TRANSPORTATION ENGINEERING

A Practical Approach to Highway Design, Traffic Analysis, and Systems Operation

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Mc Graw Hill Education

Transportation Engineering

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Preface

Transportation—the movement of people, goods, and services in a safe and efficient manner—is a foundational component of society and has been for eons. It is essential to how we live our lives, it drives the economy in countless ways, and it often only comes to the attention of society when it fails to live up to its expectations. Millions of individuals are responsible for keeping this behemoth in working order, and they face challenges at every turn. Professionals with a broad range of skills undertake the cradle-to-grave responsibility of planning, funding, designing, constructing, operating, maintaining, repairing, retrofitting, and upgrading the entire transportation system across all modes to meet society's demands. This textbook focuses on the surface roadway network, which is one aspect of this system with which nearly all travelers across the globe are familiar. It provides information on the critical scientific principles needed to create a safe and efficient system and addresses the interrelated topics of demand and operations, which directly affect the sustainability of the surface network. It also highlights emerging topics that transportation professionals are beginning to face that could revolutionize the way we travel in the future.

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CHAPTER 1
Introduction

1.1 Introduction

Transportation—the movement of people, goods, and services in a safe and efficient manner—is a foundational component of society and has been for eons. It contributes to the safety, security, and prosperity of global economies and is something that many individuals often take for granted. The action of getting into a car to drive to work on smooth roads with minor interruptions while arriving safely is undertaken millions of times each day without a second thought by the driver. Additionally, passengers take millions of commute trips by bus, train, bicycle, or walking, arriving at their destination without the hassle of driving themselves. Furthermore, they likely conducted business or handled personal issues via telephone along the journey if they were not driving alone in a vehicle. Consumers fill their shopping carts with products without considering how they got from the field, plant, or factory to the shelf in the store, much less how the various components originally arrived at the factory. Their online purchases arrive at their doors in only a few days and, in some cases, hours. Consumers fly around the country or the globe in comfort, passing through major airline hubs with every convenience available. However, when individuals do not have access to affordable transportation, their ability to make a living, to take care of their personal health and that of their family members, and to contribute to society is impaired. As individuals age, their ability to be independent deteriorates, making access to affordable mass transit or other means of mobility even more critical to a high quality of life. The same can be said for those with disabilities that make driving a personal vehicle impractical or impossible. Transportation is an integral part of life in today's rapidly advancing world that must be maintained in terms of affordability, flexibility, and sustainability.

Transportation is essential to how we live our lives, it drives the economy in countless ways, and it often only comes to the attention of society when it fails to live up to its expectations. Millions of individuals are responsible for keeping this behemoth in working order, and they face challenges at every turn. Professionals with a broad range of skills undertake the cradle-to-grave responsibility of planning, funding, designing, constructing, operating, maintaining, repairing, retrofitting, and upgrading the entire transportation system across all modes to meet society's demands. This textbook will focus on one aspect of this system with which nearly all travelers across the globe are familiar: the surface roadway network. While surface transportation is by no means the sole mode of transportation used today, it represents the most common mode with which travelers interact on a daily basis. This text will provide information on the critical scientific principles needed to create a safe and efficient system and address the interrelated topics of demand and operations, which directly affect the sustainability of the surface network. Finally, it will highlight emerging topics that transportation professionals are beginning to face that could revolutionize the way we travel in the future.

1.2 Transportation Engineering

Merriam-Webster defines engineering as the "activities or function of an engineer" in which science and mathematics are applied to matter and energy in nature and are made useful to people.[1] Thus, within the transportation context, transportation engineering is the field of study related to planning, design, operation, and maintenance of any aspect of transportation systems and networks. It is the responsibility of transportation professionals to ensure that the complex transportation facilities, which afford mobility for people and goods, do so in a safe, rapid, comfortable, convenient, and environmentally compatible manner that is sustainable and resilient in the face of numerous challenges and threats such as natural disasters, population growth, and climate change.

