



Sungkyunkwan University (SKKU) International Summer Semester (ISS) 2026

Modeling of Complex Systems for Sustainability

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SHORT COURSE DESCRIPTION

This course offers a comprehensive introduction to [sustainability](#) through the powerful lens of [mathematical modeling](#). Students will learn to conceptualize and analyze the intricate dynamics of interconnected systems in both nature and society. In particular, students will gain a global perspective on sustainability through the lens of one of the world's most dynamic technocultures—South Korea—exploring how a single society navigates demographic crisis, ecological restoration, explosive cultural influence, and rapid technological transformation simultaneously. By bridging the gap between theory and practice, the course addresses a fundamental question: How can mathematical tools help us navigate and solve the complex challenges of global sustainability?

The curriculum explores essential concepts such as stocks, flows, equilibrium, and feedback loops, applying them to real-world issues like climate change and dynamic networks. Participants will master a diverse range of modeling paradigms, from SIR epidemiological and predator-prey models to advanced topics in game theory, risk assessment, and the “tragedy of the commons.”

Korean case studies are woven throughout: from modeling the demographic cliff created by the world's lowest fertility rate, to applying Braess' Paradox to the Cheonggyecheon Stream restoration in Seoul, to measuring the fractal dimension of Jeju Island's coastline and the recursive symmetry of Dancheong architectural patterns, to framing K-pop fandom diffusion as an epidemiological SEIRS model, and to interpreting the Miracle on the Han River through the tools of complexity economics and evolutionary game theory.

Throughout the term, we will answer critical questions: What governs the stability of complex systems? How can we quantify risk and improve decision-making under uncertainty? Through engaging lectures and hands-on activities, students will gain the analytical skills necessary to tackle modern sustainability challenges. This course is designed for curious minds from all academic backgrounds; no prior experience in complex systems or advanced modeling is required to succeed.

READING MATERIALS

John Roe, Russ deForest, and Sara Jamshidi, *Mathematics for Sustainability*, Springer, 2018.

ISBN-13: 978-3-319-76659-1

SKKU Library: WW0172684 510 R698m.

Nino Boccara, *Modeling Complex Systems*, 2nd edition, Springer, 2010.

ISBN-13: 978-1-4419-6561-5

SKKU Library: WW0175173 003 B664m2.

COURSE REQUIREMENTS AND GRADING POLICY

1. Passing Criterion

Performance in this course is evaluated on a 100-point scale. To receive a “Pass” grade, students must achieve a total score of [60 points](#) or higher.

2. Attendance and Participation (20%)

While SKKU regulations require a minimum of [80% attendance](#), students in this course are strongly encouraged to maintain [100% attendance](#) to fully grasp the cumulative nature of the mathematical

modeling topics. Attendance will be recorded daily. Frequent tardiness (three instances of arriving more than 10 minutes late) will be counted as one unexcused absence. Active participation in class discussions and hands-on modeling activities is expected and factored into this component.

3. Homework Assignments and Quizzes (40%)

Regular assignments and short quizzes will be conducted to assess the understanding of modeling paradigms and mathematical tools. These are designed to provide continuous feedback throughout the term. Please note that late submissions for homework or quizzes will not be accepted unless documented extenuating circumstances are provided.

4. Final Examination (40%)

A comprehensive final examination will be held at the end of the semester. This exam evaluates the student's ability to apply course concepts to real-world sustainability scenarios. Failure to attend the final examination without prior approval and evidence of a serious emergency will result in an automatic "Fail" for the course.

5. Academic Honesty

Academic integrity is strictly enforced. Any form of plagiarism, unauthorized use of AI tools, or academic dishonesty will result in an immediate "Fail" grade and will be reported to the university administration in accordance with SKKU's code of conduct.

6. Electronic Resources

Students must regularly check the **iCampus** (Canvas-based) learning management system. All course materials, announcements, and grade updates will be posted there.

