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Engineering economic systems: Past, present and future

Ingeniería de sistemas económicos: Pasado, presente y futuro

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ABSTRACT

At Stanford University, engineering economic systems emerged as a discipline in the late 1960's. The department's curriculum had four central areas: decision analysis, optimization, economic sciences, and dynamic systems. The emphasis was on both practice and theory. The Management Science and Engineering Department at Stanford (MS&E), founded in 2000, is an outgrowth of the former Engineering Economic Systems Department. MS&E focuses on the codesign of engineering platforms and social systems in the 21st century, at scale and with pervasive data. The goal is to understand, design, implement, and control large-scale, integrated systems of people and machines. The intellectual spectrum ranges from analytics and computation to social and behavioral sciences. This article describes examples of past and present projects in the areas of energy, education, the economy, the environment, and health. Looking to the future, we are likely to see the continual emergence of new technologies, increasing amounts of data, increasing levels of connectivity, advances in computing, ubiquity of machine learning and artificial intelligence, and increasing importance of the need to address social and environmental problems. These will lead to new ways of analyzing problems and rich new opportunities for the tools of engineering economic systems to have impact.

Keywords: *Energy, Education, Economy, Environment, Health*

RESUMEN

En la Universidad de Stanford, la ingeniería de sistemas económicos surgió como disciplina a finales de los años sesenta. El plan de estudios del departamento tenía cuatro áreas centrales: análisis de decisiones, optimización, ciencias económicas y sistemas dinámicos. Se hacía hincapié tanto en la práctica como en la teoría. El Departamento de Ciencias de la Gestión e Ingeniería de Stanford (MS&E), fundado en 2000, es una extensión del antiguo Departamento de Ingeniería de Sistemas Económicos. MS&E se centra en el codiseño de plataformas de ingeniería y sistemas sociales en el siglo XXI, a escala y con datos omnipresentes. El objetivo es comprender, diseñar, implantar y controlar sistemas integrados de personas y máquinas a gran escala. El espectro intelectual abarca desde la analítica y la computación hasta las ciencias sociales y del comportamiento. Este artículo describe ejemplos de proyectos pasados y presentes en los ámbitos de la energía, la educación, la economía, el medio ambiente y la salud. De cara al futuro, es probable que asistamos a la aparición continua de nuevas tecnologías, al aumento de la cantidad de datos, al incremento de los niveles de conectividad, a los avances informáticos, a la ubicuidad del aprendizaje automático y la inteligencia artificial, y a la creciente importancia de la necesidad de abordar los problemas sociales y medioambientales. Todo ello dará lugar a nuevas formas de analizar los problemas y a nuevas y ricas oportunidades para que las herramientas de los sistemas económicos de ingeniería tengan impacto.

Palabras Clave: *Energía, Educación, Economía, Medio Ambiente, Salud*

1. INTRODUCTION

Engineering economic systems is a discipline that developed through a natural progression from engineering to systems engineering to engineering economic systems. Engineering itself is the application of scientific and mathematical principles to create and maintain structures, systems and processes: for example, the design of bridges or power plants. Systems engineering is the design, integration, and management of complex systems: for example, design and control of robotic systems for manufacturing, or design and control of the space shuttle. Engineering economic systems is the application of systems engineering to a broader range of problems (Linvill, 1966): for example, the planning of educational, health, or energy systems. This article describes the past, the present, and the future of engineering economic systems. We describe examples of past and present projects in the areas of energy, education, the economy, the environment, and health, and we identify key areas for future study.

2. THE PAST

In 1967, a department called Engineering Economic Systems (EES) was founded at Stanford University. Its emphasis was on problem solving as a discipline (Luenberger, 1985). The department's curriculum had four central areas: decision analysis, optimization, economic sciences, and dynamic systems. The emphasis was on both practice and theory.

