Lahore University of Management Sciences

SCI 205 / ENV 244 – Modeling the Environment

Spring 2023-24

Instructor
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Course Details:
The course will be taught in the form of in-person lectures.

Course Basics				
Credit Hours	3			
Lecture(s)	Nbr of Lec(s) Per Week	2	Duration	75 min
Recitation/Lab (per week)	Nbr of Lec(s) Per Week		Duration	
Tutorial (per week)	Nbr of Lec(s) Per Week		Duration	

Course Description
This course aims to expose students to the modeling process for environmental systems. The content has been divided strategically into two halves. The first half establishes the notion of the environment as a system with interacting natural, social, economic, and technological components. We will cover the theoretical principles required to study the structure of complex systems, explain counter-intuitive phenomena, and to predict the response to human intervention and policy. The second half of the course will be spent building models of environmental systems from a variety of different domains such as water, agriculture, disaster management, and food systems. We will use the System Dynamics approach to modeling and will construct models using the Vensim PLE software. Over the course, we will also hear from guest lecturers on alternative approaches for modeling environmental systems. Students will be required to demonstrate their learning through a semester project in which they will be required to model and simulate a real-world environmental system.

Course Learning Outcomes
By the end of the course, the students should be able to:
- Understand the environment as a complex system, with the ability to identify system components, interconnections, and functions.
- Identify processes inherent to the structure of coupled human-natural systems that cause resistance to human interventions and policy.
- Use the System Dynamics (SD) framework to simulate system behavior, make projections, and test hypotheses.

Pre-requisite Knowledge
Successful completion of Calculus-I (MATH-101) is a mandatory requirement. No prior knowledge of programming is assumed.

Software

The course will introduce the process of constructing and using models of coupled human-natural systems using the System Dynamics approach. The concepts will be taught using theVensim PLE software which can be downloaded freely. A significant portion of the lectures will consist of building models of environmental systems interactively in class using the Vensim platform. Much of the assignments and course project will also require use of Vensim.

Textbooks

- **Ford 2010:** "Modeling the Environment", 2nd edition, by Andrew Ford. Island press 2010.
- **Sterman 2010:** "Business Dynamics: Systems thinking and modeling for a complex world", by John D. Sterman, McGraw Hill, 2010.
- **Meadows 2008:** "Thinking in Systems: A primer" by Donella Meadows, Chelsea green publishing, 2008.

Course Evaluation

- Class attendance and Participation 10%
- Quizzes 10%
- Assignments 20%
- Group Projects 20%
- Midterm Exam 20%
- Final Exam 20%

Course Project

The course project will take place in groups of two, with both students being awarded a common grade. The groups will select a system of their own choosing with a clearly defined research problem. They will be required to construct a model of the system and use it to address the problem. The components for the project are as follows.

Component	Weight	Description
Abstract and Causal Model	5%	300-500 words (plus references). A clear introduction to the topic, sufficient background material (with citation) to lead to and articulate the question that the paper will address, a clear research question, and a causal model representation of your system with the necessary focal processes to address your question.
Project Video and Presentation	7%	The students will present their projects in pre-recorded videos of 5 minutes duration. During the presentations, the videos will be played in class, followed by an in-person Q&A. The videos should clearly introduce the topic and lead to the research question, present sufficient detail of your model to allow audience to interpret your analysis, present key results and analysis, and discuss findings and limiting assumptions in your approach.
Final Paper	8%	3000-5000 words, inclusive of bibliography with at least 20 sources, and in-text citations. A completed final paper that introduces a clear research question, develops an appropriate model to inform it, and contributes some kind of analysis to addressing it.

Tentative Lecture Plan

Week	Topics	Sources
Week 1	**What are Systems and why are Environmental systems so Complex?** We will discuss what a system is and why are environmental systems so complex. We will go over examples of policy resistance and failure of human interventions in coupled human-natural systems. **Session 1:** The definition of a system; Human-natural systems; What is systems analysis? What is sustainability? An overview of the course. **Session 2:** Policy resistance and Unintended consequences in complex systems; Analysis and synthesis; Feedback; Revisiting complex systems (Jevon's paradox, Levee effect, American wildfires); Limits to growth and the Tragedy of the Commons.	**Session 1:** "Introduction: The Systems Lens" *in* "Thinking in Systems: A primer" by Donella Meadows, 2008. "The Basics" *in* "Thinking in Systems: A primer" by Donella Meadows, 2008. **Session 2:** "Learning in and About Complex Systems" *in* "Business Dynamics: Systems thinking and modeling for a complex world", by John D. Sterman, 2010.
Week 2	**Why do Human Interventions and Policies Fail?** We will gain familiarity with Causal Loop Diagrams (CLD's) to articulate the structure of a system. We will build CLD's of simple systems, starting with models of population growth. We will observe the structure of the system to infer causes of policy resistance and ask questions such as: why building wider roads does not successfully reduce traffic congestion in the long-term. **Session 1:** Causal loop diagrams; Motivating examples; Practical issues and pitfalls in constructing CLD's; The response of gasoline demand and expenditures to price. **Session 2:** Analyzing causal loop diagrams; Using reference modes to describe expected system behavior; A model of workload management; Using CLD's to understand the traffic congestion problem.	**Session 1:** "Causal Loop Diagrams" *in* "Business Dynamics: Systems thinking and modeling for a complex world", by John D. Sterman, 2010. **Session 2:** "Conceptualization Case Study: Managing Your Workload" *in* "Business Dynamics: Systems thinking and modeling for a complex world", by John D. Sterman, 2010. "Explaining Policy Resistance: The Traffic Congestion Problem" *in* "Business Dynamics: Systems thinking and modeling for a complex world", by John D. Sterman, 2010.

