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ABSTRACT

The papers contained in the issue of Highway Research Record focus on current and emerging patterns of education and training related to transportation systems planning. The five papers are: Transportation Centers and Other Mechanisms to Encourage Interdisciplinary Research and Training Efforts in Transportation (Frederick J. Wegmann and Edward A. Beimborn); University Responses to Multidisciplinary Education (Lester A. Hoel); Role of Systems Analysis in Transportation Curricula (Richard de Neufville); Undergraduate Civil and Environmental Engineering and Transportation Engineering Needs (Herman A. J. Kuhn and William D. Berg); and The Transportation Laboratory: Teaching Fundamental Concepts of Transportation Systems Analysis (Marvin L. Manheim and Earl R. Ruiter). (JR)

HIGHWAY RESEARCH RECORD

Number 462

Education in Transportation Systems Planning

5 reports

HIGHWAY RESEARCH BOARD

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NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

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CONTENTS

FOREWORD

The papers contained in this RECORD focus on current and emerging patterns of education and training related to transportation systems planning.

Wegmann and Beimborn discuss the concept of interdisciplinary education in transportation and the mechanisms being used to establish such programs. Emphasized in their paper is the concept of the transportation center as a means to enhance research and training opportunities in transportation. The results of a survey of 17 schools having transportation centers are presented.

Hoel discusses the responses of universities to multidisciplinary education in transportation planning in terms of the content of subject matter and in terms of university restructuring to meet new demands and varying conditions.

de Neufville discusses the role of systems analysis in transportation education. Such techniques are increasingly being integrated into the planning and design of public facilities, which raises numerous questions on how these tools should be emphasized and integrated into academic programs.

Kuhn and Berg emphasize that educational programs must be designed to train individuals who have both a technical competence and an awareness of how their actions affect society and the environment. The authors discuss how the aforementioned concepts have been structured in the new civil and environmental engineering curriculum at the University of Wisconsin.

Manheim and Ruiter discuss the development of the Transportation Systems Laboratory at Massachusetts Institute of Technology. As the authors point out, the laboratory is in the form of a workbook of exercises in transportation system analysis and an integrated set of computer programs and data for executing the exercises. Emphasis has been placed on developing an understanding of the interrelationships between transportation technology and social impacts in the context of multimodal transportation systems.

TRANSPORTATION CENTERS AND OTHER MECHANISMS TO ENCOURAGE INTERDISCIPLINARY RESEARCH AND TRAINING EFFORTS IN TRANSPORTATION

Frederick J. Wegmann and Edward A. Beimborn, Systems-Design Department, University of Wisconsin—Milwaukee

The paper indicates directions and presents alternatives that may be considered in development of a transportation education program. The concept of interdisciplinary education is discussed by considering mechanisms used to establish such programs. Emphasis is given to the concept of a transportation center, and results of a survey of 17 schools with centers for interdisciplinary activities are presented. The function, administrative structure, academic involvement, and effectiveness of the centers are discussed, and comparisons are made in three fields of study: general transportation, urban transportation, and highways. Respondents' reactions to the centers in terms of meeting their objectives are presented and are intended as a guide to the future establishment of such centers. The strongest needs were expressed for continuity of funding and for the reliance on more than one sponsor. The need for administrative support and faculty interest was noted. It is pointed out that there should be a clear need for a center, which would heighten its chances of success. The types and levels of curricula are discussed, and two basic approaches (the menu and cafeteria types) are described. Other techniques in developing an interdisciplinary approach to transportation problems are seminars, team teaching, class projects, sharing of physical facilities, and use of operational gaming.

•THE past 5 years have witnessed profound changes in the basic manner in which transportation services are viewed, developed, and operated. The passage of the Federal-Aid Highway Act of 1968, the National Environmental Policy Act of 1969, and the Federal-Aid Highway Act of 1970, the expansion of programs in urban mass transit, and a rising level of concern on the part of the public over the shape of the transportation systems have all led to a new set of rules and directions for those actively engaged in the provision of transportation services. These changes have led to protection of parklands, TOPICS studies, environmental impact statements, noise and air pollution studies, relocation assistance programs, captial grants for mass transit, citizen participation panels, joint use projects, demonstration projects for innovative transportation systems, and so on. In all, this list represents extensive alterations to fundamental transportation policies and procedural considerations.