Students began with fundamental courses, for example in mathematics and sciences. Then they took two courses from each of the four central areas. These were known as "portable concepts." Then as needed, students would study special techniques and applications. They would use this learning to carry out applied projects, which often led to theoretical analysis.
Early applications of engineering economic systems were in a variety of areas including energy, education, the economy, the environment, and health. Here we describe examples in each of these areas.

Energy

The 1970s in the US was a period of significant challenges and disruptions in the availability and cost of energy resources. In response, the Energy Modeling Forum was created in the EES Department. The Energy Modeling Forum examined a range of topics in energy policy, with the goal of developing insights into policy options (Huntington et al., 1982). Studies focused on problems such as electric load forecasting, estimating aggregate elasticity of energy demand, and modeling the impact of economic growth on energy demands.

Education

A study in the area of education examined how to allocate resources for research on the US educational system (Linvill & Harman, 1966). The study presented a systems planning approach that could aid the US Department of Education in allocating research funding. This was one of the first studies to examine research funding allocation from a systems perspective.

The economy

Early work in the EES Department created various systems models of the US economy and its components. For example, one study created a model of the agriculture sector of the US economy that could be integrated with other economic models, reflecting the potential impact of higher energy costs on agricultural production (Luenberger, 1985).

The environment

A classic study in the area of the environment examined decisions for seeding hurricanes (Howard et al., 1972). The study used decision analysis to analyze the question of whether to seed a hurricane with silver iodide before it reaches a coastal region so as to mitigate the damage from the hurricane.

Health

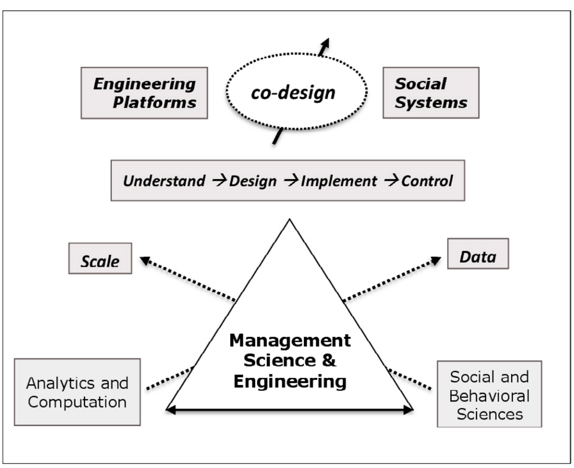
In the area of health, one influential project examined cancer screening decisions, using a Markov model of cancer growth to assess the effectiveness of different colorectal cancer screening policies (Eddy, 1980). This was one of the first studies to use an analytical model to address the problem of screening for disease.

3. THE PRESENT

The Management Science and Engineering Department at Stanford (MS&E), founded in 2000, is an outgrowth of the former Engineering Economic Systems department. MS&E focuses on the codesign of engineering platforms and social systems in the 21st century, at scale and with pervasive data (Figure 1). The goal is to understand, design, implement, and control large-scale, integrated systems of people and machines. The intellectual spectrum ranges from analytics and computation to social and behavioral sciences. MS&E has a broader focus than the EES department and thus also has a broader set of core courses. In addition to the four areas of optimization, dynamic systems, economics, and decision analysis, the department offers key courses in areas such as stochastic modeling, data science and statistics, and behavioral science.

Figure 1

Management Science and Engineering: A vision for the 21st century



Below we describe examples of recent work carried out in the department in the areas of energy, education, the economy, the environment, and health.

Energy

Car sharing systems that use electric vehicles need to plan vehicle charging. A project spearheaded by Professor Nicholas Bambos focused on scheduling charging for electric vehicle fleets (Bistritz et al., 2020). The goal is to plan the charging to maximize the number of vehicle pickups. This is a complex stochastic dynamic programming problem that cannot be solved analytically. As an alternative, the researchers used a myopic solution approach: the optimal pickup and charging strategy is first determined for each vehicle, and then a matching algorithm is used to assign customers to vehicles. The authors showed that this approach is close to optimal.

