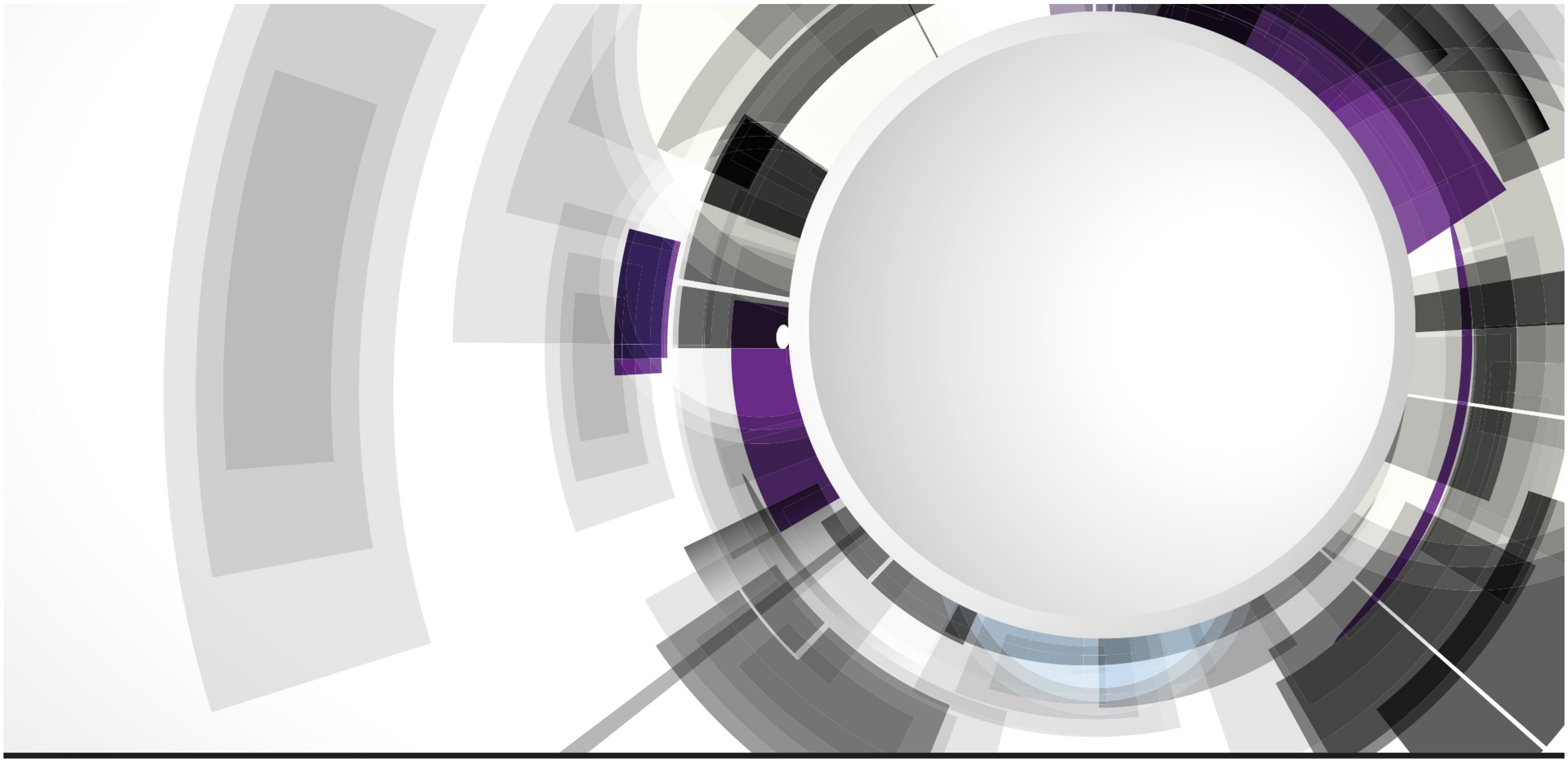

Creating Resilient Transportation Systems

Policy, Planning, and Implementation

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CHAPTER

Introduction

1

1.1 The emergence of transportation resilience in the 21st century

The first two decades of the 21st century continued the trend of increasing disaster frequency and severity. Combined with long-term changes in climate and sea-level rise, these conditions are fundamentally altering the way transportation systems and infrastructure are planned, designed, operated, maintained, and funded. In addition, growing security risks and aging of physical infrastructure further heightens the need to respond to these slow changes.