Transportation engineering has for decades been included as part of the discipline of civil engineering since transportation networks typically fall within the public domain. They are available for the general public, and their upkeep is typically the responsibility of public agency employees and their contractors. It is important to note that transportation engineering could be considered more of an art than a science. Professionals within the field are required to make many decisions based on society's needs and desires for mobility, and the answers are not always easy given the need to balance needs with the reality of limited resources. The identification of solutions involves the synthesis of different intellectual perspectives and scientific bases to solve transportation problems across the breadth of competing interests: technical, economic, social, and environmental in nature.

1.3 The Surface Transportation System

Since the turn of the previous century, the United States has grappled with the challenge of providing convenient and safe transportation options to its citizens. Over the decades, the national policy on surface transportation has shifted from construction to sustainability as evidenced by the evolution of funding bills passed by the U.S. Congress. The following provides a brief overview of critical federal funding legislation, which has shaped the transportation system in the United States over the past century.

The Federal Aid Road Act of 1916[2] recognized the rise of the automobile and the growing challenge of getting the farmer out of the mud. With this legislation, which was passed by President Wilson on July 11, 1916, Congress formally recognized that the government had the right to fund the construction of interstate highways under the constitutional right to regulate interstate commerce and that these facilities would be the backbone of the country's economic growth. The first federal highway funding legislation in the United States, this act addressed the inadequate roads in the country and the need for an increased federal role in funding.[2] The law required each state to establish and maintain a highway agency, employing engineering professionals to carry out federal-aid projects identified by the federal government. The law focused on rural post roads and illustrated the importance of working to enhance rural life in the United States. The Federal Aid Road Act of 1927[3] amended the 1916 act by expanding the roads eligible

Figure 1.1 Vehicle stuck on a muddy roadway. (© *Texas Department of Transportation [TxDOT]*.)

for funding from rural post roads to any public road being used or which formed a connecting link with other roads. As shown in Fig. 1.1, many existing roadways became muddy after heavy rains, making travel virtually impossible. These early road acts sought to provide states with the resources to help improve the quality of these roadways so that travelers could use them under a variety of conditions. Improving these facilities would also foster interstate commerce into the future.

Various forms of transportation funding progressed over the next few decades until 1956. With the National Interstate and Defense Highway System Act of 1956,[4] President Eisenhower established the interstate highway system in the United States. The law authorized the expenditure of $25 billion to construct 41,000 miles of interstate highways between 1957 and 1969. This legislation represented a fundamental shift in the country toward a surface transportation system that from that point forward would focus on the automobile. Eisenhower's support of the system was based on the need for economic development, congestion relief, improved safety, and the reduction of lawsuits involving motor vehicles.[5] The interstate highways were also intended to support national defense in the post-war era, though this was not the primary reason for their construction. The interstate system also helped establish uniform geometric design and construction standards that included such features as fully controlled access, design speeds, paved shoulders, and a minimum of two 12-foot travel lanes in each direction. Many of these design criteria still exist today.

The shift toward an automobile-centric transportation system directly impacted the pattern of community development and the transportation network into the future. For example, the interstates were frequently constructed through the rural countryside where only local roads existed previously. Figure 1.2 shows early construction on Interstate 45 (I-45) in the area north of Houston, Texas, which at the time was the rural community of Conroe. The construction of this highway connected Houston and Dallas, greatly reducing the travel time between these cities that are over 200 miles apart. A trip that at the time took the better part of a day became only a few hours in length. The existence of such new transportation facilities in rural areas often attracted development,

Figure 1.2 Early construction of Interstate 45 (I-45), Conroe, Texas. (© *TxDOT*.)

particularly around interchanges with other major roadways and highways. Areas such as Conroe transformed from the rural landscape of a sleepy town to a bustling suburb, as shown in Fig. 1.3. While the concept of selecting a location for an interstate facility through the rural countryside seems straightforward, alignments were often controversial at the local level. Small communities or counties did not always want to have an interstate close by, fearing that the roadway would negatively affect the small town atmosphere they enjoyed. Such local sentiment often impacted the final location of the facility by having the facility bypass the community and sometimes having a detrimental effect on the economic health of the region that rejected it.

