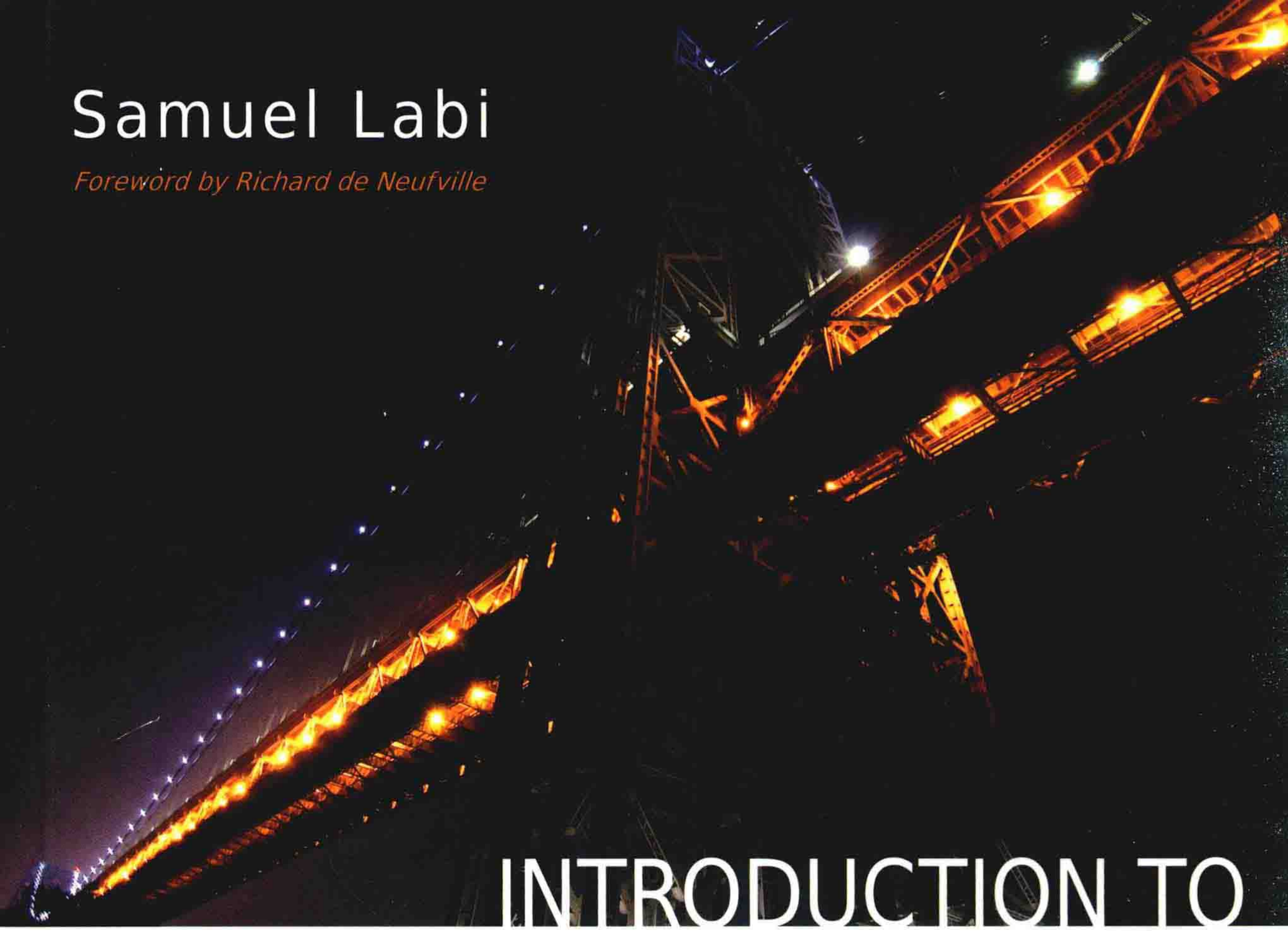

Samuel Labi

Foreword by Richard de Neufville

INTRODUCTION TO CIVIL ENGINEERING SYSTEMS

A Systems Perspective to the Development of Civil Engineering Facilities

WILEY

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FOREWORD

The book in your hands is a most welcome addition to the range of textbooks in civil and environmental engineering. There is no other up-to-date text that covers the important elements of civil engineering systems. This book provides a significant and needed resource for majors in the field.

