chain models by combining three classic methods: co-flow differential equation structures, spot price discovery, and multinomial logistic choice modeling. Chapter 2 applies this framework to build a structural theory explaining the simultaneous surge in food insecurity alongside surges in food surplus and purposeful disposal at the beginning of the COVID-19 pandemic in the United States. Utilizing this structural theory, this chapter further illustrates policies that could help mitigate these stresses. Chapter 3 continues the concepts of managing a behaviorally driven multi-echelon supply subject to shocks. Utilizing a simulated environment, different policy features implied by parallel streams of Operations Management and Supply Chain literature are directly tested. These include policies that range from myopic, limited information decision rules to more modern, but data-intensive machine learning methods.

"Enhancing methods for modeling and estimation of complex socio-technical systems"
Author: Tianyi Li (2021)
Committee: John Sterman (co-chair), Hazhir Rahmandad (co-chair), Munther Dahleh (MIT IDSS), Rogelio Oliva (Texas A&M University)
Abstract:
Chapter 1: We study parameter estimation methods in the context of epidemic models. We compare standard least-squares estimation with a panel of alternative estimation schemes in which we test various likelihood functions as well as the use of Kalman filtering. We explore the performance of these methods under different assumptions about data availability and quality, including missing data on important variables and measurement error. While all methods perform comparably in terms of bias in estimated parameters, they vary significantly in the quality of the confidence intervals they yield. Naive least-squares estimation performs poorly, while a negative binomial likelihood or the application of Kalman filtering yields more reliable results. The results should apply not only to epidemics, but to models of social contagion, innovation adoption and diffusion, and potentially other domains.

Chapter 2: When sufficient data for model specification and estimation are unavailable, how should modelers optimally determine which data should be acquired? Specifically, for a given model and set of variables to collect data on, which next k model variables provide the greatest utility for model calibration? We connect this problem with the sensor placement problem in engineering systems, which leads to a combinatorial optimization. We first translate two established solution approaches from engineering systems to social science simulation models. Then, based on the idea of Data Availability Partition and drawing on insights from existing solutions, we propose a new objective function for the optimization. Analytical results for the optimal placement solution under the new objective function are derived for binary and multi-ary trees. For a general tree structure with n nodes, the optimal placement algorithm is devised, with complexity growing at an

upper bound of O(nlog2(n)). For arbitrary model structures with feedback loops, approximate solution schemes are developed. Comparison against existing approaches shows notable advantages of the newly proposed method. These findings provide modelers across domains with an objective method and a useful toolkit to prioritize data acquisition.

Chapter 3: Because SD strive to create realistic, operationally grounded, endogenous explanations of broad-boundary issues, its efforts often result in large complex models that are difficult to understand and leverage at the aggregate level. Recent efforts have formalized the analysis the structural determinants of the system's transient behavior. In this study, we complement these efforts by focusing on the model elements that are ultimately responsible for managing the endpoint levels of the state variables, i.e., control inputs. We borrow from structural control theory and develop a set of algorithms to formally identify the control inputs in a model and assess their capacity to control the system states variables. This post-modeling workflow is summarized as the structural control analysis (SCA) of SD models. The results of these algorithms provide insights into the system controllability and policy design. We illustrate these benefits through several examples and outline potential areas of future research.

"Prevention & Reduction of Opioid Misuse with Systems Exploration: Modelling complex, uncertain problems for policy development"

Author: Tse Yang Lim (2021)

Committee: John Sterman (co-chair), Hazhir Rahmandad (co-chair), Jonathan P. Caulkins (Carnegie Mellon)

Abstract:

The opioid crisis is one of the worst public health crises in America. Annual overdose deaths have been climbing rapidly, to over 50,000 people a year. The crisis is a complex and dynamic problem, with long delays and multiple feedbacks, in which any policy actions risk triggering unexpected resistance or causing unintended consequences. In light of these challenges, the National Academies of Sciences, Engineering, and Medicine called for a quantitative systems model to guide Federal government policy to address the crisis.

Here I present a quantitative simulation model of the opioid crisis developed in conjunction with the US Food and Drug Administration to support policy analysis and decision-making. The model is built on extensive literature review and expert consultation, and calibrated to the US population using 20 years of national-level data. It encompasses misuse of prescription and illicit opioids, opioid use disorder, treatment and remission, and tracks a range of outcomes, most notably overdose mortality.

Our baseline model estimates highlight the role of various drivers of the crisis, including the impact of supply-side changes, behavioural risk responses, and the competing influences of illicit fentanyl and overdose prevention efforts. These estimates yield the most thorough quantitative understanding of the historical trajectory of the crisis available to date, and provide a solid foundation for identifying and analysing policy solutions. In addition, this work serves as an example of simulation modelling in two ways – first, as an empirically-grounded model of a complex and highly uncertain problem, and second, as a model and modelling process developed and deployed explicitly in support of policy decision-making.

"Essays on the counter-intuitive consequences of labor policies in service industries"

Author: Mahdi Hashemian (2020)
Committee: Hazhir Rahmandad (chair), John Sterman, Zeynep Ton
Abstract:
In essays one and two, I examine how unstable schedules affect financial performance. In essay one, using 52 weeks of data from over 1,000 stores and more than 15,000 employees of a specialty retailer, I estimate the effect of unstable schedules on store productivity. I use an instrumental variable approach and a natural experiment to partially address the possible endogeneity of scheduling decisions. I find evidence that increasing the adequacy and consistency of employees' hours improves employee and store productivity and find partial support for the positive effect of predictability. To study the policy impact of these findings, I build a behavioral agent-based model of scheduling in essay two. My model provides a platform to conduct counterfactual analyses and thus increases the external validity of my findings.

Results suggest that standard scheduling practices, under certain conditions, may have negative, direct labor cost consequences despite their intended rationale for aligning service capacity and demand. Findings highlight the unintended consequences of a narrow focus on matching labor supply to customer demand; designing more employee-friendly schedules could not only create better jobs but also improve firm performance. In essay three, I build a simulation model to explain why Startups play a major role in establishing many new markets when existing firms have more resources and the relevant core and peripheral capabilities. I explore how the strong link between startups' past performance and the resources available for their future capability building conditions their growth prospects. I show that this reinforcing loop leads to entrepreneurial financial markets rapidly focusing on more promising startups.

The strength of this mechanism can allow startups to over-take projects within incumbent firms that are initially better endowed. Using an online experiment, I test the key requirement for our mechanism, showing that the strength of the reinforcing loop is larger for start-ups than in-house projects.