Building upon the institutional changes that started with the environmental movement of the 1960s and continued through the sustainability and multimodal transportation movements of the 1980s, a new paradigm of transportation, emphasizing resilience, has emerged. Planners and engineers are now focusing on how susceptible transportation systems and networks are to natural and human-caused threats, including plans for response and recovery when systems fail. The increasing need to create resilient systems is particularly vital because it also calls upon expertise from many disciplines, beyond traditional planning and engineering professionals, that must consider system functionality under duress, during times of disruption, and reduce the impact of carbon emissions in mitigating future disasters.

In this book, readers will learn that the concept of resilience does not have a single definition. Instead, it means different things to different people. Furthermore, the application of resilience is also context-dependent. Emerging needs of the 21st century must increasingly focus on environmental stewardship and sustainability as part of long-term transportation goals. Resilient approaches to transportation play a significant role in achieving these goals because they require planners and engineers to think about the future and the present, especially if and when systems fail and services are interrupted or diminished from any number of causes, both large and small.

This book takes a comprehensive approach to describe resilience and how practitioners can integrate it into routine transportation services. Rather than focusing on only high-profile attention-grabbing catastrophic disasters, the authors examine a wide range of disruptive conditions that impact transportation, from the most exceptional to routinely occurring. This book also addresses resilience from theoretical and practical perspectives that range from basic definitions and concepts, to principles and methods, to applications and practices that range from well utilized to emerging

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ideas and concepts. In this way, this book provides a valuable resource to readers, whether they are students just learning about the topic, to experienced professionals seeking new ideas and effective, practical, economically achievable practices to serve users' needs, including the most vulnerable members of society.

1.2 Recognition of resilience need and its evolution into practice

The Clean Air Act of 1963 and the National Environmental Policy Act (NEPA) of 1969 were significant laws that established a national framework to protect and preserve the environment. As a result, society began to scrutinize transportation infrastructure at increasingly more stringent levels because of its prominent contribution to air pollution, environmental impacts of construction, and social disruption to communities, including ethnic and racial minority populations. NEPA set forth a rigorous new environmental assessment and impact analysis process to guide practitioners toward improvements in practice. The process involved consideration of alternatives and community engagement in decision-making. However, the field continued to increase road capacity and highway construction, leading to more land development in a sprawling fashion despite the environmental policy aims.

In the decades since NEPA, a continued and ever-increasing reliance on automobile-based personal transportation led to more traffic congestion, worsening air quality, and ongoing concerns about the fundamental societal quality of life. Later, policymakers and elected officials enabled flexibility to fund multimodal transportation systems through the Intermodal Surface Transportation Efficiency Act of 1991. However, while environmental groups pushed for actions to shift toward more sustainable modes of travel to reduce automobile dependence (Newman and Kenworthy, 1989, 1999), there were debates in the planning field as to whether Los Angeles style sprawl was desirable or not persisted (Gordon and Richardson, 1997; Ewing, 1997).

On an international level, the United Nations Brundtland Commission defined sustainability to include consideration of future generations (Brundtland, 1987). By the turn of the new century, a movement focused on the transportation sector's over-reliance on fossil fuels and excessive carbon emissions contributing to the planet's warming due to the greenhouse effect.

With the new millennium, the focus on environmental risk and impact shifted toward security risks and disruptions following the terrorist attacks of September 11, 2001, when America witnessed the weaponization of transportation (Kim, 2021). As a result, the transportation industry changed focus to Homeland Security as President Bush created the Department of Homeland Security and the Transportation Security Administration in 2002. Suddenly, there were massive changes in spending and increased focus on border control, surveillance, and interdiction. In addition, federal grants and programs focused attention on infrastructure protection and no-notice disasters, emphasizing preparation, response, and quick recovery.

