MANUALS AND REPORTS ON
ENGINEERING PRACTICE 147

Objective Resilience
Objective Processes

Edited by
Mohammed M. Ettouney, Ph.D., P.E.

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Objective Resilience

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Objective Resilience

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Mohammed M. Ettouney, Ph.D., P.E.

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MANUALS AND REPORTS ON ENGINEERING PRACTICE

(As developed by the ASCE Technical Procedures Committee, July 1930, and revised March 1935, February 1962, and April 1982)

A manual or report in this series consists of an orderly presentation of facts on a particular subject, supplemented by an analysis of limitations and applications of these facts. It contains information useful to the average engineer in his or her everyday work, rather than findings that may be useful only occasionally or rarely. It is not in any sense a "standard," however, nor is it so elementary or so conclusive as to provide a "rule of thumb" for nonengineers.

Furthermore, material in this series, in distinction from a paper (which expresses only one person's observations or opinions), is the work of a committee or group selected to assemble and express information on a specific topic. As often as practicable, the committee is under the direction of one or more of the Technical Divisions and Councils, and the product evolved has been subjected to review by the Executive Committee of the Division or Council. As a step in the process of this review, proposed manuscripts are often brought before the members of the Technical Divisions and Councils for comment, which may serve as the basis for improvement. When published, each manual shows the names of the committees by which it was compiled and indicates clearly the several processes through which it has passed in review, so that its merit may be definitely understood.

In February 1962 (and revised in April 1982), the Board of Direction voted to establish a series titled "Manuals and Reports on Engineering Practice" to include the manuals published and authorized to date, future Manuals of Professional Practice, and Reports on Engineering Practice. All such manual or report material of the Society would have been refereed in a manner approved by the Board Committee on Publications and would be bound, with applicable discussion, in books similar to past manuals. Numbering would be consecutive and would be a continuation of present manual numbers. In some cases of joint committee reports, bypassing of journal publications may be authorized.

A list of available Manuals of Practice can be found at http://www.asce.org/bookstore.

DEDICATION

This objective resilience manual of practice is dedicated to the essential workers who are exposed daily to the dangers of the COVID-19 pandemic. Included among the many groups of workers are the following: healthcare personnel, first responders, public safety officers, correction facility workers, food and agriculture, grocery store workers, teachers, US postal service workers, public transit workers, and many more people who work tirelessly to maintain a sense of normalcy in these unprecedented times.

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BLUE RIBBON PANEL
(In Alphabetical Order)

Joseph Brennan, R.A. (New York), AIA, is an architect and digital practice evangelist who has worked on projects in various capacities for SHoP Architects, Populous, and Gensler. In addition, he is currently an adjunct assistant professor at Columbia University's Graduate School of Architecture, Planning, and Preservation and has taught design technology–focused courses at various institutions in New York. In addition to practice and teaching, Joseph has mentored students at Columbia University, as well as emerging businesses through the New Museum's New Inc. Incubator program.

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PREFACE

Engineering is a balance between analysis and design. Objectivity forms, mostly, the basis of mathematics and science, which form, mostly, the basis of analysis. Subjectivity forms, mostly, the basis of art, intuition, and imagination, which form, mostly, the basis of design (see Figure 1). Achieving a proper balance between subjectivity and objectivity during

