Present and Future Role of Maintenance Management Training in Civil Engineering Higher Education

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Undergraduate (B.S. degree) civil engineers provide the majority of the professionals entering highway maintenance engineering. The continued decline in planning, design, and construction as functional activities in state departments of transportation and the proportional growth in maintenance and operations activity suggest that it is time to examine the degree to which undergraduate civil engineering education is preparing young people for highway maintenance engineering careers. A survey of the 20 largest education programs indicates little overall educational strength suitable for highway maintenance careers. The Accreditation Board for Engineering and Technology criteria were found to be both a hindrance—emphasizing traditional science, the planning-design-construction process, and general education—and a help in providing a mechanism by which TRB and AASHTO can become active in instituting change.

The bulk of the engineers working for state departments of transportation (DOTs) are civil engineers. A 1984 study of personnel found that almost three-fourths of all professionals at DOTs were civil engineers (*1*). Because civil engineering undergraduate programs are the predominant supplier of young professionals to DOTs, the suitability of undergraduate civil engineering programs for the preparation of engineers entering the field of highway maintenance management is explored.

The changing skill requirements for young civil engineers are explored in light of the maturity of the U.S. highway system. Clearly, skill requirements are shifting from those necessary to developing a system to those necessary to efficiently maintaining and operating facilities. Next, the results of a survey of the civil engineering curricula of the 20 U.S. universities that graduate the most civil engineers are presented. Many curricula do not provide ample opportunity for engineers to develop skills in the maintenance management area.

Civil engineering education has traditionally identified its responsibilities for training undergraduate engineers in broadly defined categories of knowledge. The categories usually include structural design, water resources and environmental engineering, materials engineering, surveying, and highway and transportation engineering. Some universities may include further categories such as construction engineering and management and municipal engineering. Each category can be further divided into subtopics. For example, highway and transportation engineering can be divided into subtopics such as pavement design, traffic engineering, and transportation planning.

Although civil engineering undergraduate programs contain diverse areas of knowledge, they all follow the general theme of bringing a civil engineering project through the stages of planning, design, and construction. The plan-design-construct theme is so highly integrated into the traditions of civil engineering education that it is the motto of the civil engineering national honorary society, Chi Epsilon. Chi Epsilon retains the motto of Chi Delta Chi, which stands for conception-design-construction.

The opportunity for engineers in DOTs to participate in the planning, design, and construction of new highways has diminished. The last major highway construction initiative, the Interstate highway system, is virtually finished. In the summer of 1989, the Federal Highway Administration reported that roughly 99 percent of the planned Interstate system had been completed. Of the remainder, 60 percent was under construction and 20 percent was under various stages of preconstruction (*2*).

Aside from a few, and quite remarkable, examples of private-public partnerships and toll-financed facilities, it appears that, in the foreseeable future, no significant national highway building projects will be initiated. As John Hassett, the former Executive Director of the International Bridge, Tunnel and Turnpike Association, stated while reflecting on the end of the Interstate system's construction, "Any future program will be far less dramatic and inspirational; . . . it will be more in the nature of a shoring-up, fix-it-here, fix-it-there type of plan" (*3*).

Furthermore, the financial resources necessary for DOTs to initiate all but a few stopgap construction programs are unavailable. The American Association of State Highway and Transportation Officials has projected that current annual funding levels for highways, at all levels of government, are roughly $14 billion below the expenditures needed simply to maintain highways in their current condition (*4*).

To reduce the gap between financial resources and needs, 47 states (all except Alaska, Georgia, and New York) raised gasoline taxes during the 1980s, and the federal government increased the federal gasoline tax by 5 cents/gal in the Surface Transportation Act of 1982 (*5*). Unfortunately, revenue increases have barely kept pace with inflation. For example, in dollars adjusted for inflation (1984 dollars), the federal government invested $11,112 million in highway-related

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expenditures in 1980 and $11,746 million in 1988 (*5*). Clearly, the gap between the funding needed to maintain highways in their existing condition and the funding available is widening, making it imprudent to even suggest significant additional highway construction.

In addition to current problems, the specter of growing needs and declining revenue sources looms. Vehicle miles traveled are likely to double in the next 30 years, whereas gasoline taxes (in absolute dollars per mile traveled) are likely to decline because of improved fuel economy (*6*). Truck traffic, measured in ton-miles, increased at a rate of almost 2.7 percent/year during the 1980s and is likely to continue to increase (*7*). Furthermore, the American Trucking Association predicts that another 50 billion ton-mi of freight traffic will be carried by trucks and diverted from the rail system if proposals for a national long-combination-vehicle network are adopted (*8*). All the likely traffic trends paint an even bleaker picture of the ability of available financial resources to meet needs.