Hurricane Katrina in 2005, one of the first mega environmental disasters linked to climate change, swung the pendulum back to environmental threats. Unfortunately, after the Katrina disaster, a near-annual procession of other significant disasters ensued, suggesting a long-term trend toward increasing the frequency and scale of the threat. In the United States, Hurricane Rita, Superstorm Sandy, Hurricane Irma, Hurricane Harvey, Hurricane Maria, Hurricane Michael, and countless wildfires across the West highlighted the need to account for such conditions in the planning and design of transportation systems and infrastructure. The threat is prevalent in all parts of the world, which has witnessed a changing climate and similar severe threats. Nations and communities in the low-lying coastal areas, which constitute about 40% of the global population, face a long-term existential challenge.

Planners and engineers can anticipate many of the needs for resilience. However, despite best efforts to achieve high levels of safety and maintain maintenance needs, conditions that require planned disruptions can arise. Transportation agencies can routinely budget for most circumstances, but some disruptions come unexpectedly and with tragic consequences. For example, the collapse of the I-35 Mississippi River Bridge in Minneapolis in 2007 raised the problem of aging infrastructure at the cost of 13 lives, 145 injuries, and hundreds of millions of dollars.

The American Society of Civil Engineers scores the nation's infrastructure at C- (ASCE, 2021). They reported that 43% of public roadways are in poor or mediocre condition and 7.5% of the nation's 617,000 bridges are structurally deficient. As a result of the environmental and sustainability movements, emphasis on multimodal systems, a recent focus on security risk, aging infrastructure, mega-disasters, and climate change threats, the concept of transportation resilience is emerging as the leading paradigm driving the fields of transportation planning and engineering to identify and address these needs.

1.3 Book themes

The authors identified six key themes that underlay this book within the emerging transportation resilience paradigm described above and illustrated in Fig. 1.1. Each seeks to inform and contribute to the conversation on each key topic of transportation resilience. Since transportation resilience is still evolving, the concepts presented here reflect practice as it is known and the emerging set of research and professional guidance on these topics. The six themes presented below help frame the chapters in this book that address different dimensions of transportation resilience.

Theme 1: Definitions of resilience, adaptation, and mitigation are confusing and often need to be qualified

Theme 1 includes two parts—Theme 1a: different conceptualizations confuse the definition of resilience. In engineering, the definitions focus more on "bouncing back" versus planning, which focuses on "bouncing forward"; and Theme 1b: mitigation and adaptation further confuse the conceptualizations of resilience.

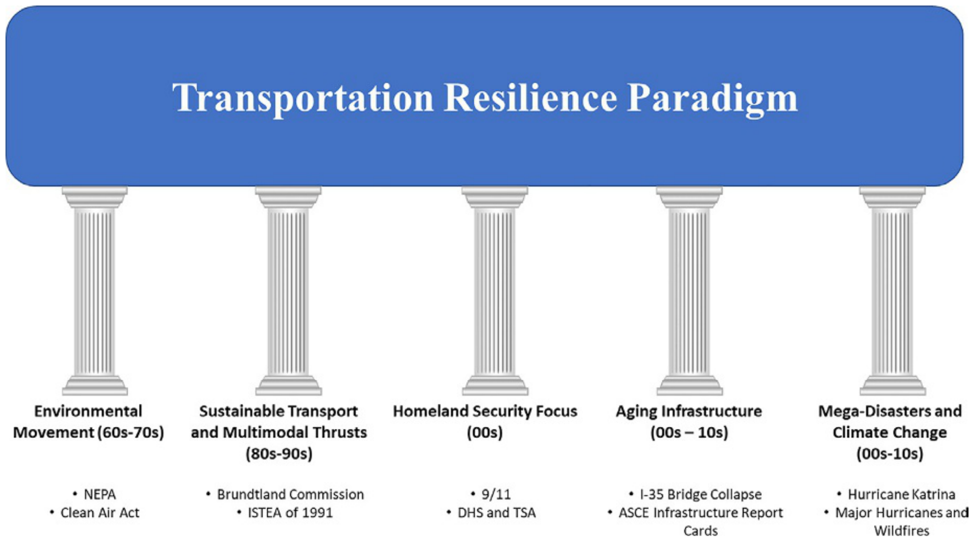

FIG. 1.1

Pillars of the transportation resilience paradigm.