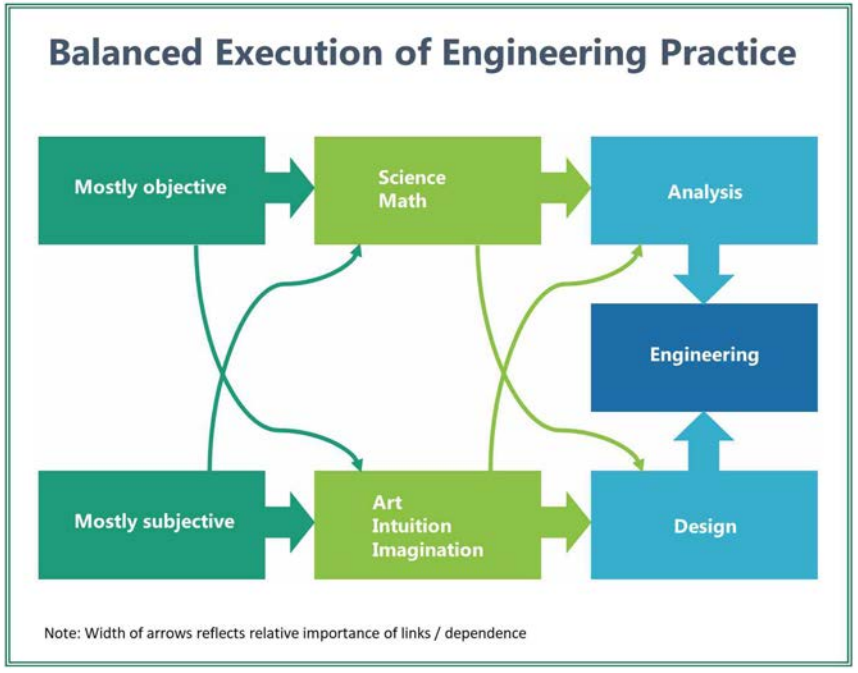

Figure 1. Balanced Execution of Engineering Practice.

the engineering process will ensure an optimal product. This is true especially for complex products that have multitudes of different types of components. Admittedly, community and asset resilience is a complex issue, and as such dealing with it from the engineering viewpoint will require a proper balance between objective and subjective processing.

The Objective Resilience Committee (ORC) of the Engineering Mechanics Institute (EMI) of ASCE was formed in 2015 to help achieve a balanced resilience treatment, especially from an objective viewpoint. Soon after its formation, the ORC initiated the development of an Objective Resilience Manual of Practice (OR-MOP) in 2016. The main objective of the OR-MOP is to provide a comprehensive basis of recommended practices that can help enhance community and asset resilience, while emphasizing the objective side of such practices. The developers of the OR-MOP quickly realized that because of the wide-ranging extent of community and asset resilience, the OR-MOP needed to split its focus into four basic categories: (1) Policies and Strategies, (2) Objective Processes, (3) Technology, and (4) Applications.

This book examines objective processes related to community and asset resilience. It aims at providing a comprehensive set of practices, after presenting and discussing the basis for those practices. It is recognized that this OR-MOP is limited, given the limiting factors of space and time, especially in view of the aforementioned wide-range extent of resilience. However, the developers hope that the OR-MOP can be used as a guide in developing additional MOPs that would address additional aspects of resilience.

The development of the OR-MOP took almost five years. Many worked tirelessly on this project. This includes the authors of the contributing chapters, the external Blue Ribbon Panel, which independently reviewed the manuscript, and the ASCE Publications editors who provided valuable insights and feedback. Special thanks to Dr. Amar Chaker, the EMI director, for his efforts and help, without which this OR-MOP could not have been possible.

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February 2021. West New York, New Jersey

INTRODUCTION

There are several popular definitions for resilience, including NIAC (2009), NSC (2011), or Office of the Press Secretary (2013). For example, NIAC (2009), defines infrastructure resilience as follows:

> Infrastructure resilience is the ability to reduce the magnitude and/or duration of disruptive events. The effectiveness of a resilient infrastructure or enterprise depends upon its ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event.

As defined, resilience represents a major issue for society, given the magnitude of disaster costs of different kinds. Recognizing the needs of society to build and sustain resilient assets and communities, stakeholders (for example, federal, state, and local officials, business owners, professionals, educators, and researchers) devoted considerable effort, time, and expense examining asset and community resilience. Given the wide range of factors that affects resilience, knowledge gaps of the subject are still significant. Similar to most important topics, treatment, handling, and communicating resilience-related matters started with a subjective basis. Objective developments lagged behind their subjective counterparts; however, these developments have been gaining momentum in the last few years. One primary reason for the elevated interest in resilience-related objective processes is that without adequate objectivity, it will remain difficult to provide optimal policies and strategies that aim at delivering practical asset and community resilience at reasonable costs.

