Development of Transportation Engineering Research, Education, and Practice in a Changing Civil Engineering World

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Abstract:

Transportation has been one of the essential areas within civil engineering since its early days. In commemoration of the 150th anniversary of ASCE, this paper presents a review of developments in research, education, and practice in transportation engineering. The review is based primarily on the issues of the Journal of Transportation Engineering over the past several decades. Main topics include transportation engineering practice, airport and highway pavements and materials, design and safety, planning and operations, pipelines, technology, and education. Historical appraisals and the current state-of-the-art for these topics are discussed. In conclusion, future directions in transportation engineering as a result of advances in technology and the attendant changing need of the transportation engineering profession in the 21st century are addressed

Introduction

Transportation has been one of the essential components of the civil engineering profession since its early days. From time immemorial, the building of roads, bridges, pipelines, tunnels, canals, railroads, ports, and harbors has shaped the profession and defined much of its public image. As cities grew, civil engineers became involved in developing, building, and operating transit facilities, including street railways and elevated and underground systems. The role of civil engineers in providing transportation infrastructure to accommodate a growing population and economy was never more prominent than in the United States around the late 19th century and the early part of the 20th century. Transcontinental railroads, national highways, canals, petroleum and natural gas pipelines, as well as major urban transit systems, are testimonials to the achievement of civil engineers. And, in the latter part of the last century, these achievements played a major role in developing the Interstate System, new rail transit lines, and major airports

In the last 150 years, railroads, transit lines, ports, and airports have helped to increase the range of cities and reduce the isolation of rural areas. They have brought the nation closer together. Such major bridges as the Eads Bridge in St. Louis, the Brooklyn and George Washington Bridges in New York City, the Golden Gate and Bay Bridges in San Francisco, and the Mackinac Straights Bridge in Michigan have not only spanned major water crossings, but have also become a dramatic part of the national landscape ~Billington 1985; Gies 1996; Petroski and Kastenmeier 1996!. The great railroad terminals—sometimes electrified with tunneled approaches, as are Penn Station and Grand Central Terminal in New York, and the Union Stations in Chicago and Washington, D.C.—continue to serve as major gateways and urban monuments. The subway, elevated, and commuter rail lines built over the last century have made the centers of cities such as New York, Washington, Chicago, and Boston possible ~Meeks 1995; Parissien 2001!. Also, the Interstate Highway System has changed the national landscape. These are a few of the many transportation contributions to the nation by members of the civil engineering profession ~Fig. 1!

To commemorate the 150th anniversary of ASCE, this paper has been prepared to document the development of the transportation engineering field within civil engineering. The paper provides a historical appraisal of how the field evolved to its current state-of-the-practice as well as a preview of future directions, and it draws heavily on volumes of the Journal of Transportation Engineering ~JTE!and its predecessor journals.

The Journal's roots go back to the early years of ASCE, the first issue appearing in 1874. It currently contains the technical and professional articles of the Air Transportation, Highway, Pipeline, and Urban Transportation divisions of the Society. The Highway Division was established in 1922, Air Transportation in 1945, Pipelines in 1956, and Urban Transportation in 1971. In 1969, the Journal of the Highway Division was renamed the ASCE Transportation Engineering Journal and was a forum for publications in the fields of air transportation, aerospace, highway, pipeline, and urban transportation. In 1983 the journal was renamed Journal of Transportation Engineering, and the Aerospace Division started its own journal in 1988. In 1999 the divisional organization of the editorial function was replaced by functional grouping. At present the editorial functions are divided into Pavements and Materials, Planning and Operations, Design and Safety, and Pipelines. In addition, there are two new features, ''Practitioner's Forum'' and ''Book Review.''

Fig. 1. 1935 reproduction of the Oregon Trail, Illinois, as it looked in

Fig. 2. I-10 and College Drive in Baton Rouge, Louisiana

Transportation as a Civil Engineering Profession

Rapid urbanization of the United States challenged civil engineers with the task of meeting the mobility needs in and around cities. Civil engineers served not only as developers and builders of transit facilities, but also as planners and operators of such facilities. For example, the Chicago Transit and Subway Commission, under the chairmanship of William Barclay Parsons, prepared in 1916 one of the most extensive studies ever made in the operation of public transportation systems, including the interrelations of these operations with population, employment and residential distribution, and commercial and industrial regions of the city ~Condit 1982!.