Theme 1a: Different conceptualizations confuse the definition of resilience. Engineering focuses more on "bouncing back" versus planning, which focuses more on "bouncing forward"

Chapter 2 discusses the different conceptualizations of resilience. For example, *Engineering Resilience* is the ability for a system to return to equilibrium, which is about "bouncing back" after a disaster. On the other hand, planners focus more on *Ecological Resilience* and *Evolutionary Resilience*. The former is the ability of a system to cope with perturbations before shifting to a new stability domain, whereas the latter focuses on the very nature of systems changing to a new state challenging the very wisdom of the status quo. In other words, if we define *Planning Resilience* as the combination of Ecological or Evolutionary Resilience, we could say that planners focus more on "bouncing forward," whereas engineers generally focus on "bouncing back" (Fields and Renne, 2021).

Multiple definitions confuse the understanding of "resilience" when the term is not qualified. The conceptualization of resilience in planning stems from the fact that planners focus on the future, as they are responsible for long-range planning activities for government agencies. Comprehensive plans typically focus on the distant future (25–40 years into the future). Therefore, the idea of "bouncing back" is not as relevant to planners since they are projecting into a distant future, and by the very nature of their planning efforts, they are seeking to advance their community or "bounce forward."

Of course, planners do not solely focus on the future. Planners are also involved in solving current issues, including affordable housing, social inequities, economic development, historic preservation, and protecting or maintaining the quality of life or existing assets and systems. There are also colonial legacies and built-up structural inequities and systems which reinforce discrimination and marginalization of poor, minority, and underrepresented groups. Many urban planners are responsible for projects in the present or near term, and to this extent, planners often are also concerned about Engineering Resilience or the ability to "bounce back."

Engineering as a profession is typically concerned with building infrastructure and designing systems to solve present problems to withstand future disruptions for long-term strength. Engineers try to design with Engineering Resilience to allow the infrastructure or system to "bounce back" when a disruption occurs.

The challenge is that Engineering Resilience means something fundamentally different from Planning Resilience (Ecological and Evolutionary Resilience). It is also not that all engineers are only concerned with Engineering Resilience or all planners are only concerned with Planning Resilience. Generally, the duties of most engineers are to design infrastructure and systems from the present to the future with a focus on protection from future disruptions. The duties of many planners are to focus on different and better or more sustainable futures. Planners then seek to work backward to identify ways to break from the status quo.

Theme 1b: Mitigation and adaptation further confuse the conceptualizations of resilience

The concepts of mitigation and adaptation are often confusing to many. Mitigation focuses on elimination or working toward fewer effects of disruptions. In the hazards field, the focus of mitigation is on harm reduction. With environmental planning, mitigation involves lessening the impacts of development. Mitigation is often qualified as *climate* mitigation, and Chapter 3 summarizes the *London Environment Strategy* and *Mayor's Transport Strategy*, which seek to achieve long-term climate mitigation goals of reducing greenhouse gas emissions to reign in global warming. Disasters are not always unavoidable; therefore, much of Chapter 4 recognizes that adaptation is necessary to lessen disaster impacts on infrastructure. Chapter 5 discusses many strategies, including strengthening and retrofitting to increase coping capacity or the ability to resist stress, absorb impact, and resist performance degradation.

While mitigation and adaptation have relatively clear definitions that can be nested under the general definition of resilience, professionals, scholars, and public agencies often use the term *resilience* interchangeable with *mitigation* or *adaptation*, which can be confusing. For example, if an agency wants to promote transportation resilience using the engineering resilience framework with an emphasis on adaptation, it may choose to invest limited public resources into widening and strengthening a highway. On the other hand, an agency that wants to promote transportation resilience using the planning resilience framework, with an emphasis on mitigation, may choose not to invest in the highway and redirect the funds into other modes.