COURSE SCHEDULE

Session	Topic	Detailed Description
Week 1		
1 Monday (29 June)	Introduction to Sustainability & Systems	<p>Defining sustainability and sustainable development. Introduction to mathematical thinking. Scientific notations, measurements, and orders of magnitude.</p> <ul style="list-style-type: none"> Defining sustainability and sustainable development: what it means in a rapidly urbanizing East Asian context. Introduction to mathematical thinking and Fermi estimation. Korean Case Study—Fermi Problems: <ul style="list-style-type: none"> (a) Estimating annual plastic waste from South Korea's takeout coffee culture (~5.8 billion cups/year); (b) Calculating the energy footprint of AI-driven social media usage in Seoul. Students practice unit analysis, orders-of-magnitude reasoning, and scientific notation. <p>Learning Objectives: Apply scientific notation and order-of-magnitude reasoning; formulate and solve Fermi estimation problems; frame quantitative sustainability</p>

		questions from real-world data.
2 Tuesday (30 June)	Stocks, Flows, and Equilibrium	<p>Core concepts of stocks and flows. Modeling simple systems with constant rates. Introduction to feedback loops and Jevons Paradox.</p> <ul style="list-style-type: none"> • Introduction to feedback loops (positive and negative) and the concept of stability. • Korean Case Study: Modeling South Korea's water reservoir system (Han River basin) as a stock-and-flow diagram. Jevons Paradox applied to South Korea's energy efficiency gains vs. total consumption growth. • Learning Objectives: Construct stock-and-flow diagrams for real systems; distinguish positive and negative feedback; define and evaluate equilibrium stability.
3 Wednesday (1 July)	Equilibrium Stability & Dynamics	<p>Defining equilibrium in systems. Linear stability analysis (qualitative). Exploring how small perturbations affect system states over time.</p> <ul style="list-style-type: none"> • Defining complex systems: emergence, self-organization, and non-linearity. • Introduction to network theory (graphs, degree distribution, small-world networks) and applications to social, ecological, and economic systems. • Korean Case Study—Cheonggyecheon and Braess' Paradox: The 2005 restoration of the Cheonggyecheon Stream in Seoul—demolishing an elevated expressway that actually improved traffic flow—serves as a real-world illustration of Braess' Paradox. Percolation theory is used to analyze Seoul's metropolitan road topology and its critical connectivity thresholds. • Learning Objectives: Identify properties of complex systems; apply graph-theoretic measures; explain Braess' Paradox using network theory; analyze percolation thresholds in urban infrastructure.
4 Thursday (2 July)	Complex Systems & Network Theory	<p>Characteristics of complexity: emergence and non-linearity. Introduction to network theory (nodes/edges) in social and ecological contexts.</p>
Week 2		
5 Monday (6 July)	The Exponential Model of Growth	<p>Understanding growth types. The exponential model of population and resource consumption. Discussing the “Limits to Growth” philosophy.</p>

		<ul style="list-style-type: none"> • Korean Case Study — The Demographic Cliff: South Korea's total fertility rate (TFR ≈ 0.72 in 2023, the world's lowest) as a case of sub-replacement logistic decline. Tipping-point analysis of crossing the 'Super-Aged Society' threshold (>20% population over 65). Nonlinear dynamics and long-run collapse scenarios under continued low-TFR trajectories. • Discussion: Policy levers (immigration, pro-natalist incentives) as bifurcation parameters that can shift equilibria. • Learning Objectives: Derive and interpret exponential and logistic differential equations; define carrying capacity and tipping points; analyze demographic scenarios using quantitative models.
6 Tuesday (7 July)	Logistic Growth & Carrying Capacity	Transitioning from exponential to logistic models. Role of negative feedback in regulating growth within environmental constraints.
7 Wednesday (8 July)	Predator-Prey Dynamics	<p>The Lotka-Volterra equations. Exploring cyclical dynamics and competition in ecological and economic social contexts.</p> <ul style="list-style-type: none"> • Korean Case Study: <ul style="list-style-type: none"> (a) Ecological application—the reintroduction of wolves (apex predators) to the Korean Demilitarized Zone (DMZ) ecosystem and projected prey-population cycles. (b) Economic application—competitive market dynamics between Korean conglomerates (chaebol) and SMEs modeled as a competition variant of Lotka-Volterra. • Learning Objectives: Formulate and analyze predator-prey and competition models; construct phase-plane diagrams; translate ecological models into economic and social contexts.
8 Thursday (9 July)	Epidemiological Modeling: SIR	<p>Introduction to the Susceptible-Infected-Recovered (SIR) model. Parameters, transmission rates, and their relevance to public health policy.</p> <ul style="list-style-type: none"> • Extension to SEIRS (with Exposed and Waning Immunity compartments), reflecting real-world dynamics of recurring outbreaks. • Korean Case Study—K-Pop Virality as Epidemiological Diffusion: Framing the global spread of K-pop fandom using a SEIRS model. 'Susceptibles' are non-fans; 'Exposed' represents passive awareness (algorithm recommendation); 'Infected' are active fans;