It is not surprising that these changes are having substantial impacts on transportation education programs at many universities. Immediately they have had the effect of creating a need to incorporate a broader array of subjects into the curriculum. Yet, a need still exists to anticipate what further changes may be forthcoming in the next 5 to 10 years so that the students leaving the program will be able to cope with future variations in policies.

Educational programs then must be responsive to current issues as well as to those of the future. Likewise educational programs must be responsive to those elements that have not been altered: the need to provide sound and economical designs, professional standards and competence, concern for safety, and a thorough knowledge of fundamentals. It is important that these qualities not be underemphasized or ignored in the rush to deal with those items that are of immediate concern.

A number of schools of higher learning ha responded to the needs of contemporary transportation students by implementing educ tonal programs of an interdisciplinary nature and away from more traditional single-discipline orientation (1, 2). The purpose of this paper is to discuss the concept of interdisciplinary education in transportation and to discuss mechanisms that are being used to establish such programs. Because of its prominence at many institutions, primary emphasis will be given to the concept of a transportation center as a mechanism to enhance research and training opportunities in transportation. The discussion will be based primarily on experience gained at the University of Wisconsin—Milwaukee (UWM) in applying such techniques. The overall thrust of this paper is not to advocate any one way of doing things but to indicate directions and alternatives that some schools are considering i developing an educational program oriented to the needs of both current and future transportation activities. It is hoped that the information presented here will be of use to others who are engaged in the development of transportation programs or to those who are faced with the task of hiring the students emerging from them.

THE INTERDISCIPLINARY APPROACH

Responsibility for providing basic transportation services today is a most complex task. It is evident from recent experience that no one profession by itself is able to contend with the many ramifications resulting from decisions to alter the quality or quantity of transportation services. In selected situations such as freeway location studies, this has given rise to joint concept teams where representatives from diverse disciplines such as architecture, engineering, economics, political science, and sociology all apply their knowledge and unique viewpoints to a complex transportation issue. In turn, greater attention has been given to the systems approach as a mechanism to make public-service decisions, e.g., provision of transportation services. Although the systems approach can be described as a sequence of steps such as defining objectives, developing alternative systems to meet the objectives, and evaluating and interpreting the alternatives in terms of their effectiveness, risks, and costs, its central contribution has been to ensure that transportation decisions reflect a large number of interrelated factors and systems. For example, highway planners must demonstrate that proposed highway improvements will be in accordance with local land use and development plans, have limited adverse environmental consequences, avoid displacement of persons without the availability of suitable relocation housing, and are coordinated with other modes of transportation.

In engineering as in other disciplines, this broader viewpoint requires a greater understanding of the social and environmental sciences, economics, political science, sociology, and ecology as well as natural sciences and mathematics. Such an understanding demands a broad background, one closely approximating the traditional concepts of liberal arts. However, engineering education still needs to be coupled with an understanding of technology and to provide the skills required to develop and intelligently use technology. With such a background, engineers in particular would be better equipped to modify and develop technology and its institutions to make them more compatible with and responsive to the changing values of our society.

The new viewpoint requires a shifting in educational programs. For example the graduating engineer interested in a career in the transportation industry (planning, design, operation, construction, or administration of transportation facilities) not only must be well grounded in the fundamentals of detailed design procedures but also must be given experience in general problem solving and analysis skills. As shown in Figure 1, the level at which the engineer desires to specialize will in part determine the breadth of his training. Advanced graduate programs in subjects such as soil mechanics, foundation engineering, or pavement design will not develop the same interdisciplinary mix as programs in transportation planning. For example the previous group will place greater reliance on applying the principles of the natural sciences such as physics and chemistry than on the social sciences. However, it is important that a soils engineer have some appreciation of the transportation planning process and vice versa. Only through broader appreciation of the total picture with acknowledgment given to the role played by other disciplines can individuals learn to work and communicate effectively as members of multidisciplinary teams. It is essential that academic institutions provide the environment to allow individuals to establish lines of communication with and foster mutual respect for other disciplines.