This example illustrates the fundamental problem with the term *transportation resilience*. While the term is applicable, it is overly broad, and without qualifications, it could mean many different things to different people. Moreover, as illustrated above, resilience could justify exactly opposing outcomes. On the one hand, resilience justifies investing more money into a specific piece of infrastructure (such as a highway noted above), or resilience could justify redirecting resources into other infrastructures, which could essentially mean abandoning some infrastructure in the name of resilience.

Generally, our society does not willfully choose to abandon infrastructure unless there is a solid reason. Therefore, Chapter 6 summarizes lessons from major disasters, which sometimes cause the need to abandon infrastructure, retrofit it, or adapt it for new uses.

Theme 2: Timescale is necessary because resilience informs and varies along three temporal periods, including: (1) disaster response, (2) recovery and restoration, and (3) long-term change

Chapter 2 defines three temporal periods: response, recovery and short-term restoration, and long-term change. As discussed in Chapter 4, it is crucial to incorporate resilience into all agency functions, including planning, design, engineering, operations, maintenance, finance, and business activities.

In practice, most government agencies that own and manage transportation infrastructure face day-to-day challenges of supplying services and managing tight budgets. The concept of resilience is often not tangible until agencies face a significant disaster that disrupts service and everyday operations. Chapter 6 summarizes lessons from significant disasters and disruptions. Disasters can affect transportation infrastructure and operations. Not only are agencies concerned with their own needs, but the Federal Emergency Management Agency's (FEMA's) National Response Framework Emergency Support Framework no. 1 focuses on transportation. FEMA notes,

> *Transportation provides support by assisting local, state, tribal, territorial, insular area, and Federal governmental entities, voluntary organizations, nongovernmental organizations, and the private sector in the management of transportation systems and infrastructure during domestic threats or in response to actual or potential incidents.*
>
> **FEMA (2016)**

Transportation resilience is critical because, like electricity, water, and sewerage, it is one of the fundamental systems that enable society to function. When the transportation system fails, many other economic and social systems, which rely on transportation infrastructure, also fail. Therefore, understanding how timescale relates to resilience is critical because it needs to be repaired and restored before other systems can come back online when a disaster strikes.

Disaster response is critical to saving lives. Recovery and restoration are critical to the economy and communities, and a resilient long-term change is critical to thriving in the future. Each temporal period offers a different set of needs and measures discussed throughout this book. Components, concepts, and processes inform each temporal period, as discussed in Theme 3.

Theme 3: Scholars and professionals have attributed many components, concepts, and processes to resilience, including but not limited to redundancy, diversity, efficiency, autonomous components, strength, collaboration, adaptability, mobility, accessibility, safety, recovery, robustness, risk, rapidity, systems, assets, and networks

Chapters throughout this book discuss a variety of components, concepts, and processes of transportation resilience. Redundancy enhances resilience because system users have an alternative way to get to their destination if one pathway fails, as was critical during the terrorist attacks on September 11. Chapter 9 identified redundancy as the "means" to achieve resilience. Diversity is related to redundancy but typically relates more to a wide range of modes. While diversity has been a staple in urban centers, such as New York and London, Chapter 3 discusses the importance of multimodal transportation systems, which are integral for diversity. In recent years, many places have increased modal offerings given transportation network companies such as Uber and Lyft along with e-bikes and e-scooters.

Efficiency is an essential concept for resilience because transportation agencies have limited resources. In some ways, efficiency and redundancy can be viewed as opposites on a spectrum because increased redundancy can often be less efficient. However, as noted above, timescale is essential because too much efficiency during blue skies (normal day-to-day operations) could lead to service cuts, resulting in less diversity and redundancy to maximize efficiency. Such an approach could cascade into catastrophic system failure during and after a disaster, which could significantly decrease the engineering resilience of the system and ultimately create less efficiency when measured over a longer temporal scale. The tricky job for administrators, planners, and engineers is to balance efficiency to ensure short-term goals without compromising the overall resilience of the transportation infrastructure and system.