Week 3	**Modeling stocks and flows: How do populations grow?** We will start learning about system dynamics and learn the concept of stocks and flows to predict system behavior. We will build simulations of illustrative systems such as a growing population. The lectures will demonstrate first-order behavior such as exponential growth, exponential decay, goal-seeking behavior. **Session1:** Introduction to stocks and flows; Dynamics of simple structures; Exponential growth; Wisdom story: The king, the con artist, the chessboard, and rice. **Session 2:** Exponential decay; Goal seeking behavior; Time constants and half-lives;	**Session 1:** "Stocks and Flows" *in* "Business Dynamics: Systems thinking and modeling for a complex world", by John D. Sterman, 2010. **Session 2:** "A Brief Visit to the Systems Zoo" *in* "Thinking in Systems: A primer" by Donella Meadows, 2008.
Week 4	**Introduction to Vensim: How can we replicate system behavior?** We will introduce the Vensim software and interactively build models in class. From here on in the course, much of the lecture sessions will consist of creating models and simulations in Vensim. We will construct simple simulations of models already discussed in class. We will simulate a popular imaginary environment called Daisyworld to illustrate the relationship between biota and the global environment. **Session 1:** Introduction to Vensim; Installation and interface; building simple stock and flow diagrams; initializing simulations and analyzing results. **Session 2:** Imagining Daisyworld; The Gaia hypothesis; Daisyworld as a feedback system.	**Session 1:** "Modeling Guide: Concepts and Examples" in the Vensim online documentation https://vensim.com/documentation/index.html "Stocks and Flows" *in* "Business Dynamics: Systems thinking and modeling for a complex world", by John D. Sterman, 2010. **Session 2:** "Temperature control on Daisyworld" *in* "Modeling the Environment", 2nd edition, by Andrew Ford. Island press 2010.
Week 5	**Second-order behavior: What constrains growth in the real world?** We will start looking at systems with multiple stocks and study examples of second order behavior such as overshoot and oscillations. We will construct models of epidemics and fish harvesting.	**Session 1:** "The Salmon of the Pacific Northwest" *in* "Modeling the Environment", 2nd edition, by Andrew Ford. Island press 2010. **Session 2:**

	Session 1: Density-dependent (or S-shaped) growth; Understanding environmental carrying capacity; A model of fish harvesting; Simulating the effect of different harvesting policies. **Session 2:** Systems with multiple stocks; Constructing a model of epidemic spread.	"S-shaped growth: Epidemics, Innovation diffusion, and the growth of new products" *in* "Business Dynamics: Systems thinking and modeling for a complex world", by John D. Sterman, McGraw Hill, 2010.
Week 6	**Modeling Agricultural Land and Soil Systems** We will study interactions between natural and human elements in agricultural systems and discuss some technological interventions in the agriculture sector. We will model the physical process of how water is transported in the soil and use the understanding to construct a model of insecticide spread through different mediums such as the soil, atmosphere, and the oceans. **Session 1 (outdoor activity):** Visit to the LUMS agriculture field; Demonstration of soil moisture monitoring systems; Evapotranspiration and root uptake; Modeling water transport processes in the soil. **Session 2:** Silent Spring and the birth of the modern environmental movement; Modeling DDT flows in the environment; DDT accumulation with several flows; Understanding the sluggish response of DDT to changes in application. **Abstracts and causal model of course projects due**	**Session 1:** Turner, B.L., Menendez III, H.M., Gates, R., Tedeschi, L.O. and Atzori, A.S., 2016. System dynamics modeling for agricultural and natural resource management issues: Review of some past cases and forecasting future roles. *Resources*, *5*(4), p.40. **Session 2:** "DDT in the ocean" *in* "Modeling the Environment", 2nd edition, by Andrew Ford. Island press 2010.
Week 7	**Delays in Systems and the Emergence of Cycling Behavior** Delays occur in systems either due to a lag in material transport (e.g., the spread of a contaminant in an ocean over several time periods), or due to a lag in information spread (e.g., the growing awareness to the availability of a new product in the market). We will discuss how delays are modeled in the system and how they can result in oscillatory behaviors and boom-bust cycles.	**Session 1:** "Cycles in Predator and Prey Populations" *in* "Modeling the Environment", 2nd edition, by Andrew Ford. Island press 2010. **Session 2:** As communicated by the guest lecturer.