Education

In many school systems, families request which school they would like to their child to attend. Families rank their preferences for different schools and then are assigned to a school. The goal is to have a fair and efficient system for assigning families to schools. This is a market matching problem: schools and families must be matched (Feigenbaum et al., 2020). Professor Irene Lo and colleagues developed an improved ranking and choice system for the San Francisco Unified School District that is pareto optimal compared to the current system (Allman et al., 2022): everyone is equally or more satisfied with their school assignment.

The economy

An increasing fraction of retail sales now occur online, and thus an increasing fraction of sales promotions occur online. Retailers would like to know whether a sales promotion for one item will reduce demand for other items. Estimating such effects is a causal inference problem. Professor Guillaume Basse developed an improved conditional randomization test for hypothesis testing that takes into account these network effects (Puelz et al., 2022). This analysis also applies to other network problems such as policing. For example, in Cartagena Columbia, intensive policing was introduced in certain districts to reduce crime. The conditional randomization test can be used to determine whether crime increased in other districts as a result.

The environment

Increasing atmospheric carbon dioxide concentrations that are occurring as a result of climate change are anticipated to reduce the concentrations of zinc and iron in many agricultural crops, particularly C3 plants. C3 plants, which constitute 85% of plant species, use a specific type of metabolic pathway for carbon fixation in photosynthesis. Examples include wheat, rice, and taro. When grown under carbon monoxide conditions expected by 2050, C3 plants are expected to have about 7.5% less zinc and iron.
We modeled the health effects of decreased zinc and iron concentrations in C3 plants and then assessed the effectiveness of interventions aimed at mitigating these effects (Weyant et al., 2018). These interventions included nutritional supplementation programs, disease mitigation programs, and the Paris Agreement. The Paris Agreement aims to keep global temperatures within 2C of pre-industrial levels. Using a microsimulation model of individuals in 137 countries, the analysis showed that increasing carbon dioxide concentrations will exacerbate inequities and zinc and iron deficiency, and that climate mitigation strategies such as the Paris Agreement are likely to be more effective than traditional public health interventions in averting this increased inequity.

Health

A number of current studies in the department focus on problems related to health. Allocating donor organs The problem of allocating donor organs to patients waiting for transplants can be thought of as a market matching problem (Ashlagi & Roth, 2021). Professor Itai Ashlagi served on a national committee to examine how donor organs should be allocated to patients who are waiting for a transplant. The committee generated recommendations for improving the system, taking into account fairness, equity, transparency, and cost-effectiveness (National Research Council, 2022). Professor Ashlagi is currently working to develop a matching system that will reduce the number of donor kidneys that are not matched with a patient and thus must be discarded.

Predicting disease outbreaks A recent study examined the problem of predicting disease outbreaks using cell phone mobility data, focusing on COVID-19 (Guan et al., 2021). Many countries implemented mobility restrictions in response to COVID-19. To appropriately target restrictions, it is important to know when and where outbreaks will occur and how widespread they will be. The goals of this study were to forecast the trajectory and severity of COVID-19 in different districts of Israel, and to determine the usefulness of human mobility data in predicting COVID-19 outbreaks.

We used machine learning to develop a prediction model to predict next seven-day average incidence and the test positivity rate and then classified the predicted values using a rule which classifies the severity of the predicted outbreak. The prediction model utilized health data from the Israeli Ministry of Health – number of COVID-19 cases and number of positive COVID-19 tests – lagged by one day, three days, or six days, as well as cell phone mobility data for 3 million cell phone users representative of Israel. The cell phone mobility data was used to create two metrics – a pressure score, which represents travel into a region, and an internal movement score which represents travel within a region.

The best prediction model was a linear regression with weekly decay and half-life two weeks. It uses the lagged health features and, interestingly, the internal movement score but not the pressure score. The study showed that prediction accuracy was worse when mobility data was not included. The prediction model had high magnitude accuracy; this means it was able to accurately predict whether the outbreak would be minimal, moderate, substantial, widespread, or critical. Accurate prediction allows for better allocation of resources, such as vaccines, medical staff and social distancing policies. At a higher level, similar methods could be used to predict outbreaks of other communicable diseases, such as influenza, measles, and SARS.