The key question then becomes how to allow an engineering student or a student from some other discipline interested in transportation as a profession to acquire interdisciplinary experiences. It is evident that an interdisciplinary effort at a university does not occur naturally. Universities are generally organized along strict disciplinary lines, and it is often quite difficult to work across these boundaries. Furthermore, the reward system in a university often discourages interdisciplinary activities. Strong administrative support coupled with deliberate actions is required to bring about a working interdisciplinary research or training program. Yet the mere establishment of seminars or organizations such as a transportation center will not ensure an interdisciplinary effort. An interdisciplinary effort must exist as a real interplay of disciplines rather than on paper. Such an effort can exist without a formal structure. However, any formal steps taken on behalf of establishing an interdisciplinary approach should meet with greater success, assuming all other factors are equal, than relying totally on natural forces without prompting.

The remainder of the paper discusses various methods that might be used to establish an interdisciplinary approach aimed at fostering research and academic training in the area of transportation. One prominent avenue used by many institutions is the establishment of a transportation center, where the center forms the structure that allows various disciplines to join and bring their respective expertise to bear on complex transportation issues. Of course not all educational institutions have the ability to establish formal centers, and likewise the mere establishment of a center does not ensure development of an interdisciplinary effort. Other approaches and concepts can be utilized such as curriculum changes and seminars. Again it must be emphasized that these approaches are not mutually exclusive; rather, they are complementary.

TRANSPORTATION CENTERS

The concept of a transportation center has achieved prominence as a mechanism to foster research and academic training in the area of transportation (3). Although it is difficult to document the precise number of active centers, a 1969 survey completed by the Transportation Center Library, Northwestern University (4), provides one of the most complete inventories of university and college programs in transportation and traffic on a nationwide basis. For purposes of comparison, the programs were subdivided into the following four fields of study and research:

1. Transportation economics,
2. Civil engineering,
3. Urban transportation, and
4. Highway safety.

As given in Table 1, almost 70 percent of the identified programs in transportation and traffic have access to a center or institute concerned with transportation. Although this does not imply that all centers are effective organs for conducting research and training, and in fact it is highly questionable whether a number of the centers listed still function, just the sheer number of centers in existence at various universities and colleges interested in transportation is impressive. Also documented by the Northwestern University report is the fact that 15 of the 20 schools issuing more than 10 doctoral degrees in transportation (based on study in the fields of economics, geography, business administration, public administration, civil engineering, and history) between 1961 and 1969 had access to a center concerned with transportation. Again this is not a complete list, nor can it be assumed that the dissertation research was necessarily conducted through the auspices of the centers or institutes.

To better ascertain the role of a transportation center and to judge the experience gained by those institutions involved with centers or institutes concerned with trans-

Figure 1. Conceptual outline of interdisciplinary training for engineering students in transportation.

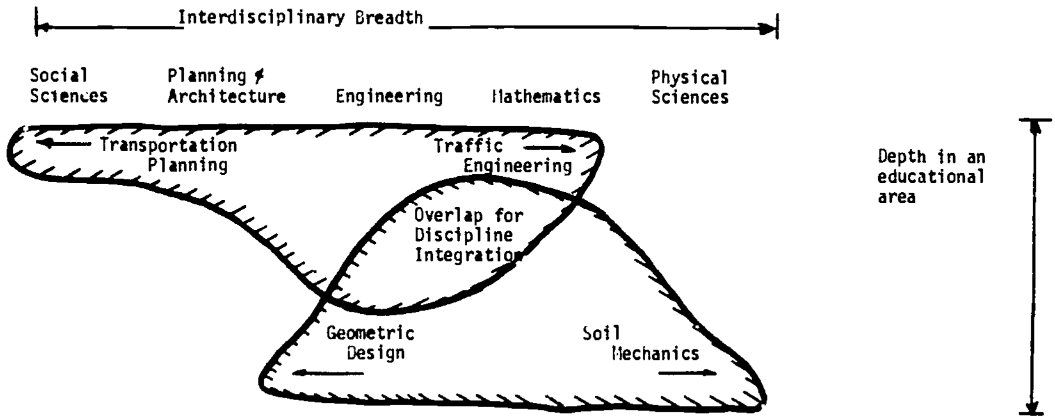

Table 1. Results of Northwestern University survey (4).

Subject Area	No. of Programs	No. of Centers	Percentage of Programs With Center Available
Transportation economics	35	21	60
Civil engineering	27	19	70
Urban transportation	29	19	66
Highway safety	15	13	87
Total	106	72	

Table 2. Distribution of centers responding to questionnaire.