An early intercity transportation engineering challenge was the rapid development of canal systems and railroads during the 19th century. This development represented major challenges for new and stronger bridges and for geometric design. The importance of economic and environmental impacts of transportation facilities became evident in these early developments ~Wellington 1887!. As the nation became motorized in the 20th century, civil engineers played a growing role in road construction. This involvement has continued to the present day. Such major roads as the Columbia River and Lincoln Highways, New York City's parkways, and Los Angeles' freeways are among their achievements. In the 1920s engineers played a role in preparing street and transit plans for many communities.

They were among the pioneers in applying traffic engineering and management methods to streets and highways. During the 19th century civil engineers involved in transportation mainly worked for public agencies and transportation providers such as railroads. However, during the 20th century, consulting firms emerged. Their numbers and importance have grown steadily, except for during the two world wars and the Great Depression. In recent years, this growth has accelerated as governmental agencies have downsized. After World War II, civil engineers' involvement in transportation projects increased dramatically as the Interstate System was developed and as transportation planning became a requirement for federal funds. However, while civil engineers were increasingly involved in transportation activities, the transportation engineer per se did not really emerge until the United States Department of Transportation ~USDOT!was established in 1967 and state highway agencies became multimodal ~Fig. 2!. At the beginning of the 2lst century, transportation engineering has evolved into a mature subdiscipline within civil engineering, with clear functions of planning, design, construction, operation, and maintenance of multimodal systems for the transportation of people and goods. This subdiscipline has greatly expanded civil engineering into such areas as economics and financing, operations research, and management. With the rapid development of Intelligent Transportation Systems ~ITS!in recent years, the transportation engineering profession has also started to make increasing use of information and communication technologies. Transportation engineering, as it is practiced today, has three major components. One component involves design, construction, and maintenance of facilities, including roads, bridges, tunnels, railroads, airports, transit systems, and ports and harbors. The second component encompasses planning, project development, and financing and management. The third component covers operations and logistics, including traffic engineering and operations of transit, trucking, and other facilities, as well as business logistics. Specialties have emerged in each as the profession has continued to mature. The current focus is on intermodal transportation systems that emphasize the connectivity of modes over the entire portal-to-portal trip length.

A specific indication of the subcomponent of the transportation engineering field with current importance to civil engineers can be obtained by examining the topics of the technical committees of the transportation-related divisions in ASCE. There are 44 technical committees, and most involve the physical infrastructure of surface transportation modes. A review of descriptions of the scope of various committees indicates that, while facility

Fig. 3. Freight train leaving urban area

planning and design continue to be the core of the transportation engineering field, such areas as operations, logistics, network analysis, and financing and policy analysis are also important to civil engineers involved in the transportation field. Another source of information, to gauge the relative emphasis placed by civil engineers in recent years on the need for new knowledge, can be attained by reviewing the papers published in the past several decades in the JTE. As the papers represent scholarly interests, which in turn should respond to the needs of the profession over a long period of time, an assessment of the stateof-the-art is presented in the next few sections ~Fig. 3!.

Highway and Airport Pavements and Materials The Role in the Field

One hundred and fifty years ago, most roads between cities were unpaved except for a few plank roads. The power stone crusher ~1858!and the steamroller ~1859!made the use of crushed stone feasible for rural roads. Cobblestones and untreated blocks were used in cities. The first brick pavement was built in Charleston, West Virginia, in 1871, and the first sheet asphalt was placed on Pennsylvania Avenue, Washington, D.C., in 1879. In the first decade of the 20th century, portland cement concrete ~PCC!was introduced in Bellefontaine, Ohio, and Wayne County, Michigan. The first theory of rigid pavement was developed at this time, and has progressively evolved since. Papers published in the area of pavements and materials in the Journal of Transportation Engineering over the past 30 years can be grouped into following categories: design, construction, materials and testing, performance analysis, and system management. Discussions that follow represent not only highway and airport pavements but also different types, such as flexible, rigid, and composite pavements. State of the Practice Pavement Design The stresses and deflections of flexible and rigid pavements were analyzed using Boussinesq theory and Westergaard theory as early as 1926. Among others, Yoder ~1959!pioneered the exploration of pavement design principles in the 1950s.

