

ADVANCED TECHNOLOGIES USE IN TRANSPORTATION ENGINEERING

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Abstract: Transportation plays a vital role in the growth of the economy and the quality of life of individuals. Transportation engineering is a major component of the civil engineering profession. It involves planning, design, construction, maintenance, and operation of transportation facilities. Advanced technology in the area of information systems, automation, and telecommunication have the potential of achieving cost savings and productivity improvements as well as enabling new developments in transportation. The purpose of this paper is to review the areas where advanced technologies can very much affect the way transportation engineering is proficient. Strategies for application of the necessary changes in practice are also discussed, along with the expected impact on civil engineering curriculum. The emphasis of the paper is on surface transportation.

Index Terms - Vehicular Navigation, Robotics, Automation, Telecommunications

Introduction -Transportation engineering is a major component of the civil engineering discipline. The importance of transportation engineering within the civil engineering profession can be judged by the number of divisions in ASCE that is directly related to. transportation There are six such divisions (Aerospace; Air Transportation; Highway; Pipeline; Waterway, Port, Coastal and Ocean; and Urban Transportation) representing one-third of the total 18 technical divisions within the ASCE (1987). Considering the national economy as a whole, transportation represents 20% of the U.S. gross national product. About one of seven or roughly 14,000,000 of 100,000,000 U.S. workers is employed in some aspect of transportation (Transportation Research Board [TRB] 1985). Most civil engineers engaged in the practice of transportation engineering are employed by transportation agencies and associated contractors and consultants. Nationwide there are about 174,000 civil engineers and about 100,000 works in transportation at least some of the time (TRB 1985)

Major Components of Transportation Engineering

Transportation engineering, as practiced by civil engineers, primarily involves planning, design, construction, maintenance, and operation of transportation facilities. The facilities support air, highway, railroad, pipeline, water, and even space transportation. A specific indication of the subcomponents of the transportation engineering field with current importance to civil engineers can be obtained by examining the topics of the technical committees of the six transportation related divisions (ASCE1987). There are 37 technical committees and most of them involve the physical infrastructure of surface transportation modes. A review of descriptions of the scope of various committees indicates that while facility planning and design continue to be the core of the transportation engineering field, such areas as operations planning, logistics, network analysis, financing, and policy analysis are also important to civil engineers, particularly to those working in highway and urban transportation. Mobility is a basic human need. From the times immemorial, everyone travels either for food or leisure. A closely associated need is the transport of raw materials to a manufacturing unit or finished goods for consumption. Transportation fulfills these basic needs of humanity. Transportation plays a major role in the development of the human civilization. For instance, one could easily observe the strong correlation between the evolution of human settlement and the proximity of transport facilities. Also, there is a strong correlation between the quality of transport facilities and standard of living, because of which society places a great expectation from transportation facilities. In other words, the solution to transportation problems must be analytically based, economically sound, socially credible, environmentally sensitive, practically acceptable and sustainable. Alternatively, the transportation solution should be safe, rapid, comfortable, convenient, economical, and eco friendly for both men and material.

Need for Improved Productivity and Performance

A recent workshop sponsored by the National Science Foundation to examine the state of the art and research opportunities in transportation indicated that the ultimate objective of research in the areas of transportation facilities is to develop technological innovations that will result in substantial improvement in the quality of transportation services, including productivity and performance (Boyce 1985). Some of the major areas that can greatly benefit from the use of advanced technologies include the Following: facilities condition assessment; repair, maintenance, and rehabilitation techniques; materials; and management of facilities. It should be pointed out that technological innovations are needed not only for better planning and design of transportation facilities, but also for improved operation and delivery of transportation services in terms of increased efficiency and safety.