		<p>'Recovered/Waned' fans who disengage. Estimating a cultural R_0 from BTS/BLACKPINK streaming and social-media data.</p> <ul style="list-style-type: none"> • Public health application: COVID-19 response in South Korea as a case of early, effective suppression lowering the effective R_e. • Learning Objectives: Derive SIR and SEIRS equations; calculate R_0 and R_e; apply epidemiological frameworks to social-diffusion phenomena; discuss public-health policy implications.
Week 3		
<p>9 Monday (13 July)</p>	<p>Data, Risk, and Probability</p>	<p>The role of data in modeling. Probability distributions and quantifying uncertainty. Conditional probability and statistical inference in sustainability.</p> <ul style="list-style-type: none"> • The role of data in modeling; probability distributions; quantifying risk and uncertainty; conditional probability and statistical inference. • Korean Case Study: (a) Risk modeling for typhoon and Yellow Dust (hwangsa) events affecting the Korean Peninsula using extreme-value distributions. (b) Statistical analysis of K-pop streaming data as a real-world Pareto (power-law) distribution, illustrating inequality and the 'long tail.' • Learning Objectives: Apply probability distributions to real data; compute conditional probabilities; quantify risk and uncertainty; interpret statistical inference results.
<p>10 Tuesday (14 July)</p>	<p>Game Theory: Strategic Interactions</p>	<p>Rationality, payoffs, and strategic decision-making. Introduction to the “Tragedy of the Commons” as a collective action problem.</p> <ul style="list-style-type: none"> • Introduction to game theory: strategic interactions, rationality, payoffs, dominant strategies, and the Prisoner’s Dilemma. • Korean Case Study—The Miracle on the Han River as Complexity Economics: South Korea’s post-war economic development (1960–1990) is modeled as an emergent, order-generating process rather than a top-down planned outcome. Using evolutionary game theory and complexity economics, we analyze how coordinated

		<p>chaebol strategy, state-directed investment, and export competition produced emergent macroeconomic order—illustrating how non-zero-sum games can transform equilibria.</p> <ul style="list-style-type: none"> • Learning Objectives: Define game-theoretic concepts (payoff matrix, dominant strategy, Nash Equilibrium); identify collective-action problems; apply complexity economics to interpret development phenomena.
<p>11 Wednesday (15 July)</p>	<p>Nash Equilibrium & Cooperation</p>	<p>Defining Nash Equilibrium. Analyzing how cooperation emerges in social dilemmas. Case studies on international environmental agreements.</p> <ul style="list-style-type: none"> • Korean Case Study: <ul style="list-style-type: none"> (a) Inter-Korean resource agreements and the East Sea fisheries dispute as multi-player Nash Equilibrium problems. (b) South Korea's participation in international climate agreements (Paris Accord NDCs) modeled as a cooperative game—exploring the conditions under which stable, cooperative equilibria are achievable. • Learning Objectives: Compute Nash Equilibria in two-player and multi-player games; identify conditions for cooperative equilibria; apply game theory to international sustainability agreements.
<p>12 Thursday (16 July)</p>	<p>Introduction to Agent-Based Modeling</p>	<p>Contrasting ABMs with system dynamics. Principles of individual-based simulation and observing emergent collective behaviors.</p> <ul style="list-style-type: none"> • Korean Case Study—Seoul Urban Dynamics: Guided modeling session in which students build a simple ABM of pedestrian flow in Hongdae or the Gangnam district — replicating emergent crowd patterns. Extension: simulate the effect of removing the Cheonggyecheon highway (Lecture 3) at the ABM level. • Review of model design principles: validation, calibration, sensitivity analysis. • Learning Objectives: Construct and run a basic ABM; distinguish emergent from top-down behavior; validate models against real data; apply design principles to original model development.
<p>Week 4</p>		
<p>13</p>	<p>Applied ABM Workshop</p>	<p>Hands-on session: Simulating emergent behavior (e.g.,</p>

Monday (20 July)		Schelling's Segregation or Forest Fire models) to understand policy interventions.
14 Tuesday (21 July)	Final Review & Problem Solving	Comprehensive course review. Solving sample modeling problems. Discussion on the future of mathematical modeling for global sustainability.
15 Wednesday (22 July)	Final Examination	Summative assessment covering all course modules (100-point scale). Final reflections and summary of key course takeaways.