However, a great surge of research activities and subsequent practical applications took place in pavement design as a result of the American Association of State Highway Officials ~AASHO!Road Test, which was conducted in Illinois from 1958 to 1960. Using data from that test, a set of widely accepted pavement design procedures for new construction or reconstruction, overlay, and rehabilitation of pavements was developed and first published in 1972, with the latest revision in 1993 ~AASHTO 1993!. For flexible pavements, selecting optimal thickness of various pavement components to achieve minimum total pavement costs was an important topic of investigation among researchers ~Hegal et al. 1993; Garcia-Diaz and Liebman 1978!. With regard to rigid pavement design, appropriate joint design and design of concrete block pavements were extensively explored

~Fordyce and Yrjanson 1969; Rada et al. 1990!. Recognizing that increasing pavement construction and rehabilitation costs make it imperative to have a quick and rational method of designing the overlay thickness, several papers dealt with the topic of overlay design ~Bandyopadhyay 1982; Fwa 1991!. Currently, there are more than 2.6 million miles of low-volume roads that typically carry less than 500 vehicles per day. Pavement design for low-volume roads is especially challenging because cost is always a major factor and alternative designs and materials can be used ~Kestler and Nam 1999!. Design procedures were also developed for airfield pavements in terms of magnitude of applied loads, tire pressures, geometric section of pavements, and number of load repetitions applied to pavements during their design lives ~Murphree et al. 1971;

Ahlvin et al. 1974; Seiler et al. 1991!. The Strategic Highway Research Program ~SHRP!, in the 1980s, launched a major research activity in the area of pavements and materials. As a part of this program, a comprehensive 20-year study of in-service highway pavements ~long-term pavement performance, LTPP!was undertaken.

Pavement Construction

A number of papers covered the issue of compaction of graded aggregate bases and subbases ~Marek 1977; Halim et al. 1993!. Benefits of the use of hot-mix asphalt were investigated by several researchers ~Colony et al. 1982!. The technique of non-fines concrete with single-sized coarse aggregates held together by a binder consisting of a paste of hydraulic cement and water was also discussed ~Ghafoori and Dutta 1995!.

Materials and Testing

Along with pavement design procedures, investigations were made on properties of new construction materials as well as on recycled materials. Examples include engineering properties of soil-lime mixes for stabilization ~Sauer and Weimer 1978!, tensile fracture and fatigue of cement-stabilized soil ~Crockford and Little 1987!, low-temperature fracture parameters of conventional asphalt concrete and asphalt-rubber mixture ~Mobasher et al. 1997!, field studies on polymer-impregnated concrete ~Mehta et al. 1975!, and service lives of pavement joint sealants ~Biel and Lee 1997!. Examples of testing procedures for pavements and materials include variably confined triaxial testing, fatigue response of asphalt concrete mixtures, rut susceptibility of large stone mixtures, viscoelastic behavior of asphalt concrete, field impregnation techniques for highway concrete, moisture content in PCC pavements, and back calculation of moduli of pavement layers ~Allen and Thompson 1974; Chen et al. 1977; Uzan 1994!. The LTPP program also addressed key questions about the revised resilient modulus laboratory tests and procedures.