The construction of the interstate system also impacted the urban environment, as shown in Fig. 1.4. In many cities, the proposed alignment for the interstates often divided established neighborhoods and created conflict between their residents and the local leaders.[6] Some critics of the system noted that many of these facilities divided lower-income neighborhoods, having them bear a disproportionate burden for the progress brought by the interstate. Additionally, the interstates made the commute from outlying suburbs easier for workers, encouraging suburban sprawl with low-density, affordable development and an ever-increasing reliance on the automobile as a mode of transportation. Many early mass transit services faded from the urban landscape. Air and noise

Figure 1.3 Aerial view of Conroe, Texas. (© *Google Maps*.)

Figure 1.4 Construction of Interstate 45 (I-45) in Houston, Texas. (© *TxDOT*.)

Figure 1.5 Early roadway congestion. (© *Texas A&M Transportation Institute [TTI]*.)

pollution increased in the urban centers along with growing traffic congestion. In short, the interstate system likely contributed to the transportation-related problems it was intended to solve.

As early as the 1960s, these new interstates were experiencing congestion, as pictured in Fig. 1.5. The commuters from the suburbs traveling to the employment centers in large cities were forced to sit in traffic on a daily basis. Such situations created the ongoing challenge to provide adequate capacity for peak period travel. Early efforts to monitor traffic on the roadway network included such innovative strategies as the construction of towers along the roadway (see Fig. 1.6) to observe traffic behavior and to identify bottlenecks in the system. Motion picture cameras were also installed along interstate corridors to record traffic flow during congested periods. Films were then used by traffic engineers in monitoring the conditions and improving operations (see Fig. 1.7). These scenes were repeated in urban areas across the country. Since the inception of the interstate system, transportation professionals have been striving to determine how best to operate and maintain that investment and tackle the challenge of congestion and growth.

In 1969, Congress passed the National Environmental Policy Act (NEPA),[7] which represented one of the first broad efforts by the government to establish a framework for protecting the environment. This law, which applied to all branches of the government, directed agencies to consider the environment before advancing any major federal action or project that would significantly impact the environment in the United States. It goes without saying that NEPA requirements had a direct impact on transportation-related project such as airports, highways, and other transportation facilities. Among the most visible of impacts, federal agencies were required to conduct environmental assessments (EAs) and develop environmental impact statements (EISs) in advance of major projects.[5] These assessments are designed to identify the likelihood of environmental impacts of projects when compared to other courses of action.

In addition to the NEPA act, Congress passed the 1970 Clean Air Act (CAA) and 1977 Clean Air Act Amendments (CAAA),[8] which shifted the role of government in controlling air pollution. The intent of these acts was to protect public health and public welfare and to regulate emissions of hazardous air pollutants. They authorized

Figure 1.6 Early traffic monitoring on Interstate 45 (I-45) Gulf Freeway, Houston, Texas. (© *TTI*.)

Figure 1.7 Early traffic monitoring technology, Interstate 45 (I-45) Gulf Freeway, Houston, Texas. (© *TTI*.)

federal and state regulations to limit stationary and mobile source emissions and created four regulatory programs to oversee these regulations. They were the National Ambient Air Quality Standards (NAAQS), State Implementation Plans (SIPs), New Source Performance Standards (NPS), and National Emission Standards for Hazardous Air Pollutants (NESHAPs). The 1977 amendments included provisions for the Prevention of Significant Deterioration (PSD) of air quality in areas attaining the NAAQS and requirements for non-attainment areas. Non-attainment areas are those geographic regions not meeting the federal air quality standards.

The 1990 CAAA[9] amended the original CAA to set new goals (dates) for achieving attainment of NAAQS since many areas of the country were having difficulty meeting the deadlines. Key components of the amendments included the requirement of technology-based standards for major pollution sources and certain area pollution sources, and the establishment and periodic review of emission standards (i.e., maximum achievable control technology) that require the maximum degree of reduction in emissions of hazardous air pollutants.