OVERVIEW OF SOME ADVANCED TECHNOLOGIES AND TRANSPORTATION APPLICATIONS

Knowledge-Based Expert Systems

Knowledge-based expert systems (KBES) evolved from research in artificial intelligence with the overall objective of producing intelligent behavior with computers (Harmon 1985). Numerous artificial intelligence research areas exist, including theorem proving, automatic programming, vision, learning, natural language processing, and others. KBES differ from these other areas by the restriction to a limited problem solving domain such as diagnosis of malfunctions in particular equipment types. These systems are finding a wide range of suitable application areas. Several reviews of transportation (Ritchie 1986; Yeh 1986) and civil Engineering (Kim 1987; Kostem 1986; Sriram 1986) applications exist. Applications have included a variety of areas such as design (Harris 1987), diagnosis (Ritchie et al. 1986), vehicle control (Weisbin 1986) and operations control (Hendrickson 1987). As computer hardware and software develops and as more experience is accumulated, KBES will become a common alternative to conventional programming. The integration of expert systems and conventional programming approaches is likely to be particularly rewarding in this regard (Glover 1986; Hajek 1986).

Vehicular Navigation, Control, and Location

Recent advances in technology provide some significant new opportunities in the vehicular control area and, by extension, to the entire area of vehicle operations. New sensors and control procedures make continuous monitoring of locations possible and even introduce the possibility of widespread automated vehicle control (Skomai 1981). For example, several railroads have installed NAVSTAR satellite receivers so that precise locations of all locomotives are available at all times. Transit agencies have experimented with passive signpost systems to provide similar information on bus locations. The uses of autonomous ground vehicles have become economical in applications such as warehousing and factory materials movement. With these hardware developments, a variety of control and other operations information becomes of interest. Immediate dispatching and routing of vehicles in response to current locations and demands requires new management strategies. Integration of sensing and control procedures provides many new challenges (Moravec 1981; Weisbin 1986). Although operation of automated vehicles in uncontrolled roadways may still be a distant prospect, applications in automated guide ways, or maintenance activities are realistic possibilities. Better sensing and control of roadways may prevent the familiar backward-bending congestion phenomenon prevalent on roadways. For the transportation engineer, these new technologies present challenges to devise effective vehicle control strategies, to design more efficient and capable transportation systems, and to improve system operations over a travel network. Under the Automated Highway System (AHS), a system of vehicles was developed that uses both conventional roads under manual control and special guide ways under automatic control (Elias 1977; Fenton 1980; Saxton 1980). The design goals of AHS are to increase lane capacity and improve travel time performance. However, the problems of decision-making network, computer-to-vehicle communication, and roadway devices still remain to be solved. Computer-based route finding (Elliott 1982) and electronic trail finding (O'Rourke 1957) can both be used as part of AHS. The first simulates human thinking and can be employed on a smart vehicle. The second uses an electronic control system installed on the vehicle to trail the two-wire guided route by detecting the signal phase difference. Additional applications of automation in transportation include methods for reducing the demand, such as electronic road pricing (Fong 1984) and automatic vehicle monitoring (AVM) (Symes 1980) that can be used to dispatch, monitor, and control vehicles to optimize a fleet performance. Traffic control strategies can be classified as retimed and on-line (real time). Retimed (open-loop) control strategies are applicable to steady state flow conditions. Real-time control is applicable in traffic systems that experience frequent state transitions and rapid flow variations, i.e., in most urban systems. The need for developing real-time control methods for traffic systems is evidenced by the excessive amounts of delays, energy consumption, pollution levels, and other user or indirect costs resulting from highway congestion in urban areas. Much recent work has been done in this area (Isakson 1973; Looze 1978; Payne 1971; Payne et al. 1973; Phillips 1978). However, one of the major difficulties in real-time control is associated with the lack of realistic, yet sufficiently simple and effective, models describing the traffic dynamics in critical roadway components of the freeway corridor. Major modeling problems that have not been resolved include treatment of interrupted flow, especially in merging, diverging, and weaving areas, and consideration of lane-changing effects and geometric variations. Additional problems include the problem of ramp diversion, the lack of an on-line demand predictor, and an on-line determination of the freeway origin-destination matrix.