Improving health using smartwatch data Worn by approximately 20% of the US population, wearable devices are a promising technology for healthcare applications because they can continuously monitor physiological measures such as an individual's heart rate, oxygen saturation, and physical activity. A recent project focused on using smartwatch data to assess COVID-19 vaccine side effects. With colleagues at Tel Aviv University, we carried out a prospective observational study of participants in Israel who received a COVID-19 vaccination. Participants were equipped with a smartwatch, and filled out a daily questionnaire via a dedicated mobile app. We examined post-vaccination smartwatch data on heart rate and heart rate variability and assessed potential side effects up to 14 days after COVID-19 vaccination (Mofaz et al., 2022). We compared these measurements with data from patient questionnaires.
The analysis found that the smartwatches captured changes in heart rate and heart rate variability that were not captured in patient self-reports: for example, after the third vaccination (first booster shot), patients who reported no reaction in fact did not return to normal (in terms of cardiac measures detected by the smartwatches) until three days after vaccination. The study demonstrates the potential of smartwatches and other wearable devices to gather improved data on patient health and thereby lead to improve health outcomes.

Remote monitoring of patients Another project, carried out by Professor Ramesh Johari with colleagues at Lucille Packard Children's Hospital Stanford (LPCH), focuses on remote patient monitoring. LPCH treats many Type 1 diabetes patients who wear continuous glucose monitors to monitor their insulin levels. Because wearables generate orders of magnitude more data than a care team can look at, the hospital needs an automated system to analyze the data. The goal of this project is to use the continuous glucose monitoring data to assess the health of the pediatric diabetes patients and determine which patients should be followed up (for example, with a phone call or with a visit to the clinic) (Ferstad et al., 2021).

The approach taken is to prioritize patients by their likelihood of benefiting from the intervention. The researchers first examined the glucose time-in-range for each patient, and then used machine learning to estimate the potential improvement for that patient from contact by the care team. This enabled them to develop a prioritized list of patients for followup.

Thus far, the system has been implemented at LPCH with 225 patients. As a result of this new system, the time spent reviewing patient data and contacting patients has been reduced by 60% from 3.2 minutes per patient per week to 1.3 minutes. This translates to a 147% increase in weekly clinic capacity. More importantly, patients who received remote review had 8.8% greater glucose time-in-range. LPCH is currently expanding this system to 1000 patients. At a higher level, this project shows how data from wearables uploaded to a platform or an app can be used in a decision support system to help patient care teams provide personalized treatments to patients. One could expand the system to other chronic diseases such as asthma and hypertension.

4. THE FUTURE

Although no one can predict the future with certainty, a number of trends seem clear at this point. These include the emergence of new technologies, proliferation of data, increasing levels of connectivity, advances in computing capability, ubiquity of machine learning and artificial intelligence, and increasing importance of social and environmental problems.

New technologies

New technologies are continually emerging. For example, numerous wearable medical devices currently exist, and many more are being developed. These devices can provide valuable real-time data for monitoring and improving health. Quantum computing may change the way many systems operate, and may change the way we do computations. Quantum computers excel at solving optimization problems and thus could have impactful applications in areas like supply chain management, financial portfolio optimization, and logistics. Autonomous vehicles, if successful, will lead to many systems problems for us to solve. Robotics and automation will becoming increasingly prevalent in areas such as health, agriculture, construction, and warehouse operations – and undoubtedly in many areas we have not yet thought of. Finally, technologies we have not even yet imagined will appear.

Data

In recent years, we have seen an exponential rise in available data. This phenomenon is often referred to as "big data." Data has become increasingly available because of factors such as the widespread adoption of digital technologies, the proliferation of internet-of-things devices, the rise of e-commerce platforms, increasing use of social media platforms, and advances in cloud computing and storage. The newly available data can be exploited for informed decision making, predictive analytics, personalization of products and services, process and supply chain optimization, and many other purposes.