In addition to environmental legislation related to clean air, Congress focused on disabled citizens with the passage of the Americans with Disabilities Act (ADA)[10] in 1990. This act, which was signed into law on July 26, 1990, by President George H. W. Bush, represented one of the country's most comprehensive pieces of civil rights legislation related to people with disabilities. The primary focus of the legislation was to ensure that citizens with disabilities have the same opportunities as everyone else to participate in all aspects of life, including employment opportunities, the purchase of goods and services, and to participate in state and local government programs and services. The ADA had broad transportation implications including the accommodation of disabilities in surface transportation services such as city buses, public rail transit, and sidewalks.[11]

In 1991, Congress passed the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA),[12] which continued to focus on authorization for highways, highway safety, and mass transit. Signed by President Bush, the bill authorized expenditures of $155 billion, established the National Highway System (NHS), and gave state and local governments more flexibility in determining transportation solutions for their jurisdictions. Additionally, the legislation highlighted new technologies as potential solutions to improving the efficiency and safety of the transportation network. Key components of the law allowed highway funds to be used for transportation-related environmental projects and emphasized highway safety by establishing a new program to encourage use of safety belts and motorcycle helmets. Other measures established uniformity in state vehicle registration and fuel tax reporting to streamline efforts and improve productivity.

President Clinton signed the Transportation Equity Act for the 21st Century (TEA-21)[13] in 1998, which built on the initiatives of ISTEA. The legislation had four key thrust areas: rebuilding America, improving safety, protecting the environment, and creating opportunity. The guaranteed $198 billion investment included in the bill was intended to balance the federal investment across highways, transit, intermodal projects, and technologies while continuing to encourage state and local flexibility in expenditures. Safety programs highlighted the importance of improving safety belt use, fighting drunk driving, and improving truck safety programs across the country. Other efforts targeted increasing pipeline safety and that of rail-highway grade crossings. Protecting the public health and the environment included the expansion of Congestion Mitigation and Air Quality (CMAQ) improvement and transportation enhancements programs, extension of programs for the construction of National Scenic Byways, pedestrian and bicycle paths, and recreational trails, as well as incentives to increase transit ridership. Finally, as with virtually every other transportation authorization bill, TEA-21 helped expand access to jobs and through innovative programs as well as continued the effective Disadvantaged Business Enterprise program.

The Safe Accountable Flexible Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)[14] was a funding bill signed in 2005 by George W. Bush. This bill, which guaranteed $244.1 billion in funding for highways, highway safety, and public transportation, had the following focus areas: safety, equity, innovative finance, congestion relief, mobility and productivity, efficiency, environmental stewardship, and environmental streamlining. Unique aspects of the bill include the establishment of the highway safety improvement program (HSIP) and other programs targeting safe routes to school, work zone safety, bicycle and pedestrian safety, and the improvement of traffic control devices targeted to older drivers and pedestrians, toll facilities, and motorcycle safety. Congestion relief provisions gave states more options to use road pricing to manage congestion and enhanced and clarified the use and operations of high-occupancy vehicle (HOV) lanes to ensure degradation of operations does not occur.

In 2012, President Obama signed the act entitled Moving Ahead for Progress in the 21st Century (MAP-21).[15] This bill had as its key tenets to strengthen America's highways by expanding the NHS to incorporate arterials, to establish the National Highway Performance Program, and to establish a performance-based program for more efficient investment of federal transportation resources. The bill authorized $82 billion for road, bridge, bicycling, and walking improvements to help create jobs and support economic growth. It continued the HSIP by doubling funding for infrastructure safety projects to improve progress toward reducing highway fatalities and also focused on distracted driving, transit safety, and motor carrier safety. Furthermore, it emphasized the importance of improving timely delivery of projects and efficiency in the development process from planning to completion.

The most recent authorization bill, signed by President Obama in 2015, was the Fixing America's Surface Transportation Act (FAST Act).[16] This legislation authorized $305 billion for highway, highway and motor vehicle safety, public transportation, motor carrier safety, hazardous materials safety, rail, research, technology, and statistics programs. Included in its major provisions were programs to improve safety, maintain the condition of the transportation system, reduce congestion and improve efficiency and freight movement, protect the environment, and to further reduce delays in project delivery. All of the programs were intended to help create jobs, support economic growth, and improve mobility for all citizens.