Recognizing the need for comprehensive and practical objective views of asset and community resilience, the Objective Resilience Committee (ORC) of the Engineering Mechanics Institute (EMI) ASCE embarked on developing an Objective Resilience Manual of Practice (OR-MOP). The

MOPs of ASCE aim at providing discussions, overviews, developments, and/or best practices concerning different topics. To better attain the stated goals, the OR-MOP endeavors to explore and discuss some of the many issues regarding objective resilience. The OR-MOP also strives to provide best practices sections in all the resilience-related subjects it covers. The OR-MOP attempts to address the intersection of three different areas: resilience (*Re*), civil infrastructure (*CI*), and objective processes (*OP*) (Figure 1). In a set-theory formalism, we can express OR-MOP as follows:

$$\text{OR-MOP} \equiv Re \cap CI \cap OP \tag{1}$$

Owing to the different nature of the chapters of the OR-MOP, we expect that the extent of their treatment of *OP* would vary.

To cast as wide a net for resilience-related objective issues as possible, which is not an easy task in itself, the OR-MOP is subdivided into four books. Each book examines objective resilience from different viewpoints. Figure 2 illustrates the general subjects of the four books.

Providing for resilient assets and communities requires multitudes of types of objective processes. These objective processes are the focus of this book. In particular, we are interested in two resilience objective attributes:

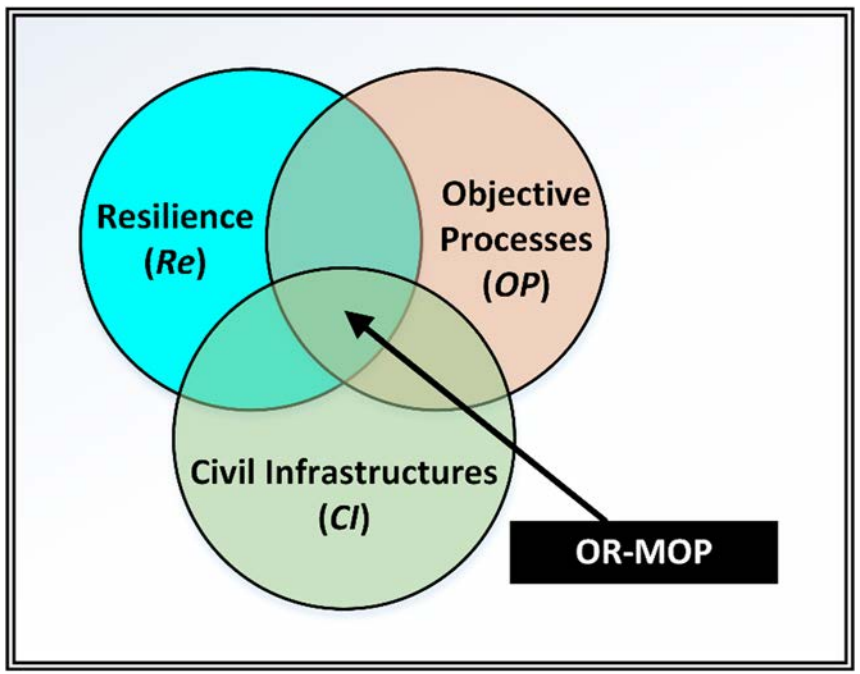

Figure 1. Confluence of domains of the OR-MOP.