Connectivity

Along with the explosion in the amount of available data, the number of connected devices has been steadily increasing. This includes not only traditional computing devices like computers and smartphones but also a wide range of other devices such as sensors, actuators, wearables, and household appliances. Our devices increasingly can all be connected with one another, enabling data sharing and more complex systems of control. We can now have smart homes, smart cities, smart transportation systems, and precision agriculture, for example. The increasing connectivity of devices is transforming the way we live, work, and interact with the world, offering numerous benefits while also posing challenges that need careful consideration and mitigation.

Computing

Supercomputers and high-performance computing clusters continue to evolve, enabling scientists and researchers to tackle ever-more complex problems. Edge computing has gained prominence, allowing for data processing closer to the source of generation, thereby reducing latency and improving efficiency. This is particularly important for applications like the internet-of-things, where real-time processing is critical.

Machine learning and artificial intelligence

Of course, a key trend for the future is the increasing importance of machine learning and artificial intelligence. Although we may not yet know whether robots will be taking over our jobs, it is clear that artificial intelligence, for example, large language models such as chatGPT, will become increasingly embedded in systems. Machine learning and artificial intelligence will become increasingly integrated into various industries, transforming traditional processes and business models in sectors such as healthcare, finance, manufacturing, and logistics. In areas such as climate change, artificial intelligence may also play a key role: for example, machine learning models can analyze environmental data, optimize resource usage, and contribute to sustainability efforts in areas such as energy, agriculture, and urban planning. As artificial intelligence systems become more pervasive, making such models more interpretable and explainable will become increasingly important, particularly in areas such as health, finance, social decision making and resource allocation.

Social and environmental problems

In recent years engineers have become increasingly aware of the importance of social and environmental problems and the role that engineers can play in helping to solve these problems. For example, climate change may affect the frequency and scale of natural disasters, our ability to grow crops, and even our human health. Thus, natural resource management will become increasingly critical. The tools of engineering economic systems can play a crucial role in natural resource management by providing insights, optimizing decision-making processes, and promoting sustainable practices. Pollution of land, water, and air is also a key challenge. Analytics can be used to examine the effect of proposed pollution control policies, help design new and more efficient supply chains and transportation systems, and contribute to the design of smart energy grids.

Engineering economic systems can also contribute to solutions for many important social problems. For example, significant disparities in health outcomes and access to healthcare services exist between different populations, regions, and countries worldwide; health care costs are rising; and quality of care is often worse in poorer regions. Designing and managing the provision of healthcare that is effective, affordable, and equitable is a critical challenge. Educational systems worldwide face various challenges that impact their effectiveness in providing quality education, including disparities in access to education and in access to technology and the internet, and funding constraints. There is a great need to examine our educational systems to make them more efficient, effective, and equitable. In areas with high poverty, there is a need to design and optimize poverty alleviation programs by analyzing data, identifying key factors, and optimizing resource distribution to maximize impact and there is a need to optimize the delivery of social services, such as welfare programs and community outreach initiatives. These are just a few examples of social problems where analytics can contribute to solutions.

5. CONCLUSION

As highlighted in this article, engineering economic systems has a rich past and present, and there are many opportunities to have future impact using the tools of engineering economic systems. With the emergence of new technologies, increased available data and connectivity, advances computing and in machine learning and artificial intelligence, and increased complexity of systems, the tools of engineering economic systems are more important than ever. By leveraging mathematical modeling, optimization, and other analytical techniques, engineers can play a vital role in addressing complex social, economic, and technical problems and contributing to the development of more efficient, equitable, and sustainable solutions.

REFERENCES

Allman, M., Ashlagi, I., Lo, I., Love, J., Mentzer, K., Ruiz-Setz, L., & O'Connell, H. (2022, July). Designing school choice for diversity in the San Francisco Unified School District. In *Proceedings of the 23rd ACM Conference on Economics and Computation* (pp. 290-291).