They are geared to highway engineers, laboratory managers, and technicians. Performance Analysis The pavement serviceability-performance concept was first introduced by Carey and Irick ~1960!. To study the performance characteristics of flexible pavements, Hertz's theory of the deflection of an elastic plate on a fluid subgrade was used ~Wiseman 1973!. The relationship between the cumulative peak pavement deflections and condition of that system, the stress/strain response of asphalt concrete under cyclic loading, threshold values for friction index, and crack propagation between beam specimens and layered pavements were also investigated by a number of researchers ~Highter and Harr 1975; Ramsamooj et al. 1998; Fulop et al. 2000; Castell et al. 2000!. The breaking load for rigid pavements was studied in early 1970s ~Ghosh and Dinakaran 1970!. Later, the use of finiteelement analysis of pile-reinforced pavement systems was also introduced ~Tabatabaie and Barenberg 1980!. In the mid-1990s, the issue of probability that a continuously reinforced concrete

~CRC!pavement section with a certain amount of distress manifestations would last at least a certain number of equivalent single axle load ~ESAL!applications was addressed ~Weissmann et al. 1994!. By modeling a pavement structure as a beam resting on a viscoelastic foundation, a physical picture associating vehicle dynamics, road profile, and pavement response in a theoretical framework was constructed recently ~Liu and Gazis 1999!. Lack of strain characteristics of rigid pavement overlays, the susceptibility of overlays to abrasion wear, fuel spillage, and stripping led to the research on this topic ~Al-Qadi et al. 1994!.

The fracture behavior of interface between interlayer and asphalt overlay as well as the entire overlay pavement system was studied in recent years ~Tschegg et al. 1998!. System Management An increasing interest could be seen in the area of pavement system management over the past two decades. A framework for pavement management systems was the topic of several papers ~Findakly et al. 1974; Kilareski and Churilla 1983!.

Utility theory was introduced in pavement rehabilitation decisions in the mid- 1980s ~Mohan and Bushnak 1985!. An integrated project-level pavement management model, consisting of life-cycle cost analysis and cost-effectiveness method, was developed in the same period ~Rada et al. 1986!. In later years, a framework for evaluating the effects of pavement age and traffic loading on pavement routine maintenance effectiveness was introduced ~Al-Suleiman et al. 1991!. Integrating pavement and bridge programs started to appear in mid-1990s ~Ravirala and Grivas 1995!. Project-level optimization and multiobjective optimization for pavement maintenance programming began to be implemented in recent years ~Mamlouk et al. 2000; Fwa et al. 2000!.

Transportation Design and Safety Historical Appraisal of the Field

During the 20th century, the private automobile in the United States went from being rarely sighted to a ubiquitous presence as the supporting road system was methodically expanded and improved, making automobile use safe and convenient. As engineers were successful in these undertakings, the dependence of the public on other modes of transportation generally eroded. While other modes remain important, the domination of the automobile is, nonetheless, fairly complete. To be sure, the emergence of the automobile meant unprecedented freedom of movement for the population and is closely tied to the continued growth of the American economy. However, problems associated with its use are also widespread, such as urban sprawl and air pollution ~Altshuler et al. 1993!..

The transportation engineers have been engaged in a constant struggle to make the system safe and to overcome congestion, whether of horse-drawn vehicles in New York City long ago or on Los Angeles' freeways. Although the rates of occurrence of crashes and fatalities are lower than ever, the absolute numbers are still high ~BTS 2000!. For congestion, the engineer's response has largely been to increase system capacity. This has proven to be a short-term solution in the larger urban areas. Congestion, once restricted to the downtown areas of our older cities, now occurs daily in suburban areas as freeways are extended, arterials are widened, and local roads are designed to ever higher standards. The lack of adequate and continuous streets in many suburban settings, coupled with the lack of effective land-use controls, overloads many major arterials. And public transport service remains inadequate to provide congestion relief in suburban corridors, especially for circumferential trips. At the outset of the 21st century, many components of our transportation system are fast approaching or have already exceeded their design lives, and much of the vaunted roadway system is suffering from wear and tear due to higher than expected use. Since the era of building large systems or substantially enlarging existing ones seems to be at an end ~except, perhaps, for new transit lines!, the major challenges are now to rebuild the transportation system in place and to use it more efficiently and responsibly ~Fig. 4!.

