Operations Research Applications in Integrated Systems Engineering

Applied research uses fundamental analytical tools, including data analytics and optimization and stochastic models, to study and solve problems involving real-world systems. In many cases, disparate tools and models must be brought to bear to study a particular problem. Oftentimes, similar modeling methodologies can be applied to problems that seem quite different from one another.

Our applied research spans many areas, including:
- cloud computing,
- cyber and homeland security,
- energy systems,
- logistics and supply chain,
- social networks,
- sustainable mobility, and
- water resources management.
This research area involves the application of mathematical modeling and optimization techniques to reduce costs and improve system readiness.

The focus for this work is the Security & Efficiency thru Analytics Laboratory (SEAL) which involves collaboration between the Departments of Integrated Systems Engineering and Computer Science Engineering as well as industrial partners. Examples of applications include:

1. **Data-Driven Vulnerability Maintenance**: Vulnerabilities accumulate on hosts, which can be PCs, servers, printers, or other devices. Some are repaired by automatic patching each month. With thousands of hosts and different levels of data and access criticality, what is the cost-optimal policy for directing resources to manually patch vulnerabilities? What actions should be taken if repairing a host would cause a loss in functionality, *e.g.*, because upgrading software makes legacy software unusable? We are among the first to provide related software and methods to answer these questions.

2. **Optimal Network Security**: Large organizations are attacked thousands of times each day by hackers all across the world. Firewalls can observe patterns of activity and perceive, with effective rules, compromised accounts in the process of giving up sensitive data and block the hosts or issue warnings. What are optimal policies to balance disruption costs with losses to the firm and society?

3. **Optimized Password Policies**: Regular password change requirements are annoying. Yet, regular password changes can offer an excellent opportunity for a user to gain full control of a compromised account and facilitate detection. How often should each user group be required to change passwords? Also, what are the optimal policies including choices about password strength requirements?

4. **Tuned Phishing and Spear Phishing Response**: Phishing involves a hacker sending an email to obtain account information. In spear phishing, the hacker uses target-specific data possibly obtained through previous hacks. Substantial percentages of firm stakeholders are currently being fooled by these attacks and giving access away. How to prevent this? How to mitigate the damage? How to repair compromised accounts? Data-driven optimization offers cost effective policy options to help tune organizational responses.

5. **Cyber Life Cycle Analysis**: Choices that developers make like using Linux and Java can have surprisingly negative effects for organizations years later. Our research is at the forefront of modeling and displaying life cycle costs to bring data about current losses up to the front of the design process.
Modeling and Analysis of Energy Systems

This research area deals with mathematical models for analysis, reliability, control, operations, planning, economics, and regulation of electric generation, transmission, and distribution systems, with a system-wide focus.

Relevant problems include:

1. **Decarbonization of Electricity Production**: Questions include what is the most effective way to reduce carbon generation in the power sector—carbon taxes, a cap-and-trade mechanism, or indirect methods, such as renewable portfolio standards?
2. **Transmission Infrastructure Planning**: In the face of aging transmission infrastructure, how should the existing system be reinforced and expanded to meet efficiency, reliability, robustness, and economic criteria?
3. **Renewable Integration**: What is the impact of renewable integration on the power system? What is its impact on dynamics, stability, and control? What is its impact on daily operations? What is its impact on long-term generation and transmission capacity planning?
4. **Production Capacity Adequacy**: How can we ensure that enough production capacity will be available to supply future energy needs? What are the appropriate mechanisms to ensure that enough capacity is added to the system, especially in a market-based environment that does not have centralized system planning?

5. **Operation and Planning of Distribution Systems with Increasing Communication and Automation (Smart Grid)**: To what extent would consumers respond to price signals and adjust their consumption patterns? How effective is demand-side management in providing flexibility and capacity to the system? What is the best way to integrate storage and renewables in distribution systems?
6. **Electric Vehicles**: What is the impact of large-scale integration of electrical vehicles on network operations and planning?
7. **Integration of the Electricity and Natural Gas Sectors**: As electricity production increasingly relies on natural gas, what is the best way to coordinate the operation and long-term planning of both the electricity and gas systems?
8. **Market Design**: Are current wholesale electricity markets properly designed? Can such designs be improved? Should the commitment decision of production facilities be left to the owners of such facilities or coordinated in a centralized fashion? Are pricing mechanisms adequate?
9. **Energy Policy and Regulatory Design**: How do energy-related policy decisions (e.g., subsidies and taxes) affect technology adoption and use? What combination of centralized planning and regulation versus competitive markets will most effectively deliver reliable, low-cost, and environmentally benign energy?
Logistics and Supply Chain Management in Integrated Systems Engineering

Logistics is the science of design, control, and maintenance of the effective and efficient flow of resources, service, manufactured goods, personnel, and information. While this science is important in government, military and humanitarian relief, it is frequently used in manufacturing environments in the supply chain.