Computer-Aided Planning and Design

Traditionally, transportation has been a test bed for new theories and methods of design. Transportation applications provided a context for new developments such as mathematical programming or econometric models of discrete choice analysis (Ben-Akiva and Lerman 1985). As a new wave of computer-aided planning and design theory develops, transportation can provide another important application area. With limited budgets, effective planning and design have become more important. Computer-aided planning and design systems are evolving to incorporate a constellation of analysis, evaluation, and synthesis application programs with shared data and interposes communication (Rehak 1985). Graphic displays, knowledge-based expert systems, and databases, as well as conventional analysis programs, are all important components. Theories of design synthesis and creativity are finding an important role in the design of such systems (Gero 1985; McDermott 1982). Both technological developments to aid computer performance as well as new concepts of design are appearing and available for application and further development. After considerable effort devoted to planning and design system development in the past 30 years, transportation has not experienced widespread application of the new integrated design systems. This is now changing, particularly for private-sector operations planning. A similar effort in traffic systems, transit providers, port facilities, and other systems of interest to transportation engineers can be expected.

Robotics and Automation

While construction and maintenance have seen considerable mechanization over time, the use of robotics and automation for these purposes is in its infancy. These technologies offer the potential for productivity improvements, cost savings, quality improvements, and increased workforce safety. Given the enormous investment and maintenance needs evident for transportation infrastructure, vigorous pursuit of these technologies is extremely important for civil engineering. Introducing robots and automation into transportation will be a challenging task. Construction robots must be hardened for extreme conditions of vibration and environment distress. Maintenance robots should be designed and operated to avoid conflict with the users of facilities. In addition to the technical problems, institutional and organizational impediments to the introduction of automation might be expected from existing workers and managers. It is likely that widespread introduction of robots in the transportation domain will require the use of smart or cognitive robots that can sense, model the world, plan, and act to achieve working goals (Whittaker 1985). In transportation, numerous useful application areas for robots and automation may exist. A partial list was provided by Zuk (1985) for roadways to include: culvert inspection; bridge inspection (both underwater and superstructure); shop welding; shop fabrication of signs; fabrication of structural steel and reinforcing bars; placing of reinforcing bars; striping roadways; culvert repair; underwater repair; grass cutting; grading and excavating; painting and cleaning bridges; pothole patching; fastening structural members; changing lamps on ampoules; washing signs and luminaries; servicing vehicles; and security patrolling. Construction productivity on large projects, including road construction, has been constant or declining since the 1970s. This has been coupled with a dramatic increase in construction labor cost and shortage in funding for new road construction and maintenance. At the same time, highway construction costs have been increasing, even after correcting for general inflation (Statistical 1986) (see Table 1). These economic factors, as well as the resulting gradual deterioration of the U.S. road infrastructure, motivate the search for improved work productivity. One viable solution is partial or full automation of a number of work tasks. Automation is particularly germane due to the relative simplicity, repetitiveness, and large volume of work involved with roadways. Of course, any investment in automation must consider sound economic analysis of the proposed applications and the financial resources of contractors (Skibniewski 1988a). In addition to any strictly financial benefits, an expected advantage of automated road construction equipment is improvement in work safety and health. In some instances, laborers will be completely removed from the work loop and thus prevented from being run over by the working machine or other vehicles. In other cases, the health hazards associated with the worker's proximity to carcinogenic materials may be reduced. Despite this motivation, there is a surprising lack of research and development of partially automated and autonomous road construction and maintenance equipment. At the most recent International Symposium on Robotics in Construction, only two papers referred directly to automation and robotics.

