Princeton University

Honors Faculty Members Receiving Emeritus Status

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The biographical sketches were written by staff and colleagues in the departments of those honored.

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for Receiving Emeritus Status

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Warren Buckler Powell

Professor of Operations Research and Financial Engineering Warren Buckler Powell will transfer to emeritus status on September 1, 2020, after 39 years on the faculty.

Warren graduated from Princeton University in 1977 with a bachelor's degree in civil engineering specializing in transportation systems, and then received his Ph.D. from MIT, also in transportation systems. While at MIT he was introduced to the field of operations research which he describes as the "mathematics of everyday life" and realized that he had found his calling. He returned as a faculty member in civil engineering at Princeton in 1981, accepting the challenge of starting an operations research program, where he saw the opportunity to bring the mathematical foundations directly to engineers solving real problems. He helped to transition an existing program in "Basic Engineering" to "Engineering and Management Systems," and moved the existing transportation program to the new EMS program doing operations research.

Warren's career coincided with the deregulation of freight transportation in 1980, creating a sudden market for advanced planning tools at a time when computers were just starting to become useful. He was quickly attracted to the analytical challenges faced by the trucking industry. In the 1980s, he developed the first interactive optimization model for less-than-truckload (LTL) carriers, which operated hub and spoke networks similar to airlines (this model was written in Fortran, on an IBM mainframe). During the 1980s, 80 percent of LTL carriers went out of business. By the 1990s, virtually the entire industry was using the model he developed ("SuperSPIN"), which stabilized the entire industry. SuperSPIN was used to plan Roadway Package Express (now known as FedEx Ground) and American Freightways (now known as FedEx Freight). He also enjoyed 25 years of funding from what is now known as YRC, currently the second largest less-than-truckload motor carriers, for which he developed strategic and operational planning models that are still in use today.

His passion, however, was the industry known as truckload trucking, which can be thought of as Uber for freight: the problem is to decide which driver should move each load of freight, where the choice of drivers and loads had to reflect conditions after the load was delivered, which might be up to three or four days into the future.

The problem combined high-dimensionality, requiring the matching of hundreds to thousands of drivers and loads at the same time, while also handling the uncertainty of the future. This was his first introduction to stochastic optimization.

Modeling and designing computationally tractable algorithms for this problem proved to be Warren's defining problem, and it started his tour through what he would later call the "jungle of stochastic optimization," which addresses the broad problem of making decisions over time under uncertainty. He would later identify over 15 distinct academic communities that all contributed to mathematical models and algorithms for sequential decision problems in the presence of uncertainty, but not one provided the tools to solve his fleet management problem.

In 1990, he founded CASTLE Lab, which was originally an acronym for Computational Stochastic Transportation and Logistics Engineering, but later was adjusted to the more modern ComputAtional STochastic optimization and LEarning. In the 1990s, CASTLE Lab became renowned for bringing advanced analytics to a wide range of problems in transportation and logistics, spanning LTL and TL trucking, locomotive management for rail, military airlift, drayage, spare parts management, vehicle routing and scheduling, and supply chain management.

Most prominent was Warren's development of a class of techniques in an emerging field known as "approximate dynamic programming" (ADP), which had been limited to simple "mouse-in-a-maze" problems or engineering control applications. Warren was the first to develop ADP methods for high-dimensional control problems (his "decisions" had over 50,000 dimensions) using a modeling device called the "post-decision state." This work would lead to his popular book, *Approximate Dynamic Programming: Solving the Curses of Dimensionality*.

In the early 2000s, he took advantage of the downturn from the dot-com era to transition to new problems, settling initially on energy systems. He founded PENSA (Princeton Laboratory for Energy Systems Analysis) and brought the same research model to energy problems to help address the emerging problems related to handling the variability and uncertainty of increasing investments in wind and solar. In fact, it was his work in freight transportation that combined optimization and uncertainty that launched his first project with Lawrence Livermore to optimize an energy storage system.