Labi's *Introduction to Civil Engineering Systems* fills an important gap. The previous lack of a current text on the subject has been most unfortunate. It is clear that the proper development of our infrastructure requires a holistic, coherent understanding of all the important elements that will make our products successful. Civil engineers have a responsibility for the entire life cycle of what we build: from planning, through design, to the management of the facility over its useful life. A civil engineering curriculum should thus provide its students with the opportunity to learn how to consider carefully the range of issues in civil engineering systems. This text now provides a basis for such a capstone course.

This text has the great merit of being thoughtful, innovative, comprehensive, and forward-looking.

- Beyond procedures and methods, Labi thoughtfully presents issues and discusses their whys and hows.
- He has innovatively structured the material as a coherent cycle of eight phases through the life cycle of a project in a way that makes it much easier to make sense of systems thinking.
- He comprehensively defines the tasks that should be done at each phase in the life cycle and describes the tools for each task.
- Aside from being the most forward-looking work in the field, the text recognizes the great uncertainty about future demands on our systems, and the consequent need for a flexible approach to systems design.

Readers will appreciate that this treatment of engineering systems focuses on civil engineering. Its extensive excellent illustrations display a most interesting array of infrastructure projects. This is a book for us. I hope you will like it!

Richard de Neufville
Professor of Engineering Systems and of Civil
and Environmental Engineering
Massachusetts Institute of Technology
Life Member, American Society of Civil Engineers

PREFACE

GENERAL BACKGROUND

The civil engineering discipline involves the development of structural, hydraulic, geotechnical, construction, environmental, transportation, architectural, and other civil systems that address societies' infrastructure needs. The planning and design of these systems are well covered in traditional courses and texts at most universities. In recent years, however, universities have increasingly sought to infuse a "systems" perspective to their traditional civil engineering curricula. This development arose out of the recognition that the developers of civil engineering systems need a solid set of skills in other disciplines. These skills are needed to equip them further for their traditional tasks at the design and construction phases and also to burnish their analytical skills for other less-obvious or emerging tasks at all phases of system development.

The development of civil engineering systems over the centuries and millennia has been characterized by continual improvements that were achieved mostly through series of trial-and-error as systems were constructed and reconstructed by learning from past mistakes. At the current time, the use of trial-and-error methods on real-life systems is infeasible because it may take not only several decades but also involve excessive costs in resources and, possibly, human lives before the best system can be finally realized. Also in the past, systems have been developed in ways that were not always effective or cost-effective. For these and other reasons, the current era, which has inherited the civil engineering systems built decades ago, poses a unique set of challenges for today's civil engineers. A large number of these systems, dams, bridges, roads, ports, and so on are functionally obsolescent or are approaching the end of their design lives and are in need of expansion, rehabilitation, or replacement. The issue of inadequate or aging civil infrastructure has deservedly gained national attention due to a series of publicized engineering system failures in the United States, such as the New Orleans levees, the Minnesota and Seattle interstate highway bridges, and the New York and Dallas sewers, and in other countries. The current problem of aging infrastructure is further exacerbated by increased demand and loading fueled by population growth, rising user expectations of system performance, increased desire for stakeholder participation in decision-making processes, terrorism threats, the looming specter of tort liability, and above all, inadequate funding for sustained preservation and renewal of these systems.

As such, civil engineers of today need not only to develop skills in the traditional design areas but also to continually seek and implement traditional and emerging tools in other related areas such as operations research, economics, law, finance, statistics, and other areas. These efforts can facilitate a more comprehensive yet holistic approach to problem solving at any phase of the civil engineering system development cycle. This way, these systems can be constructed, maintained, and operated in the most cost-effective way with minimal damage to the environment, maximum system longevity, reduced exposure to torts, optimal use of the taxpayers' dollar, and other benefits. Unfortunately, at the current time, graduating engineers enter the workforce with few or no skills in systems engineering and learn these skills informally only after several decades. With limited skill in how to integrate specific knowledge from external disciplines into their work, practicing engineers will be potentially handicapped unless their organizations provide formal training in the concepts of sytems engineering. This text addresses these issues.

THE TEXT

The first part of this text discusses the historical evolution of the various engineering disciplines and general concepts of systems engineering. This includes formal definitions, systems classifications, systems attributes, and general and specific examples of systems in everyday life and in civil engineering. The part also identifies the phases of development of civil systems over their life cycle and discusses the tasks faced by civil systems engineers at each phase. Most working engineers are typically involved in only one or two of these phases, but it is important for all engineers to acquire an overall bird's eye view of all phases so that decisions they make at any phase are holistic and within the context of the entire life cycle of their systems. The next two parts discuss the tasks that civil engineers encounter at each phase and the tools they need to address these tasks. For example, at the needs assessment phase, one possible task is to predict the level of expected usage of the system, and the tool for this task could be statistical modeling or simulation. Certain tools are useful in more than one phase. Given this background, Part IV provides a detailed discussion of each phase of civil systems development and presents specific examples of tasks and tools used to address questions at these phases. Part V presents topics that may seem peripheral but are critical to civil systems development, such as legal issues, ethics, sustainability, and resilience, and discusses their relevance at each phase.