Machine Vision and Image Processing for Vehicle Detection

The advantages of vehicle detection through image processing over detection by existing loop detectors are several. In particular, an imaging detection system has multitask capabilities, i.e., it can simultaneously detect traffic, derive traffic measurements, perform surveillance, detect incidents, recognize special vehicles, and alert a human operator, among others. The system does not disturb the pavement thus improving reliability, and can perform the function of multiple detectors. In addition, it can vary detection location and this flexible detection configuration accommodates future development of advanced truly dynamic control strategies for both arterial networks and freeway corridors. Application of advanced image processing technology to traffic surveillance has been pursued by the Federal Highway Administration (Schurmeier 1980). In Europe, eleven countries participated in a joint project for research and development of electronic traffic aids. In Japan, University of Tokyo conducted research on measuring traffic flow using real time video processing. The major problem with all existing systems, all experimental, is that they employ "fixed geometry" sensors; this implies that the points of the roadway being measured cannot be changed unless the camera is physically moved. Therefore, existing systems cannot extract all the necessary traffic information and, therefore, are not better than loop detectors. Moreover, existing experimental systems do not extract all the traffic parameters needed for surveillance and control in real time. In short, no practical cost-effective imaging detection system is available today.

STRATEGIES FOR IMPLEMENTATION

Organizational Strategies

Transportation-related organizations face both challenges and opportunities in responding to the role of advanced technologies in transportation engineering. The challenges concern adjusting organizational frameworks to best choose and implement new tools, and the opportunities relate to tremendous increases in productivity. This double-edged situation has been clearly observed in recent years as civil engineering firms and agencies have faced the microcomputer revolution. Some have adjusted their organizational structure and shifted resources to take full advantage of computer-assisted drafting and design (CADD), data-base development, and so on, and have benefited as a result. Others have been unable or unwilling to adjust, and have suffered. Organizations need to plan methodically in implementing advanced technologies. A good model to observe in government is the California Department of Transportation (Caltrans). Within its Division of Transportation Planning, Caltrans has constituted an Office of New Technology and Research. The primary role of this office is to seek out and evaluate advanced technologies, and to recommend their implementation. For example, the office leads in examining new methods to reduce congestion on California's freeways. It is also developing a strategic plan to implement a series of artificial intelligence tools throughout Caltrans. Whatever the nature of the organization, it must be prepared to alter its way of doing business in order to accommodate new technologies. This will certainly require effective planning, and commitments of resources.

Personnel Development

Human resources are the most important of all resources in transportation engineering. To most effectively incorporate advanced technologies into transportation, it is imperative that transportation professional be prepared technologically. This applies to new graduates entering the profession, and to those with experience. There are two items in personnel development. First, in order to

incorporate advanced technologies in civil engineering curriculum, there is an immediate need for faculty development. An organized effort should be made to offer summer programs and interagency cooperative arrangements so that the civil engineering faculty who want to retool themselves have the opportunity to do so. An example of such an effort is the 1987 American Society for Engineering Education (ASEE) Summer Program organized primarily for electrical engineers. The second item in personnel development is the training of civil engineers in public and private sectors. Unless the governmental agencies recognize the importance of advanced technologies and commit resources to train personnel much of the implementation effort will be in vain. Employees must be given ample opportunity for continuing education in order to maintain usefulness in organizations involved in advanced technology applications. Industry, government, and university must cooperate for supporting and encouraging those continuing education efforts needed to keep skills current.

Research and Development Priorities

Several initiatives are already underway to establish research agenda in transportation engineering applications of advanced technology. Among these is Project 3-38(1) funded by the National Cooperative Highway Research Program (NCHRP) of the Transportation Research Board. This project is assessing alternative technologies to relieve urban traffic congestion. The long-term goals of this effort are a mid-1990s pilot demonstration, and a large-scale research program similar to the current Strategic Highway Research Program. In addition, the Federal Highway Administration and the National Science Foundation are each funding several projects involving expert systems applications to highway problems. However, the available resources are minimal and a strong commitment of the U.S. Department of Transportation and National Science Foundation are essential to make a significant impact in this area. State and local governments also need to play a critical role in setting research and Development priorities. Standards the increased role of advanced technologies will naturally result in a greater dependence on processor-based devices and instrumentation and software. Consequently, it is essential that standards of performance be developed and enforced. This is particularly true in the areas of analysis and design software and decision support software. The ASCE Technical Council on Computer Practices (TCCP) is increasing its involvement in the evaluation of software. Specific issues of importance in standards development relate to the accuracy of algorithms contained with code, the integrity of code, and the validity and completeness of data bases and knowledge bases. It is especially important for the profession to develop and distribute valid test cases for analysis and design software. There is a need for a more coordinated effort in the area of standards for advanced technology applications. The federal government, through either the National Bureau of Standards or the Department of Transportation, must take the lead in this activity.