Year of Origin	Type of Center			Total
	General Transportation	Urban Transportation	Highway	
Pre-1961	1	—	2	3
1961-1965	2	—	1	3
1966	—	—	—	—
1967	1	—	—	1
1968	—	3	—	3
1969	1	2	—	3
1970	2	1	—	3
1971	—	1	—	1

portation, we distributed a questionnaire to 30 schools that listed the availability of a transportation and traffic center. From these 30 schools, 20 replies were received, of which 17 were directly applicable to the questions posed. Although the survey did not include all transportation centers of national prominence, it is felt that the survey sample adequately reflected cross sections of currently operating centers.

For purposes of tallying the responses, the centers were stratified into three distinct groups. This was done with the intent of sharpening the responses. The distinctions were based on the premise that transportation centers or institutes generally have the broadest responsibilities including transportation and traffic, rural and urban problems, and a number of different modes. Urban transportation centers or institutes specifically focus on issues confronting urban areas, whereas highway programs primarily focus on the highway mode of travel.

Functions of a Center

The functions to be performed by a transportation center were most commonly characterized by combinations of the following:

1. Foster and/or initiate research in transportation,
2. Promote and/or enrich educational training programs in transportation,
3. Encourage interdisciplinary efforts,
4. Provide for the dissemination of knowledge, and
5. Provide community services and interaction between the community and the university.

Commonly a transportation center would have two or three of these functions as its mission. Most frequent reference was made to fostering research, promoting educational training programs, and providing for the dissemination of knowledge. Emphasis on the interdisciplinary effort indicated how these functions were to be accomplished and was common to many of the replies.

Specific responsibilities of a transportation center generally include

1. Identification of potential research sponsors,
2. Provision of research support through secretarial and library facilities,
3. Coordination of research between sponsor and researcher,
4. Serving as a research clearinghouse, and
5. Publication and distribution of research results.

Only 65 percent of the centers had responsibility for overseeing an academic program. Interestingly, all the urban transportation centers included in the survey identified overseeing of an academic program as a function, whereas only four of the 10 remaining centers identified this as a responsibility. The high degree of involvement in overseeing academic programs by urban transportation centers may be attributed to their involvement in research and training programs in urban mass transportation under financial assistance from the Urban Mass Transportation Administration (UMTA) of the Department of Transportation.

Age and Size of Center

Data given in Table 2 point out the recent proliferation of centers. For example, eight of the 17 centers included in this survey originated since 1968. Also it is interesting that all of the centers or institutes concerned exclusively with urban transportation were initiated after 1968. All but one of these urban centers are currently receiving financial support from UMTA Research and Training Grants that were initiated in 1968. The impact of government programs on the establishment of centers is again quite evident. The recent emphasis on establishing transportation centers is undoubtedly related to the changing mix of concerns confronting the transportation profession. To ascertain the size of operation of existing centers, we requested information on dollar size of current research involvement, number of research projects, and number of faculty and staff associated with the center. With this information we hoped to define the minimum level of research effort required to sustain a transportation center.

Table 3. Annual budgets of centers responding to questionnaire.

	Type of Center			
Annual Budget (thousand dollars)	General Transportation	Urban Transportation	Highway	Total
0-49.9	—	1	—	1
50.0-99.9	1	2	—	3
100.0-149.9	1	2	—	3
150.0-199.9	2	—	2	4
200.0-299.9	1	—	—	1
300.0-499.9	1	1	—	2
>500.0	1	—	1	2

Note: Average annual budgets are general transportation center, $280,000; urban transportation center, $115,000; and highway center, $345,000.

Table 4. Academic disciplines represented at centers responding to questionnaire.

	Type of Center			
Disciplines	General Transportation	Urban Transportation	Highway	Total
Urban planning	3	3	1	7
Economics	4	4	1	9
Civil engineering	5	4	3	12
Industrial engineering	1	1	1	3
Mechanical/aerospace engineering	2	1	3	6
Electrical engineering		1		1
Engineering-general	3	1		4
Geography	4	2		6
Law	2	1	1	4
Sociology	1	3	1	5
Political science	2	4	1	7
Business	4	1		5
Computer science	1	1		2
Real estate		1		1
Social research		1		1
Psychology	2	2	2	6
Chemistry, biology			1	1
Medicine			1	1
Physical education			1	1
Agriculture			2	2
Architecture	1			1
Mathematics statistics	3			3
Regional science	1			1
As required	1	1		2

Table 5. Number of disciplines represented at centers responding to questionnaire.