Ashlagi, I., & Roth, A. E. (2021). Kidney exchange: An operations perspective. *Management Science, 67*(9), 5455-5478. https://doi.org/10.1287/mnsc.2020.3954

Bistritz, I., Klein, M., Bambos, N., Maimon, O., & Rajagopal, R. (2020). Distributed scheduling of charging for on-demand electric vehicle fleets. *IFAC-PapersOnLine, 53*(4), 472-477. https://doi.org/10.1016/j.ifacol.2021.04.043

Eddy, D. M. (1980). *Screening for Cancer: Theory, Analysis, and Design*. Prentice-Hall. https://cir.nii.ac.jp/crid/1130000795440510464

Feigenbaum, I., Kanoria, Y., Lo, I., & Sethuraman, J. (2020). Dynamic matching in school choice: Efficient seat reassignment after late cancellations. *Management Science, 66(*11), 5341-5361. https://doi.org/10.1287/mnsc.2019.3469

Ferstad, J. O., Vallon, J. J., Jun, D., Gu, A., Vitko, A., Morales, D. P., Leverenz, J., Lee, M. Y., Leverenz, B., Vasilakis, C., Osmanlliu, E., Prahalad, P., Maahs, D. M., Johari, R., & Scheinker, D. (2021). Population-level management of type 1 diabetes via continuous glucose monitoring and algorithm-enabled patient prioritization: Precision health meets population health. *Pediatric Diabetes, 22*(7), 982-991. https://doi.org/10.1111/pedi.13256

Guan, G., Dery, Y., Yechezkel, M., Ben-Gal, I., Yamin, D., & Brandeau, M. L. (2021). Early detection of COVID-19 outbreaks using human mobility data. *PLoS One, 16*(7), e0253865. https://doi.org/10.1371/journal.pone.0253865

Howard, R. A., Matheson, J. E., & North, D. W. (1972). The decision to seed hurricanes. *Science, 176*(4040), 1191-1202. https://doi.org/10.1126/science.176.4040.1191

Huntington, H. G., Weyant, J. P., & Sweeney, J. L. (1982). Modeling for insights, not numbers: The experiences of the Energy Modeling Forum. *Omega, 10*(5), 449-462. https://doi.org/10.1016/0305-0483(82)90002-0

Linvill, W. K. (1966). Engineering-economic systems: A new profession. *IEEE Spectrum, 3*(4), 96-102. https://doi.org/10.1109/mspec.1966.5216587

Linvill, W. K., & Harman, W. W. (1966). *Systems Planning Approach to Educational Research Planning*. Stanford Research Institute.

Luenberger, D. G. (1985). Engineering-economic systems: A problem-solving discipline. *IFAC Proceedings Volumes, 18*(9), 15-19. https://doi.org/10.1016/s1474-6670(17)60254-4

Mofaz, M., Yechezkel, M., Guan, G., Brandeau, M. L., Patalon, T., Gazit, S., Yamin, D., & Shmueli, E. (2022). Self-reported and physiologic reactions to third BNT162b2 mRNA COVID-19 (booster) vaccine dose. *Emerging Infectious Diseases, 28*(7), 1375-1383. https://doi.org/10.3201/eid2807.212330

National Research Council. (2022). *Realizing the Promise of Equity in the Organ Transplantation System*. The National Academies Press. https://doi.org/doi:10.17226/26364

Puelz, D., Basse, G., Feller, A., & Toulis, P. (2022). A graph-theoretic approach to randomization tests of causal effects under general interference. *Journal of the Royal Statistical Society Series B: Statistical Methodology, 84*(1), 174-204. https://doi.org/10.1111/rssb.12478

Weyant, C., Brandeau, M. L., Burke, M., Lobell, D. B., Bendavid, E., & Basu, S. (2018). Anticipated burden and mitigation of carbon-dioxide-induced nutritional deficiencies and related diseases: A simulation modeling study. *PLoS Medicine, 15*(7), e1002586. https://doi.org/10.1371/journal.pmed.1002586