Clearly, this text differs from other texts in the manner in which it presents the material. The systems tasks and tools are presented not in a scattered fashion but rather in the organized context of a phasal framework of system development. Why is it so important to view the entire life cycle of civil engineering systems within a phasal framework? And why do we need to acquire those skills that are needed for the tasks at each phase? One reason is the typically large expense involved in the provision of such facilities. Every year, several trillion dollars are invested worldwide in civil engineering systems, to build new facilities or to operate and maintain existing ones. The beneficial impacts of these investments permeate every sphere of our lives including safety, mobility, security, and the economy and thus need to be identified and measured systematically. Also, adverse impacts such as environmental degradation, community disruption, and inequities are often evident and need to be assessed and mitigated. In summation, given the large expanse and value of civil engineering assets, the massive volume of national and state investments annually to build and operate these systems, and the multiplicity of stakeholders, there is need for a comprehensive yet integrated approach to the planning, design, implementation, operations, and preservation of these systems. A second reason for advocating an organized systems approach is the nature of recent and ongoing trends in the socioeconomic environment: at the current time of tight budgets, increasing loadings and demand, aging infrastructure, global economic changes, and increased need for security and safety, civil engineering systems are facing scrutiny more than ever before and the biggest bang is now sought for every dollar spent on these systems. As such, civil system engineers are increasingly being called upon to render account of their fiduciary stewardship of the public infrastructure and assets. This is best done when the development of such systems is viewed within a phasal framework, when civil engineering system managers acquire the requisite tools needed to address the tasks at each phase, and when these managers provide evidence of organized planning for long-term life-cycle development of their systems.

DIDACTIC STYLE AND RESOURCES

There is a wealth of engineering knowledge that is well documented in textbooks that address specific branches and domain areas in civil engineering and also in other system engineering related disciplines including economics, operations research, and statistics. The author's purpose in writing this text is not to duplicate what already exists but to link the systems concepts from the different disciplines and traditional roles of the civil engineer, and to do this within the context of each system phase, tasks at each phase, and tools for the tasks.

The reader is afforded a clear and understandable text that presents well-explained methodologies and procedures useful for addressing tasks at each phase. Throughout its chapters, the text emphasizes practical applications of the concepts. Theoretical backgrounds are provided only to enable the reader to enhance their understanding of the concepts and to recognize the merits and demerits of alternative theories in solving a particular problem. The chapters and concepts are presented in a sequence and style that are expected to encourage the student to define and solve problems with requisite tools in a manner consistent with engineering and professional excellence. As such, each chapter is an integrated blend of theory and practice, and numerous conceptual and computational illustrations are provided.

As educational experts have acknowledged, students' didactic experience is more fruitful when they are asked to apply the concepts to a real-world problem. As such, a term project, to be carried out by multiperson teams, is recommended as part of any course for which this book is used. A list of possible topics for the term project can be found at the website purposely established for this book. Additional information on each of the 30 chapters, such as updated tools and news items relating to civil systems development at various countries worldwide, Facebook discussions, and YouTube presentations can be found at the book's website.

The subject of civil engineering systems is indeed a broad subject that could fill several texts. As such, there is a limitation to the scope and depth that can be provided in a single text as this. The text therefore provides only a basic fundamental understanding of what civil systems are, the various phases of their development, and the tools needed to address the tasks at each phase. The text serves as a central repository of references for persons interested in further inquiry. Also, recognizing that only a limited number of numerical examples can be included within the covers of this book, the author has provided a set of useful resources at the end of most chapters for the reader who wishes to acquire further knowledge on the subject.

ABET REQUIREMENTS AND AUDIENCE

This text satisfies a significant section of Accreditation Board for Engineering and Technology, Inc. (ABET) requirements for undergraduate civil engineering education such as problem solving, experiments and simulations, data analysis, optimization and financial analysis tools, and use of systems approaches in design of facility components and processes. Also, the text addresses other ABET requirements of socially and environmentally responsible design, engineering practice issues, ethics, licensure requirements, and managerial skills. The text's online resources addresses the requirement of student participation in multidisciplinary project teams.