	Type of Center			
No. of Disciplines	General Transportation	Urban Transportation	Highway	Total
0-2	1	1	0	2
3-4	1	1	0	2
5-6	0	1	2	3
7-8	2	2	0	4
9-10	1	0	0	1
>10	0	0	1	1
As required	1	1	0	2

The range in annual budgets varied from zero (one of the centers reported it was between research projects) to in excess of $1 million (Table 3). Most centers had an annual research budget of at least $50,000 per year. Generally, the older and more established the center was, the larger its budget was. The total budget represented by all the centers responding to the questionnaire was $3,685,000, with an average of $265,000 per center.

The source of funding most frequently indicated was the federal government. Specifically, only two institutions out of 12 did not rely on any federal funding to support the core staff (director and associate director), and only three institutions out of 14 did not rely on any federal funding to support the research staff. In fact, three institutions relied totally on federal grants to support the core staff, and four relied totally on federal grants to support the research staff. The number of institutions relying on individual, state, or university funding was small and generally limited to the lower percentages of support.

The number of projects undertaken varied at any given time depending on current contract obligations. Most commonly, centers undertook between one and five different projects and had a staff involvement of between two and 10 members at any one time. Not considering the center currently between projects, the number of projects varied from one to 40, with a faculty association of between one and 72 members.

Data given in Table 4 evince a broad range of disciplines represented in the centers. Just about all the centers had some degree of involvement with engineering. Within engineering, civil engineering was included at 12 centers, and mechanical and industrial engineering follow with four and three respectively. In four instances, engineering—general was listed. Other disciplines ranking high after civil engineering (12) were economics (9), urban planning (7), political science (7), mechanical/aerospace engineering (6), psychology (6), and business (5). Besides the specific disciplines involved with a center concerned with transportation and traffic, the total number of disciplines involved is of great interest. To a certain extent the number of disciplines represents the concept of "critical mass." Two institutions indicated that disciplines would be involved with the center as needed. However, most centers involved five to eight disciplines (Table 5).

Data given in Table 6 identify the type of research involvement classified by the topic areas commonly encountered in transportation and traffic studies. The interdisciplinary nature of the centers is evident from the fact that a broad spectrum of activities was encountered. Centers did not tend to specialize in one or two select areas but rather provided a broad base of capabilities and utilized individuals from many diverse disciplines. Interestingly, all but one general transportation center indicated participation in transportation planning and transportation engineering, whereas all indicated participation in traffic engineering. All but one of the urban transportation centers noted involvement in urban planning, transportation planning, and transportation impacts. Likewise, all the highway centers indicated involvement in transportation administration, environmental engineering, traffic engineering, and transportation engineering.

Academic Involvement of Center

Of interest is how a transportation center responsible for promoting research and community services relates to academic programs. It is expected that research and academic programs in transportation will develop as mutually supportive elements. Even for centers without direct responsibility for overseeing an academic program, the research component will improve educational opportunities and heighten student interest in transportation. Even though most centers do not directly offer degrees, they provide classes and seminars, coordinate individual student academic programs through advising responsibilities, serve as a central clearinghouse to direct students to respective disciplines for academic programs, and provide financial assistance (Table 7). Thus, the presence of a research-oriented transportation center will provide benefits for related academic programs.

Self-Evaluation of Center

As a guide to others contemplating establishment of a transportation center, it was felt desirable to determine the respondents' reactions to the centers in terms of meeting their objectives. One question asked was whether the availability of a center has led to furthering the interest in transportation in the faculty, students, and local community. In response to this question, the centers were unanimous in their feeling that the presence of a center had helped their programs. Only two of the centers expressed some disappointment in the degree to which it occurred. The benefits derived from the availability of a transportation center, which would otherwise not have accrued, were stated as follows:

1. Encourages expanded research to enhance academic programs,
2. Attracts students,
3. Encourages and facilitates interdisciplinary activity in transportation,
4. Encourages focus on real-world research problems,
5. Attracts funding and visibility,
6. Provides faculty support,
7. Provides for better dissemination of information, and
8. Improves community involvement.