Automation is increasingly driving our society. Soon, vehicles will become self-driving, but even today, there are many examples of autonomous components in our transportation system, from traffic signalization on highways to driverless metro systems. Moreover, this technology connects people through smart devices to better engage with the system, including real-time traffic, mobile ticketing, rental cars, shared bikes, and e-scooters. As discussed in Chapter 9, autonomous systems can enhance resilience efforts and open new avenues for cyber-security threats, which could cause problems for resilience. For example, a hacker cannot disable an independent vehicle not connected to a computing network, but the benefits of autonomy appear to outweigh security threats.

Strength is a straightforward concept, but again, it could serve as an opposing concept to efficiency. Building stronger infrastructure often comes at a cost, which some may view as inefficient. However, collaboration and adaptability are concepts that can help to rectify these issues.

Theme 4: Social, economic, and environmental systems and environments are both inputs to and outcomes of transportation resilience

Transportation resilience includes social, economic, and environmental systems and environments as both inputs and outputs. For example, the level of preparedness in a community relates to social capital and includes governance, community engagement, and civil society. The more prepared a community is, the more resilient they become. Thus, a virtuous cycle can emerge because they can return to normalcy faster when an emergency or disaster strikes with social, economic, and environmental benefits.

On the other hand, a vicious cycle may ensue due to a lack of preparedness from a lack of community interest or commitment. Factors may stem from a lack of funding, community discord, or environmental factors. For example, a neighborhood built in a hazardous location could be at more risk than another neighborhood located in a safer location. Once a disaster strikes, the lack of social, economic, and environmental preparedness could result in more casualties, social strife, economic impact, and environmental consequences. These impacts could continue longer, creating a negative feedback loop making a recovery more challenging.

This process could occur in short or long timescales. Climate change, for example, is a long timescale and arguably caused by social, economic, and environmental policy and decisions. Over time, the impacts of climate change create adverse outcomes that impact communities, economies, and the environment.

This theme is implicitly addressed in every chapter but is most relevant to Chapters 2–6 and 8.

Theme 5: Technology, including autonomous vehicles and connected and web-enabled transportation systems, allows for increased solutions to enhance resilience and increased threats due to cyber-security

There is much excitement for the role of technology in the future of transportation, including autonomous and connected vehicles, along with web-enabled transportation systems. Such systems can enable more resilient transportation outcomes and open up new threats to the transportation network through cyber-security threats. While Chapter 9 focuses on this topic specifically, it is also particularly relevant to Chapters 3, 6, and 7.

Theme 6: As climate change unfolds and the severity of disasters increases, the need for resilience will also increase

The final theme is crucial and emphasized in Chapter 10. In some ways, this theme reinforces the importance of Theme 1 and builds upon it. As the impacts of climate change become acute, transportation infrastructure will be affected by the increasing frequency and severity of natural disasters. As a sector, transportation serves a vital role in implementing carbon reduction strategies, known as mitigation. However, as the severity of disasters increases, adaptation will also be critical.

Leaders working on transportation policy and funding bills in many nations, including the United States, increasingly recognize the need for a proactive approach to transportation resilience. There is hope that as the industry shifts from petroleum-based fuel to electric vehicles (EVs), transportation can generate lower levels of carbon emissions, staving off the worst-case scenarios of climate change predictions. However, in most countries, the bulk of the funding for transportation infrastructure comes from gasoline taxes.

As gas taxes plummet into the future with the increasing adoption of EVs, funding for transportation infrastructure, including resilience, will also be in jeopardy, which is a critical factor that transportation resilience is a paradigm shift and not just a new policy program or movement. As we embrace transportation resilience, including the decarbonization of the system, we lose the ability to pay for transportation infrastructure resulting in significant implications for public policy in all states and nations that use gasoline taxes to pay for infrastructure.

This juggernaut is more of a political issue than a technical problem. Experts have proposed solutions such as a vehicle mile traveled tax, but that has not been widely popular and may also reinforce automobility in an era where people shift their transportation behaviors to a suite of modes. Using technology, such as mobility-as-a-service apps, could be a way forward.