STRATEGIES FOR CURRICULUM CHANGE

Undergraduate Program

It is obvious that a considerable change is essential in civil engineering curriculum to accommodate the changing requirements for the profession. First, civil engineering curriculum has been traditionally oriented towards facility design. However, much of the challenge, particularly in transportation and other infrastructure areas, lies in maintenance and rehabilitation of the existing facilities. Consequently, attention needs to be given in developing courses that incorporate facility condition assessment; maintenance, repair, and rehabilitation strategies; and facility management. These courses should be developed with current needs as well as future requirements in mind. Also, these courses should be based on the use of advanced technologies that can reduce cost and improve productivity and safety. Because the use of advanced technologies is essential in almost all aspects of civil engineering, it is suggested that a sequence of 2-3 courses be included in undergraduate civil engineering core curriculum that will incorporate the essentials of advanced technologies as they relate to civil engineering, including computer-aided design and system management, robotics and automation, and other information systems and telecommunications technologies. These courses should be considered in addition to other basic computer-related courses. The introduction of these courses will obviously require a rearrangement of existing undergraduate curricula and a redistribution of resources within civil engineering departments.

Graduate Program and Continuing Education

Much of the integration of advanced technologies in transportation engineering will take place in graduate programs. Because of the evolutionary nature of the field, research and experimentation will be a major part of the development. Consequently, transportation engineering graduate programs should include courses in appropriate areas of advanced technologies. Expert systems, robotics and automation, and other information systems- and telecommunications-related courses offered in electrical Engineering and computer science departments are already becoming required minor areas in many graduate programs throughout the country. Along with the coursework, cooperative research between civil and other engineering faculty should be encouraged to allow new developments. Support for such research can come from federal, state, and local agencies, if the payoff can be clearly established. Initial basic research, however, needs to be supported by the National Science Foundation. Support from Private foundations and industry must also be sought. An important part of future curriculum in transportation as well as in Other fields of civil engineering are continuing education. As mentioned earlier in the section on personnel development, it is essential that transportation professionals in various agencies and consulting and other organizations be trained in the use of advanced technologies. This can be accomplished through various means of continuing education offered by universities. Careful plans of study should be developed that can satisfy the current and future needs of the operating agencies, private consultants, and contractors.

CONCLUSIONS

Advanced technologies in the area of information systems, automation, and telecommunications provide civil engineers with extraordinary opportunities for improving planning, design, construction, maintenance, and operation of transportation systems.

New tools and techniques have the potential of achieving cost savings and productivity improvements as well as enabling new developments in transportation. There is a general feeling among transportation engineers that much of the future growth and Development in transportation engineering would depend upon how effectively these new technologies are adopted in the field. The basic purpose of the paper was to review the areas where advanced technologies can significantly affect the way transportation engineering is practiced. The strategies for implementation of the necessary changes in the practice were also discussed along with the expected impact on civil engineering curriculum. Transportation accounts for the major portion of infrastructure investment. In order to maintain and preserve the highways, bridges, railroads, ports, harbors, pipelines, and airports as well as to plan for future developments in space transportation, civil engineers must seize the opportunities presented by the emerging technologies in information systems, automation, and telecommunications. A concerted effort in this area by government, private industry, and universities can make a significant impact on productivity and performance of transportation systems.

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