	Session 1: Introduction to predator-prey systems; the Lotka Volterra model of predator-prey interactions; cycles in predator-prey populations. **Session 2 (Guest Lecture):** Using mathematical models to study the dynamic behavior of environmental systems.	
Week 8	**Mid-term** **Session 1:** Mid-term course review and introduction to course projects. **Session 2:** Mid-term exam.	
Week 9	**Water and Life: Understanding Human-Water interactions.** We will discuss the complexity of interactions in human-water systems starting with experiences of over 4 years of investigations in the Namal valley. Next, we will simulate the water balance in an agricultural system with provision of irrigation withdrawals. The effects of different withdrawal patterns will be considered. **Session 1:** The history of the Namal dam; water scarcity and floods in the valley; the presence of multiple stakeholders and their competing interests; mapping the human-water interactions into a CLD. **Session 2:** Modelling the physical water balance in an agricultural field; relating water movement with physical properties of the soil; approximating crop evapotranspiration; predicting the response to different irrigation management scenarios.	**Session 1:** Field experiences from investigations in the Namal dam reservoir, Mianwali. **Session 2:** Khan, S., Yufeng, L. and Ahmad, A., 2009. Analysing complex behaviour of hydrological systems through a system dynamics approach. *Environmental Modelling & Software*, *24*(12), pp.1363-1372.
Week 10	**How can models help build capacity for disaster management?** **Session 1 (Guest Lecture):** Using game theory to model environmental problems.	**Session 1:** As communicated by the guest lecturer. **Session 2:** Ahmad, S. and Simonovic, S.P., 2000. System dynamics modeling of reservoir operations for flood

	Session 2: Understanding human-flood interactions; understanding the Levee effect in flood-plain settlements; modeling reservoir operations; developing an operational policy for high inflow years to minimize flooding.	management. *Journal of computing in civil engineering*, *14*(3), pp.190-198. Di Baldassarre, G., Viglione, A., Carr, G., Kuil, L., Salinas, J.L. and Blöschl, G., 2013. Socio-hydrology: conceptualising human-flood interactions. *Hydrology and Earth System Sciences*, *17*(8), pp.3295-3303.
Week 11	**Eco-food-agri Systems and the Collapse of a Civilization** We will construct models for two different applications. The first application will be the use of system dynamics to understand Eco-food Agri systems which is an umbrella term for the vast and interacting complex of agricultural lands, pastures, inland fisheries, labour, technology, policies, culture, traditions, and institutions that are variously involved in growing, processing, distributing and consuming food. Next we will study and model the case of the Easter Islands which contains important lessons for limits to growth in a society that continually deteriorates its natural resource base. **Session 1:** The components and inter-connections of eco-food-agri systems; modeling the effect of energy subsidies on groundwater extraction; limitations of efficiency as a policy objective; a generic CLD of an eco-food-agri system. **Session 2:** The Easter Island Story; constructing a stock and flow simulation of the Easter Island populations; Generation of sustainable scenarios; Lessons for co-existence of the human-race with planet Earth.	**Session 1:** TEEB (2018). *TEEB for Agriculture & Food: Scientific and Economic Foundations*. Geneva: UN Environment. **Session 2:** "The lessons of Easter Island" *in* "A new green history of the world: the environment and the collapse of great civilizations" by Clive Ponting, 2007.
Week 12	**Introduction to Agent-Based Modeling** **(these lectures are subject to time availability after execution of the previous lectures)** Agent-based modeling (ABM) is a separate approach to modeling that is distinct to system dynamics. While the system dynamics approach models the aggregate behavior of a system, the ABM approach models the behavior of single entities (or agents) in	**Session 1:** "What is Agent-based Modeling?" *in* "An Introduction to Agent-Based Modeling: Modeling Natural, Social, and Engineered Complex Systems with Netlogo", by Uri Wilensky and William Rand. MIT Press, 2015. **Session 2:**

	the system with the intention to mix large populations of these agents in a simulated environment. Systems may exhibit emergent behaviors i.e., behaviors that were not modeled explicitly in the agents, but emerge collectively from the aggregate behavior of the population. The aim of these lectures is to instill inspiration and motivation in students regarding the potential of agent-based modeling for environmental systems. **Session 1:** What is agent-based modeling; motivating examples and simulations; an agent-based model of ant foraging behavior. **Session 2:** Creating simple agent-based models in simulation; The "Game of Life" model; A simple model to understand why traffic jams happen; Demonstration of a wolf-sheep predator-prey model.	"Creating Simple Agent-based Models" *in* "An Introduction to Agent-Based Modeling: Modeling Natural, Social, and Engineered Complex Systems with Netlogo", by Uri Wilensky and William Rand. MIT Press, 2015.
Week 13	Session 1: Final project presentations Session 2: Final project presentations	
Week 14	Session 1: Final project presentations Session 2: Final project presentations **Project paper due**	