While the topic of this book is not about transportation infrastructure finance, it is vital to recognize the connections with finances as a component of resilience and the paradigm shift it represents. For example, if society continues a status quo path, the transportation system will continue to exacerbate climate change, and the need for resilience will increase. On the other hand, if society shifts to EVs and other sustainable modes, the funding system that has been in place for decades to pay for infrastructure will evaporate.

This book focuses on transportation modes, engineering, and system design, network resilience, international case studies of disasters and disruptions, traveler adaptations, measuring and assessing resilience, and automation and connected vehicles. However, we hope this book serves to open a broader dialog that relates to the emerging topic of transportation resilience and how it relates to other topics such as finance and public policy.

1.4 Book outline and chapter summaries

This book contains eight content chapters that address critical areas of interest on ongoing work in the field and highlight tools, practices, and experiences that illustrate the need for and benefits of resilient approaches to transportation. The following section provides a summary of each chapter.

1.4.1 Chapter abstracts

1.4.1.1 Chapter 2—Defining resilience

This chapter provides the definition of resilience used in the theoretical and applied literature to contextualize the materials in this book that pertain to engineering resilience, measuring resilience, and discussing resilience from a network perspective. Given the number and scale of recent natural and man-caused disasters, resilience is emerging as an essential framework for transportation agencies to ensure that the transportation system can withstand increasing vulnerabilities resulting from risks such as climate change, terrorism (including cyber-attacks), and aging infrastructure. This chapter focuses on definitions provided in both theoretical as well as applied literature, which is helpful to gain an understanding of prior work, both domestically and internationally; its evolution into current transportation planning and policy; and the likely directions of its continued integration into Transportation Systems Management and Operation.

It provides several definitions of transportation resilience, followed by a section on risk, vulnerability, and transportation system threats, including climate change, sea-level rise and extreme weather, terrorism, and aging infrastructure. Next, the chapter addresses transportation planning and policy within a resilience paradigm. The chapter then focuses on resilience in the context of agency planning, policy, and operational approaches followed by intermodal freight. Finally, the chapter concludes with a discussion of these resilience definitions in the context of materials provided in subsequent chapters of this book.

1.4.1.2 Chapter 3—Multimodal transportation systems

A resilient, multimodal transportation system consists of modes of travel that provide people with options and choices during normal conditions and emergencies. This chapter begins with a discussion of different modes and how they relate to resilience. The chapter then discusses the importance of multimodal evacuation planning to increase resilience during emergencies and disasters, followed by a discussion of the COVID-19 pandemic and how it is reshaping the transportation system, potentially creating a greater level of resilience to climate change through travel reduction and shifting from a system that is focused mainly on automobiles to one that is more balanced across modes.

1.4.1.3 Chapter 4—Engineering and system design for resilience

Engineering, construction, and maintenance practices for civil infrastructure systems have evolved to reflect routine and expected conditions. Increasingly, however, there has been greater effort to incorporate the needs and conditions associated with periodic, less-frequent, and unexpected disruptive events into routine practice. These efforts are broadly classified as resilient-oriented engineering. And while catastrophic disasters tend to capture most of the attention, ideal resilience practices are also easily adaptable to counter minor and routinely occurring disruptions that frequently result in travel delays and inconvenience. This chapter discusses these emerging and evolving engineering practices as well as the standards, policies, as well specialized approaches that complement them to more resiliently plan, design, construct, operate, and maintain transportation infrastructure systems. Since there are no universally accepted methods to achieve resilience, this chapter also examines research and emerging policy-creation as these will likely point the way toward resilient engineering systems and methods of the future.

1.4.1.4 Chapter 5—Increasing transportation network resilience

Transportation systems are critical to society for everyday activities, evacuation, disaster response, and recovery. When a disaster or other event affects other infrastructures, they cannot be repaired without an intact transportation network. Thus, transportation systems need to be resilient—able to maintain an acceptable level of service and recover quickly when necessary. This chapter examines one general element of the complex transportation system—the network, representing an arrangement of infrastructure components. To improve the resilience of the network, several general strategies exist, including, but not limited to, retrofitting network elements and designing them to higher standards, designing the network with extra capacity and redundancy, expanding the network through new paths and/or capacity, responding to the disruption with flexible uses of the network, and having repair resources that can be accessed quickly. These strategies help increase the network's ability to resist failure and performance (e.g., connectivity or travel time) degradation. Infrastructure interdependencies complicate the analysis and prioritization of network components and resilience activities. Funding resilience improvements is a challenge since there are few dedicated funding streams and the resilience activities compete with other transportation project priorities. Strategies that can serve both rare events and more common events may be easier to prioritize.