As in many fields, there appears to be a gap between the practitioner in the field and the cutting edge of research in system design and safety. Researchers dealing with issues in these areas are largely ‘‘tinkering at the margin’’ or with high-tech applications in order to develop suggestions for making the system still safer and operationally more efficient. Unfortunately, practitioners are often put in a position of taking more and more ‘‘on faith.’’ The information explosion in transportation-oriented journals has put day-to-day exploration of new findings beyond the attention span of end users. For example, the widely used Highway Capacity Manual ~HCM!has gone from a primer on high way operations to a complex treatise that requires a solid background in traffic flow theory to even begin to understand it. Calculations of volume-to-capacity ratios and levels of service that were done with an adding machine and slide rule now require special-purpose software with routines that, for many practitioners, defy understanding or are simply viewed as a black box that may or may not work. While large agencies can and do employ transportation engineers who are specialized enough to understand these evolving approaches, there are many transportation engineers whose duties are so broad as preclude ‘‘keeping up’’ across the board. Concurrent with evolving technology and burgeoning information, the safe use of the highway system has moved from being solely the user’s responsibility to a model of shared responsibility that includes the users, the system providers, and the vehicle manufacturers. Notwithstanding this shared model, tort liability still looms large as a driving force in transportation safety-related endeavors. Indeed, in some instances it can be argued that there are institutional constraints to both the identification of problems on the highway system and the implementation of reasonable solutions due to the exposure that a state might incur if differences in opinion are publicly aired or problem sites identified. Despite everything that transportation engineers and those in related fields know about the relative safety of the system, there is still a gap between what is really ‘‘known’’ and what is ‘‘done’’ in the field. Safety audits that find problems before crashes take place are a step in the right direction, as there remains great variation among agencies in a given state regarding when and how horizontal curves might be signed and the appropriate advisory speed determined, from paper and pencil analysis to use of sophisticated in-vehicle equipment to a guess in the field. Providing safer and more consistent designs remains a challenge.

Given that the treatment of highway curves goes back virtually to the first road, it is alarming that there is still a significant divergence in deciding on treatments within a given state, let alone among states. The litany of problems being dealt with by transportation engineers as the 21st century is embarked upon is not that different from a similar list compiled 100 years ago—progress has been made, but much remains to be done. Transportation Planning and Operations From Wellington’s classic study of railroad location ~1887!to contemporary multimodal corridor studies, the planning of transportation facilities has been an integral part of civil engineering profession. While the scope and focus of these activities has evolved and broadened, planning continues to be a major effort. Civil engineers developed the first systematic comparison of urban land use, formulated the methods for forecasting future travel demands ~trip generation, trip distribution, mode split, and traffic assignment!, and analyzed spacing requirements for urban freeways ~Peterson 1960!

The Role in the Field

The role of planning in transportation is vital for strategic or tactical evaluations and predictions of travel demands, land use patterns, and air quality issues for various transportation modes for both passenger and freight movements. The body of knowledge about planning, traffic operations, control, and management has witnessed drastic growth over the past several decades, and papers published in the Journal of Transportation Engineering have contributed to this growth. The information published in the Journal mirrors the need to share experiences about problems facing engineers and planners, new technologies being deployed to help remedy the situation, what worked and what did not work, and the academic contribution to improve the understanding of why and how to use basic and applied research to solve these problems. Planning and operations appear most prominently in the field of traffic engineering for surface transportation. However, transportation engineers also confront planning and operations issues in facility management, particularly for large complexes such as airports

. Transportation engineers also often become involved with urban-planning processes in developing long-term transportation plans.

Conclusions

The early engineers, by their training, experience, and inclination, were often generalists. Many engineers worked pragmatically with a strong sense of physical and political reality. As the field became more diverse and complex, this was no longer possible. Growing federal, state, and local requirements called for a broad range of skills and capabilities, and new analysis tools. These new tools have in many ways transformed approaches to transportation engineering. But they have created many technical specialists who are often unfamiliar with or insensitive to many other aspects of transportation engineering. This growing dichotomy between the generalist and specialist has been aided by contemporary transportation education. Although universities have often broadened their curriculum programs, they are increasingly theoretical, sometimes at the expense of practicality; part of this dilemma stems from a growing emphasis on training for research rather than practice. It also stems from a growing number of faculty with little experience with and interest in practical matters. A related concern is how best to attract new talent. In today's society transportation engineering, despite its promise and importance, remains far less on the cutting edge than do fields like biomedical engineering and computer science.

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