As evidenced by the progression of federal funding bills, the transportation industry has moved from the initial construction of the interstate system to the wholesale operation and maintenance of a system that is safer, more efficient, and sustainable. Today, the overall national policy agenda with respect to transportation focuses on maintaining and expanding the national transportation system and fostering a sound financial base for that system to create jobs and ensure its long-term reliability. Additional tenets focus on ensuring that the system supports public safety and national security, protects the environment and quality of life, is sustainable into the future, and looks to incorporating rapidly advancing technologies that can enhance the government's ability to provide a safe and efficient method of transporting people, goods, and services across the country. Transportation professionals inherit this system.

1.4 The Transportation Profession

The transportation profession, which originated within the discipline of civil engineering, has evolved to include a broad range of professionals across a multitude of disciplines. Today, civil engineers make up only one segment of the transportation profession. These more traditional players in the transportation industry are now joined by professionals with expertise in such fields as economics, psychology, geography, public administration, city planning, political science, industrial engineering, electrical engineering, physics, mechanical engineering, mathematics, statistics, logistics, communications, archeology, geology, and environmental engineering. They all work together as a team to advance the improvement of transportation for all users.

The critical challenges that these transportation professionals face on an ongoing basis include managing congestion, improving safety, providing equal access, and protecting the environment. They also strive to incorporate and adapt new technologies to enhance the system, work to secure financial resources for the transportation network, and develop institutional arrangements that foster collaboration and work toward a seamless network for the user. Sample focus areas include daily urban operations (Fig. 1.8), interchange design (Fig. 1.9), international border crossing inspections and

Figure 1.8 Houston TranStar control room. (© *TxDOT*.)

Figure 1.9 Interchange design. (© *TTI*.)

wait times (Fig. 1.10), bridge design (Fig. 1.11), pavement design (Fig. 1.12), and the impact of vehicle emissions on the environment (Fig. 1.13), in addition to a multitude of other topics all working to provide a safe and efficient transportation network for the traveling public.