The supply chain is the network of resources, people and activities that take part in the manufacture and delivery of a service or product. It includes the purchasing and shipping of raw materials, intermediate storage, production and distribution of finished and partially-finished goods.

The Industrial Engineer typically focuses on certain aspects of logistics in the supply chain. These include:

- Transportation of raw materials to the manufacturer
- Handling and storage of raw materials
- Production and storage of goods
  - Scheduling and control of jobs and activities
  - Management of the labor force
- Warehousing of finished goods
- Delivery of product to the customer
- Design of various portions of the supply chain that include raw material and distribution networks, production, and warehouse facilities
- Design and control of information flow

Each of these areas requires specialized methods for developing and creating effective and efficient solutions, which are usually based on mathematical theories and methods. Research in the Integrated Systems Engineering Department involves applications in most of these areas. We also have a growing research focus in humanitarian logistics, which involves disaster preparedness, relief response operations, and evacuation planning.
Sustainability and Resilience of Coupled Human-Natural Systems

This research area involves the application of mathematical modeling and optimization techniques to improve both the long-term sustainability and short-term resilience of manufacturing processes, industrial supply chains, urban infrastructures, and the essential ecosystem services that support them.

The focus for this work is the Center for Resilience, a collaboration between the Departments of Integrated Systems Engineering and Chemical & Biomolecular Engineering. Examples of applications include:

1. **By-Product Synergy:** Companies can reduce their ecological footprint by converting their waste by-products into feedstocks for other companies. We developed Eco-Flow™, an innovative software tool that helps optimize material flows in industrial networks, and in 2009 we founded the Ohio By-Product Synergy network, which has grown to include about 35 member companies and is now managed by Sustainable Ohio.

2. **Life Cycle Assessment:** To support sustainable innovation, we utilize life cycle assessment (LCA) tools to analyze the energy, emissions, resource use, and cost trade-offs over the full value chain of any product or service. Our applications of LCA range from conventional products such as plastic bottles and home insulation to emerging technologies such as nano-composite materials and cellulosic biofuels.

3. **Regional Growth and Development:** It is a continuing challenge for states and regions to achieve resilient economic growth that assures availability of jobs, protection of natural resources and quality of life. In collaboration with Ohio University, we developed the Dynamic Energy and Environmental Policy Simulation (DEEPS) tool to analyze the benefits of alternative energy policies. The model was adopted by the U.S. EPA as a basis for the Triple Value Simulation (3VS) approach, which is being applied in several regions of the U.S.

4. **Sustainable Wastewater Management:** Conventional wastewater treatment is energy intensive and produces sludge that is typically sent to landfills. We worked with the City of Columbus Department of Public Utilities to consider alternative, more environmentally-conscious approaches to sludge management. Using mathematical optimization, we found a win-win solution that would save the City up to $2 million a year while reducing greenhouse gas emissions by about 25%. This approach was incorporated into their capital plan.

5. **Supply Chain Resilience:** Working with major companies such as Dow Chemical and Limited Brands, we teamed with the Fisher College of Business to develop a comprehensive approach and toolkit for Supply Chain Resilience Assessment and Management (SCRAM). This approach complements enterprise risk management by enabling companies to anticipate, prevent and recover from severe supply chain disruptions, including unforeseen catastrophic events.
Water, water, everywhere,
Nor any drop to drink.
- Samuel Taylor Coleridge

Water Resources Management

Water supplies are depleted at a rate not possible to replenish naturally. Many of the world’s major aquifers are being over-pumped. At the same time, much freshwater is contaminated by natural or human-related causes. Furthermore, reliable water supplies are not available due to long-term droughts, severe water events, and climate variability.

Operations research models and methods present great opportunities to solve this global problem with a systems approach under the uncertainties of water demands, climate variability, and economic development.

Research topics of interest include:

1. **Municipal Water System Design and Operation**: How can we best design and operate municipal water systems to save precious fresh water resources for future generations?
2. **Climate Adaptability**: The aim of this research area is to increase the resilience to climate variability by improving the management of water resources and ecosystems and control risks associated with severe weather conditions.

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