The dreary outlook leads to the conclusion that significant new highway construction is unlikely and that DOTs are apt to be preoccupied with stretching their resources to provide for maintenance and restoration. Engineers entering DOTs are more likely to be charged with better managing current activities and more efficiently allocating available resources than with planning, designing, and constructing new facilities. Larson and Haack defined the "shift from transportation system development to transportation system management" as a megatrend that changes the skills that future transportation professionals will need (*9*). Furthermore, because of public infrastructure funding shortfalls in general, more civil engineers in all subdisciplines (i.e., environmental engineering, structural engineering, geotechnical engineering, etc.) are likely to become increasingly involved in infrastructure maintenance and maintenance management.

CIVIL ENGINEERING CURRICULA CONTENT

Engineering educators recognize the importance of monitoring and adjusting the content of the civil engineering curriculum as needs change. However, a change of emphasis in one area must be continuously balanced by an equally great need in other areas. For example, in the environmental engineering area, an argument could be made to expand curricula beyond traditional water and wastewater treatment to more diverse areas of air pollution, hazardous waste management, and occupational health and safety. Arguments that civil engineers would be well served by more preparation in planning issues, including public administration, law, finance, and economics, have also been made (*10*).

In considering the arguments, the university must develop a program that meets minimum standards established by the Accreditation Board for Engineering and Technology (ABET) but is not so high in credit hours that the engineering program cannot attract students (*11*). Several undergraduate programs were reviewed to assess the current position of engineering curricula in providing students with the skills needed to manage maintenance.

The university catalogs of the 20 largest civil engineering programs in the United States, on the basis of total undergraduate and graduate degrees granted, were surveyed for content appropriate to enter the maintenance engineering profession. Table 1 gives the programs surveyed, the number of graduates in 1987–1988, and the credit hours required for the B.S. degree in civil engineering.

TABLE 1 SAMPLE OF CIVIL ENGINEERING PROGRAMS IN THE UNITED STATES, 1987–1988[a]

University	BS Degrees	MS&PhDs Degrees	BS Credits Required
Colorado State Univ.	72	70	130.0s
Georgia Inst. of Tech.	88	56	206.0q
Iowa State University	107	23	133.5s*
Mass. Inst. of Tech.	34	101	133.0s
N. Jersey Inst. of Tech.	57	66	136.0s
No. Carolina St. Univ.	170	42	138.0s
Penn State University	124	34	132.0s
Purdue University	115	101	131.0s
Stanford University	33	111	180.0q
Texas A&M Univ.	209	64	136.0s
Univ. of Cal.-Berkeley	68	204	120.0s
Univ. of Colorado	90	66	128.0s
University of Florida	83	59	143.0s
Univ. of Illinois	98	94	129.0s
Univ. of Maryland	74	58	132.0s
Univ. of Missouri-Rolla	97	29	139.0s
Univ. of Texas-Austin	72	90	131.0s
Univ. of Washington	106	68	183.0q
Univ. of Wisc-Madison	90	48	135.0s
Virginia Poly. Inst.	146	80	136.0s

s=semester credits; q=quarter credits
* estimated equivalent semester credits
a Source: Degree data are from the March, 1989 issue of Engineering Education

There is a significant range in the number of credits required for a B.S. degree in civil engineering. On the basis of equivalent semester credits, the largest credit program is approximately 20 percent greater than the smallest. The curriculum of each school's civil engineering program is examined to determine how it meets accreditation requirements and whether additional credits have provided an opportunity for a student to prepare for a career in maintenance and operations when compared with programs requiring fewer credits.

ABET does not specify the number of credits necessary in a basic B.S. program, but it does specify a breakdown of 3 years of study in areas including mathematics and basic sciences (1 year), engineering sciences (1 year), engineering design (½ year), and humanities and social sciences (½ year). Programs having more than 128 semester credits may consider 16 credits to be ½ year. In addition to these defined areas, universities must demonstrate that students have developed competency in written and oral communications and an understanding of the ethical, social, economic, and safety considerations in engineering practice. The latter requirements may be met by formal course work or, as a minimum, by the faculty including these concepts in regular course work.

Courses from the university programs were reviewed to determine how the credits are divided among the ABET categories and to assess the availability of courses that would allow the student to develop skills in economics, systems analysis, management, or maintenance engineering that would be needed in infrastructure maintenance programs.

Table 2 shows the distribution of credits among the major ABET subareas. Because engineering science and engineering design are difficult to separate in many engineering courses on the basis of the catalog description, these courses could not be specifically identified, and only a range of credit hours is listed. However, it must be recognized that the ABET reviewers examine the entire course content and student transcripts to ensure that minimum requirements are met. A communications section is also shown in the table, even though this is an area for which ABET has a content requirement but no specific credit requirement. As indicated in the table, communication skills in English and technical areas have been combined.