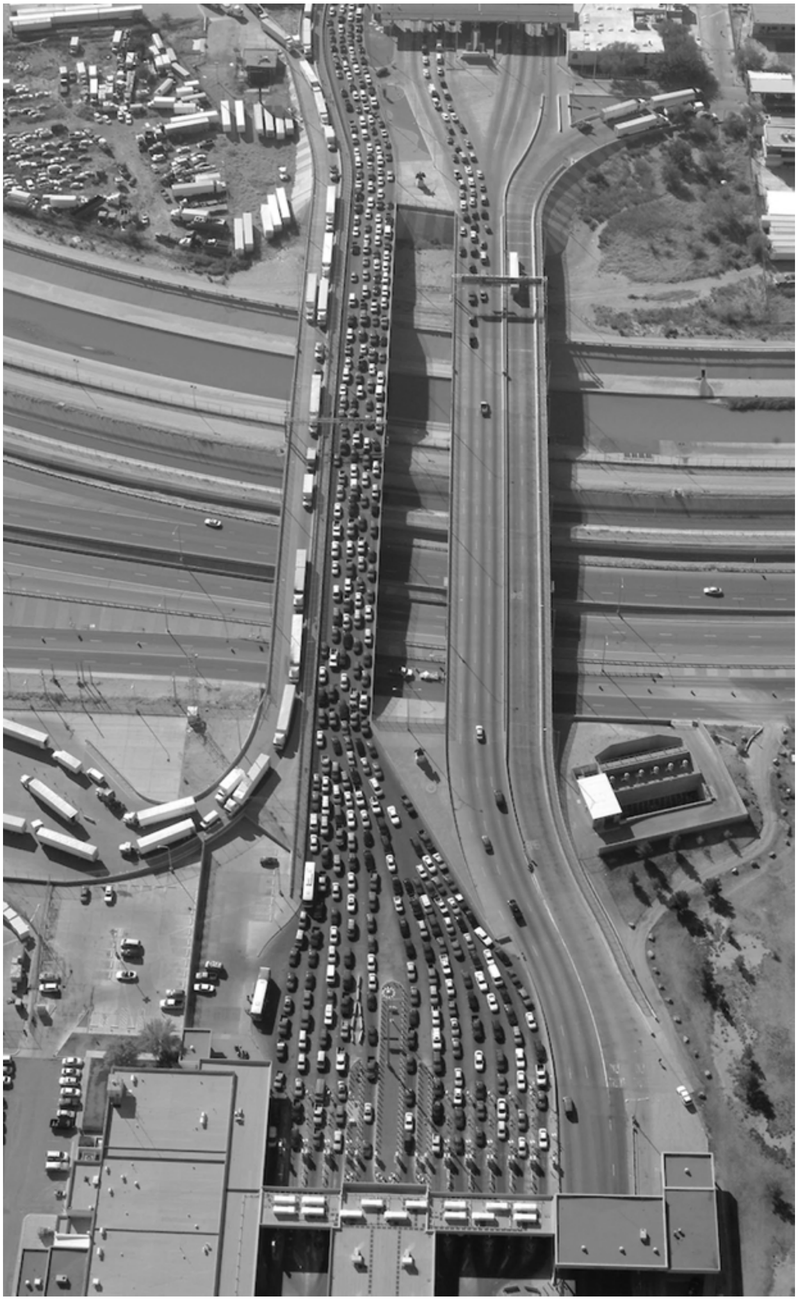

Figure 1.10 U.S.-Mexico border crossing. (© *TTI*.)

Figure 1.11 Bridge research and inspection. (© *TTI*.)

Figure 1.12 Asphaltic pavement design research. (© *TTI*.)

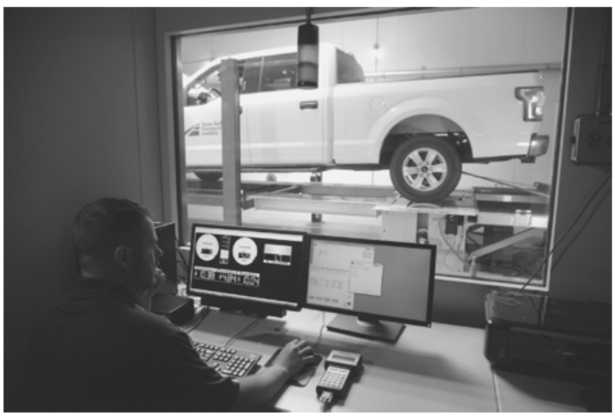

Figure 1.13 Environmental and emissions research. (© *TTI*.)

1.5 Summary

Transportation is a foundational component of society and contributes to the safety, security, and prosperity of global economies. Transportation professionals are responsible for ensuring that this complex network serves its primary purpose of moving people, goods, and services in a safe and efficient manner so that it is sustainable over the long term. This textbook will provide information on the critical design, analytical, and system operational elements and skills that transportation engineers need to undertake the challenge. With a focus on the technical aspects of the job and the recognition that collaboration with a broad range of professionals is essential, today's transportation engineers can ensure that future generations will enjoy the mobility needed to lead productive lives in society.

Glossary of Acronyms

CAA—Clean Air Act

CAAA—Clean Air Act Amendments

CMAQ—Congestion Mitigation and Air Quality

EA—Environmental assessment

EIS—Environmental impact statement

FAST Act—Fixing America's Surface Transportation Act

HOV—High-occupancy vehicle

ISTEA—Intermodal Surface Transportation Efficiency Act of 1991

MAP-21—The Moving Ahead for Progress in the 21st Century Act

NAAQS—National Ambient Air Quality Standards

NEPA—National Environmental Policy Act

NESHAP—National Emission Standards for Hazardous Air Pollutants

NPS—New Source Performance Standards

PSD—Prevention of Significant Deterioration

SAFTEA-LU—Safe Accountable Flexible Efficient Transportation Act: A Legacy for Users

SIP—State Implementation Plan

TEA-21—Transportation Equity Act for the 21st Century

U.S.DOT—United States Department of Transportation

Exercises

1.1 Write a paper (no more than 10 pages) on the critical link between transportation and economic prosperity at the federal, state, local, and individual level.

1.2 Write a paper (no more than 10 pages) providing a critical discussion on the national progression of federal transportation investments since 1916 and the positive and negative impacts it has had on communities and overall mobility for Americans.

1.3 Write a paper (no more than 10 pages) discussing how the advancement of technology has impacted the provision of transportation options to travelers over the past 30 years.

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