1.4.1.5 Chapter 6—International perspectives

Based on research on recent disasters from around the world, this chapter identifies lessons and strategies for strengthening the resilience of transportation systems. It argues that transportation is essential to the resilience of other systems which support disaster response and recovery. There are three reasons to focus on international perspectives of transportation resilience. First, in both developed and developing countries across the world, there are useful ideas, policies, and practices supporting transportation resilience. Second, a broad spatial and temporal perspective provides insight into not just different hazards and threats but also effective transportation strategies related to response, recovery, mitigation, and preparedness for disasters. Third, many threats and hazards faced by those managing transportation systems including climate change, sea level rise, and other global problems and require plans, actions, and interventions of public and private actors at different scales including neighborhood, city, regional, national, and global. International perspectives are useful for comparative analysis and for the development of collective actions to reduce stressors and increase resilience. Urbanization, globalization, and new technologies affect not just the quality of transportation services but also the longer term performance and resilience of these systems. There are important lessons to be distilled from international cases in terms of exposure to future threats and hazards and in understanding coping mechanisms, adaptation strategies, and transportation resilience.

1.4.1.6 Chapter 7—Traveler adaptation to transportation disruptions

This chapter focuses on how people adapt their travel to disruptions in the transportation system. This adaptation can reduce travel and/or transfer volumes to other modes of transportation, routes, and times of day to take advantage of reduced congestion for the alternatives. Some travel changes, such as departure times and routes, are more common and easier to make. Other changes occur at a strategic level and require resources. This chapter discusses resources and limitations that affect these travel changes. Furthermore, this chapter recognizes that the travel conditions during a disruption and restoration of infrastructure and service are dynamic as travelers' personal situations and their environment evolve. Transportation providers need to understand these adaptations and constraints so that their strategies align with travelers' need and capabilities.

1.4.1.7 Chapter 8—Measuring and assessing resilience

The ability to effectively apply resilience-oriented thinking into practice starts with understanding, measuring, and evaluating the benefits and costs of resilience. With this knowledge, it also becomes possible to comparatively assess potential planning, design, and maintenance options to be able to most effectively plan and allocate financial and personnel resources to address needs. Other key components of practical and meaningful measurements and assessments of resilience are establishing metrics that quantify its performance and knowing what and how much data to collect; then understanding what these data mean so that goals, objectives, and expectations of resilience can be set—both within transportation organizations and for the consumers of the services they provide. Unfortunately, there is no universal agreements on what resilience even is, let alone how to systematically measure and assess it. However, recent reviews of practice and research show that ideas and methods to evaluate and assess resilience are evolving at a rapid pace, both within and outside of transportation. This chapter presents a summary of these ideas and compares and contrasts the effort they require implement and the benefits they are expected to bring.

1.4.1.8 Chapter 9—Resilience, automation, and connected and automated vehicles

Breakthroughs in connected and automated vehicle (CAV) technologies seem poised to revolutionize transportation systems along with the ways we live, work, and build our communities. This chapter provides a review of recent literature on CAVs in the context of how the CAV revolution might impact or be impacted by concerns around resilience. It places the role of CAVs in resilient communities in an appropriate context. The discussion is framed around resilience-related challenges and opportunities that stem from the CAV revolution. The review demonstrates that both the challenges and opportunities arise from interdependencies among cyber, physical, and social systems as they evolve in light of CAV adoption. CAV adoption will accelerate the trend of cyber-security becoming the critical component of the interdependent infrastructure's resilience. The chapter concludes by providing future venues for students, researchers, policymakers, and regulators to explore.

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