This book is useful for college instructors and students for courses related to civil engineering systems. Most of the material could be covered in one semester if at least three credit hours per week are used for the course. The book is written primarily for midsenior undergraduate and beginning graduate students. The book should be useful not only in academia but also to practicing civil engineers, civil systems managers and policymakers in general. This includes private and nongovernmental organizations, consultants, international development agencies and lending institutions, public policy makers, government (state, county, provincial, or city) departments, municipal authorities, public works departments, regional planning agencies, metropolitan planning organizations, and other institutions involved in at least one of the phases of civil systems development. These persons will find that the text provides useful fundamentals for understanding and implementing systems perspectives at any of their system development phases of need assessment, planning, design, construction, operations, monitoring, maintenance, or end of life.

ACKNOWLEDGMENTS

The development of a textbook is very much like the development of a civil engineering system—it goes through the initial phases of needs assessment, planning and design of the chapters, feedback from readers, and improvement of subsequent editions. This is particularly true for *Introduction to Civil Engineering Systems*.

First, I recognize the contribution of the pioneers of civil engineering systems: Robert Stark, Robert Nichols, Jeff Wright, Charles Revelle, Earl Whitlach, Lester Hoel, Nicholas Garber, Richard de Neufville, C. Jotin Khisty, Jashmid Mohammadi, Dale Meredith, Kam Wong, Ronald Woodhead, Robert Wortman, Richard Larson, Joseph Stafford, Gerard Voland, and Graeme Dandy. They deserve tremendous credit for blazing the trail, navigating the difficult waters, and thus making it possible for civil engineers to recognize the usefulness of systems concepts to their field.

My appreciation goes to all those who created the materials that served as sources for this text. A large number of books, technical papers, and reports were reviewed during the writing of this text. The work of those who developed these materials served as a valuable knowledge base for developing this book. Without their work, this book would not be the valuable learning resource that it currently is and hopefully will continue to be.

I gratefully acknowledge the support of my colleagues in academia as well as the industry. These include the following professors: Kumares Sinha of Purdue University; Richard de Neufville, Fred Moavenzadeh, and Joe Sussman of MIT; Neville Parker of the City College of New York; Sue McNeil and Nii Attoh-Okine of the University of Delaware; and Adjo Amekudji of Georgia Tech. They also include Dr. Chuanxin Fang of Microsoft Corporation; Mr. Gilbert Kporku of Conterra Limited; and Mr. Arun Shirole, former chief bridge engineer of the New York State Department of Transportation; and Dr. Jung Eun Oh of the World Bank.

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The staff at John Wiley & Sons has been extremely supportive, and I am thankful to editors Bob Argentieri and Margaret Cummins for their continual support and understanding.

Finally, for all the good aspects of this book, I duly reserve credit to my helpers, contributors and supporters; for any flaw, the full responsibility is mine.

AUTHOR BIOGRAPHY

Dr. Samuel Labi is an Associate Professor at Purdue University's School of Civil Engineering. He has seven years experience in consulting at Conterra Limited, where his work traversed different civil engineering disciplines and included economic and technical feasibility studies, facilities planning and design, geotechnical investigations, contract administration, and construction and maintentance supervision. Dr. Labi has worked on projects such as the World Bank–sponsored Transportation Rehabilitation Projects in Ghana, in the late 1980s. His national academic awards include the 2002 Milton Pikarski Award for outstanding doctoral dissertation in transportation engineering, the 2007 Bryant Mather Award for best paper in concrete materials awarded by the American Society of Testing and Materials (ASTM), the 2008 K.B. Woods prize awarded by the Transportation Research Board for the best journal paper in design and construction, and the 2014 Frank Masters Award from the American Society of Civil Engineers (ASCE) for innovative or noteworthy contributions to the planning, design and construction of transportation facilities. He is a member of Sigma Xi (Scientific Research Society) and Chi Epsilon (National Civil Engineering Honors Society) and several professional organizations including the American Society of Civil Engineers (ASCE), International Association for Life-Cycle Civil Engineering (IALCCE), Institute for Operations Research and the Management Sciences (INFORMS), and the American Association for the Advancement of Sciences (AAAS). Dr. Labi has taught a number of undergraduate and graduate-level courses at Purdue University and the Massachusetts Institute of Technology, and he has served as a major thesis advisor for several doctoral students. He is an associate editor of the ASCE Journal of Risk and Uncertainty and member of the editorial board of the ASCE Journal of Infrastructure Systems. He is a reviewer for several major international technical journals, conferences, and textbook publishers and a co-author of *Transportation Decision Making—Principles of Project Evaluation and Programming* published by John Wiley & Sons in 2007.

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