By 2015, he had brought in over $7.5 million in funding from the Department of Energy, Lawrence Livermore, NRG Energy, and a large grant from SAP to support energy systems research. This work produced the first detailed model of PJM Interconnections, the grid

operator for the mid-Atlantic states serving 60 million people. His other work spanned bidding and forecasting, but also produced what is today the most comprehensive set of models and algorithms for energy storage, a critical technology for handling the variability and uncertainty of wind and solar.

During this period, Warren continued to mature in his formal methodological research in stochastic optimization, which emerged with his work on approximate dynamic programming. An important issue that arises throughout the design of ADP algorithms is known as the "exploration vs. exploitation" problem: do we make a decision because it appears best (based on current estimates), or to help refine our estimate of the value of the state the decision takes us to?

He decided to tackle the "exploration vs. exploitation" problem as an area of research, which produced his book *Optimal Learning*, and a series of papers developing a powerful learning policy that he called the "knowledge gradient." He realized the broad appeal of this idea and introduced a popular undergraduate elective course called "Optimal Learning." Undergraduates have been attracted by the broad applicability of the core problem of optimal learning and the relative simplicity of the tools.

Warren's work in optimal learning led to a major grant with the Air Force focusing on sequential design of experiments for materials science, which brought him into an entirely new community with a new set of questions. This work required interactions with materials scientists, electrical engineers, and chemical engineers, and produced new tools that apply to anyone working in the laboratory sciences.

By 2010, Warren had been exposed to an exceptionally wide range of sequential decision problems. This experience led to a series of articles, starting in 2014 with a tutorial called "Clearing the Jungle of Stochastic Optimization," progressing through two articles in 2016 and 2019 that developed a unified framework for stochastic optimization that bridges all 15 communities that work on sequential decision problems. In 2018-19, he put together two new courses, one graduate and one undergraduate, that brought these ideas (traditionally limited to mathematically sophisticated communities) to a broad audience. He wrote an online book for the undergraduate course that uses a teach-by-example style, and is nearing completion of a graduate-level book, all available at jungle.princeton.edu.

Warren's work was supported by over $50 million in funding from over 70 different projects, including almost 40 projects from a range of industrial companies, and over 30 government grants from

the National Science Foundation, the Air Force Office of Scientific Research, and the Department of Energy.

Warren's research produced 250 publications, most in top-tier journals that have attracted over 18,000 citations. He has written two books, *Approximate Dynamic Programming* (now in its second edition) and *Optimal Learning*, along with an online book: *Sequential Decision Analytics and Modeling*. As he retires, he is nearing completion of *Reinforcement Learning and Stochastic Optimization: A Unified Framework for Sequential Decisions*.

Warren is perhaps most proud of his 60 graduate students and post-docs. He retires with almost 30 placements in academia (including Cornell University, Columbia University, University of Pennsylvania, London School of Economics, Lehigh University, Stevens Institute of Technology, University of Toronto, and Hong Kong University of Science and Technology) and research labs (Lawrence Livermore, IBM TJ Watson, AT&T Bell Labs). He also supervised over 200 senior theses and independent projects.

Over his career, his work contributed to three startups. The first, Princeton Transportation Consulting Group, was started in 1988. PTCG brought his software for both less-than-truckload and truckload trucking to rapidly evolving post-deregulation market. In 1995 he started Transport Dynamics. His third company, Optimal Dynamics, was started in 2016 with his son Daniel Powell as president and CEO, and Warren is looking to continue working with Optimal Dynamics after he retires from Princeton.

Warren is looking forward to bringing his new ideas for sequential decision analytics to an international audience, starting with a series of tutorial workshops (all the material is available at jungle.princeton.edu). He is also looking forward to developing his first MOOC course, and has been actively interacting with researchers around the world. While he will miss teaching at Princeton, he is looking forward to bringing these ideas to a much larger audience.