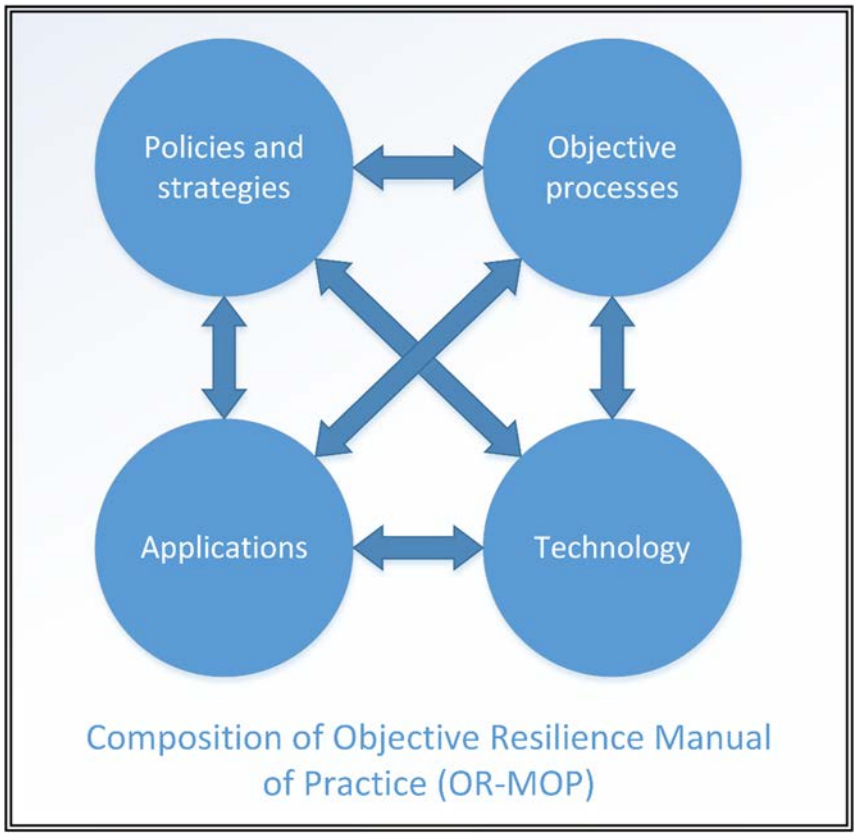

Figure 2. Composition of the OR-MOP.

uncertainties and complexity. Recognizing this, the chapters of this book address these two attributes from different perspectives. Chapter 1 offers comprehensive discussions of different methods that address uncertainties of resilience and its components. Chapter 2 explores the relationships between resilience and reliability while highlighting the fact that reliability is a subset of resilience. Similarly, Chapter 3 provides a comparison between resilience and sustainability. The chapter argues that resilience and sustainability, although having several similarities, are different paradigms that need different treatments. Chapters 4 through 7 offer discussions of resilience complex modeling techniques. Chapter 4 studies the interdependent functionality and recovery. Chapter 5 looks at applying the emerging machine learning processes to objective treatment of resilience. Chapter 6 offers an objective application for achieving resilient cities. Finally, Chapter 7 describes a new method for resilience assessment of regions via considerations of their lifeline systems. All chapters propose