Table 3 shows the breakdown of the curricula credits that are either technical electives, usually from a defined subset of courses, or free electives. Wide ranges occur, which result

TABLE 2 CREDITS BY TOPICAL AREA GROUPING

Humanities & Social Sciences: (ABET requires one-half year or a minimum of 16 semester credits)

16 credits - 4 programs
17 credits - 1 program
18 credits -10 programs
19 credits - 0 programs
20 credits - 1 program
20+ credits -4 programs

Mathematics and Basic Sciences: (ABET requires one year or a minimum of 32 semester credits)

32 credits - 9 programs
33-36 credits - 3 programs
37-39 credits - 5 programs
40+ credits - 3 programs

Engineering Sciences: (ABET requires one year or a minimum of 32 semester credits)

Range is from 10 credits plus portions of shared courses to 32+ credits plus portions of shared courses.

Engineering Design (ABET requires one-half year or a minimum of 16 semester credits)

Range is from 4 credits + portions of shared courses & electives to 16+ credits plus portions of shared courses

Communications: (writing, speech, graphics, presentation seminars)

None required - 2 programs
3 credits - 2 programs
4 to 6 credits - 2 programs
7 to 9 credits - 7 programs
10+ credits - 7 programs

ABET criteria are from 57th Annual Report of the Accreditation Board for Engineering and Technology

TABLE 3 PORTION OF B.S. CIVIL ENGINEERING CURRICULUM AVAILABLE IN TECHNICAL ELECTIVES

Elective technical credits		% of total credits
6 or less	-3 programs	3
7 to 12	-5 programs	9
13 to 18	-3 programs	12
19 to 24	-6 programs	15
25 or more	-3 programs	25

from the philosophy of the departments. Some programs require only introductory courses in two or three of the traditional areas of civil engineering, whereas others may specify at least two courses in each major area of the department.

It should not be assumed that a higher percentage of electives indicates a more flexible program. For example, one school in the group with 19 to 24 credits for electives restricts the choices to a small number of courses, all of which are in the traditional analysis or design categories.

A variety of courses that would be especially useful to a maintenance engineering professional were identified. They include courses in traditional areas such as transportation engineering and pavement design, but also include engineering economy, statistics with decision theory, systems analysis and optimization concepts, construction and management, and maintenance engineering. Table 4 summarizes the availability of these courses.

Four universities do not require any transportation engineering courses, but three of them provide an elective that gives the potential to take one or several transportation courses. A majority of universities also require a basic course in engineering economics. Offerings in the other areas are much more limited. Both undergraduate and graduate courses open to undergraduates are shown, even though some undergraduates may not be eligible because of university policy. Courses in highway engineering and pavement design were identified here even if only a small portion deals with restoration or rehabilitation of infrastructure. As can be seen, only two universities offered a course that emphasized maintenance or management of pavements.

RECOMMENDATIONS

Faculty background and capability may be one of the constraints on the breadth of educational opportunity available for persons interested in highway maintenance engineering. ASCE has changed ABET accreditation criteria for civil engineering programs from requiring that a faculty have persons qualified in at least three specialty areas (subdisciplines) to requiring four specialty areas. Unfortunately, ASCE has not yet defined which civil engineering subdisciplines must be represented. Recognition of the importance of transportation maintenance and operations could be stimulated if AASHTO and TRB cooperate with ASCE to create a subdiscipline list that includes those topics.

As a related matter, the civil engineering programs may examine their content with a view to incorporation of infrastructure rehabilitation in much the same way as an ABET engineering design requirement. A course in the senior year that (*a*) analyzes existing facility quality, reliability, and the economic aspects of various stages of maintenance compared with new facility design and (*b*) develops a maintenance management system would have as much educational value as a design course in a single structural, pavement, or highway design project.

TABLE 4 HIGHWAY MAINTENANCE-RELATED COURSES IN CIVIL ENGINEERING CURRICULA

Subject Area	Number of programs with at least one course: Required	Elective
Transportation	16	3
Engineering Economics	14	3
Systems Analysis	6	8
Statistics	10	(a)
Highway Engineering	-	12
Pavement Design (with limited maintenance)	-	8
Construction and management	(b)	15
Maintenance Engineering	-	2

(a) Statistics courses may be available as electives through other departments
(b) Required courses with CPM or similar emphasis are not shown.

In summary, it is clear that young engineers are not likely to have the same opportunities as prior generations of civil engineers to participate in the planning, design, and construction of new facilities. The shift from system development to system management represents a significant change in direction for the profession. Analysis of curricula at U.S. universities with the largest number of civil engineering graduates suggests that, in general, existing programs lack the breadth and flexibility to develop knowledge in areas that are especially useful to a maintenance engineering professional. Therefore, the academic community is likely to be better able to meet the skill requirements of future civil engineers by amending curricula to include more maintenance management content.

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