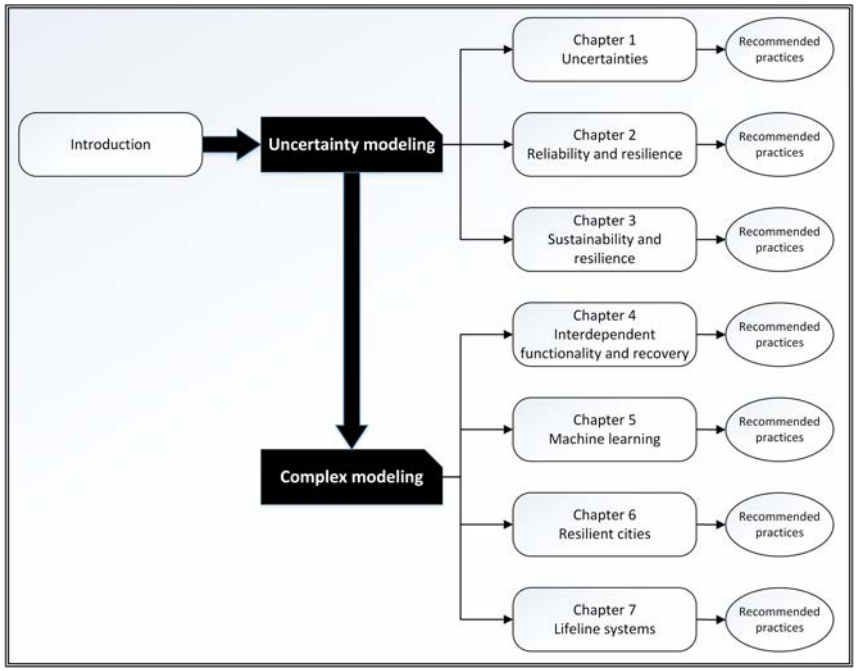

Figure 3. Map of this book (objective processes).

a set of recommended practices at the conclusion of each chapter. See Figure 3 for a map of the organization of the book.

The intended readers of this OR-MOP include all civil infrastructure stakeholders, who may broadly include the following:

- Public and private civil infrastructure organizations (transportation, water resources, bridges, healthcare);
- City, county, and state officials;
- Emergency managers;
- Public safety personnel;
- Facility managers;
- Security consultants;
- Engineers, architects, and other design professionals;
- Educators; and
- Researchers.

Although a wide range of objective complexities are covered in the chapters, a deep knowledge of these objective topics is not required to achieve familiarity and benefit from the content. For readers who may not have the time to go in depth into each subject matter, it is suggested that they initially become familiar with the "recommended practices" at the

end of each chapter. Each reader can then look at the chapter in depth to learn the reasonings/sources of these recommended practices.

Note that ASCE Manuals of Practice (MOPs) are developed by ASCE technical committees, such as the ORC, under the direction of an ASCE sponsor such as the Engineering Mechanics Institute (EMI). The distinguishing characteristic of an MOP, including this one, is that each one undergoes a peer review by a Blue Ribbon Panel of experts before final approval is sought from the appropriate executive committee. Thus, the peer review by the Blue Ribbon Panel gives added weight to the MOP.

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CHAPTER 1
UNCERTAINTY QUANTIFICATION IN OBJECTIVE RESILIENCE

George Deodatis

1.1 INTRODUCTION

Uncertainties are extremely common when studying the civil infrastructure. Civil engineering infrastructure systems exhibit uncertainties as we do not know their various properties (e.g., strength) with sufficient accuracy. To complicate the problem further, these system properties are not constant in time, because the civil infrastructure undergoes continuous aging and deterioration. Furthermore, the excitations/loads acting on structures involve a high degree of uncertainty, especially in cases of extreme disturbances (e.g., natural and technological hazards).

The natural consequence of all these uncertainties is the introduction of risk. Resilience is intimately related to risk, as it is, in general, considered to be a subset of risk. As resilience is, in general, dealing with the time necessary for an infrastructure system to return to an acceptable operational state following a disturbance of its operation, it becomes immediately clear that all the aforementioned sources of uncertainty play an importance role in resilience. This chapter mentions that resilience is directly connected to the commonly known 4Rs: robustness, resourcefulness, recovery, and redundancy. All 4Rs exhibit various degrees of uncertainty.

Virtually every chapter in this manual of practice makes reference directly or indirectly to the various uncertainties involved in the problem of resilience and provides guidance on how to account for them.

The chapter on "Quantitative Models for Interdependent Functionality and Recovery of Critical Infrastructure Systems" makes reference to the random dependence of failures of different infrastructure components and to discrete-event simulation models such as fault tree analysis and event