Encouraging programs and attracting students were benefits that were cited most frequently. Providing a better atmosphere for research through interdisciplinary approaches and contact with the community were also mentioned frequently.

Many interesting and thought-provoking replies were received to the question, What factors should be seriously considered before a center is established so that its chances for success are enhanced? Many of the 11 considerations given in the following were identified by more than one institution:

1. For an interdisciplinary program to exist it must not be housed in a specific college. Also place the center in the administrative structure to promote its own budget control.
2. An attractive office and physical plant to encourage interdisciplinary action.
3. Have a full-time director with adequate support staff.
4. Have a continuous commitment from a broad array of sponsors. Do not rely totally on one sponsor.
5. Have a faculty (or at least two individuals) committed to the idea. One of these individuals should be capable of leadership.
6. Provide university funding for base level of support over at least a 3-year period.
7. Ensure administrative support from university.
8. A history of interdisciplinary cooperation.
9. A real need for the services provided by the center.
10. Have guaranteed annual support to maintain the basic organization.
11. Define a focus relying on local strengths to develop a distinctive image and visibility.

Strongest in emphasis were the needs for continuity of funding and not jeopardizing the center by relying exclusively on one sponsor. Also the need for administrative support and the interest of the faculty were noted as critical. For a center to function, it must have a source of leadership and appropriate placement within the administrative structure. If a truly interdisciplinary program is desired, then the center must not be housed in any specific college or department, thus minimizing intercollege and interdepartmental rivalries. Of course, the administrative machinery must exist to permit such a placement.

A review of the questionnaires indicated that "an interdisciplinary approach" represented a common thread identifying how to promote research and training programs in transportation. The strong interdisciplinary ties of the centers now functioning are quite evident from a survey of the disciplinary mixes encountered. The particular mix of disciplines varied from institution to institution depending on local resources and interest on the part of the faculty to become involved in transportation problems. The centers were then providing the atmosphere and structure where various disciplines could meet to work on common problems. A paper by Romvaldi and Hoel (5) provides further thoughts on how to encourage a truly interdisciplinary effort.

It might also be pointed out that there must be a clearly defined need for a center in order to enhance its chances of success. A number of respondents pointed out the recent trend toward proliferation of centers without sufficient research or student support. It can be said that educators have little appreciation for the demand aspects of transportation program development. Little information is available on how many students various segments of the transportation industry will be able to absorb in future years. Yet independent decisions continue to be made on altering the supply of transportation education without regard for demand. Currently no information indicating the total number of students enrolled in transportation programs is available. Table 8 gives partial information based on a sample of 10 schools. The results indicate that emphasis is concentrated on MS degrees. The point that overcapacity in transportation centers might soon be reached was one warning provided. This raises an interesting question: How can the benefits of a transportation center be extended to other institutions, particularly smaller or undergraduate-oriented programs not currently pursuing sizable research or graduate training programs in transportation? To provide insight into this question requires that the contributions of a center appropriate to a smaller operation be seriously considered. That is to say, for the scale of operation identified by the survey, the transportation center is perhaps the most expedient technique to stimulate research and give a common focus to transportation courses, but alternate directions might be available to better suit the unique characteristics of each institution. A center is frequently established to coordinate elements internal to the university by providing contact with outside agencies and by providing a certain degree of mission identity and visibility. However, curricula and educational formats can be altered as part of internal procedures by any size university and need not be related to concerns for extramural funding.

CURRICULUM

Whether or not a transportation center exists, the question of the types and level of curriculum to be provided in the academic programs needs to be addressed. As experienced educators can attest, curriculum development and change can be quite a difficult area. Changes resulting from the ways in which transportation is being viewed by society can be dealt with most effectively by including in the curriculum material from a broad array of disciplines.

At the same time there is a danger of making the student too shallow in one area so that he does not have the capability of working through to the details of a problem. For example, it may be desirable to give an engineering student background in economics, architecture, biology, urban affairs, and so forth; however, if by doing this he learns so little engineering that he cannot perform ordinary engineering tasks that might be assigned to him, he may be unable to put his broad background to any useful purpose. The key to dealing with this type of conflict is to provide as much flexibility in the program as possible but not at the sacrifice of presenting a core body of information.

There are two basic approaches to the development of a curriculum. The first approach is to offer the student a menu that specifies to him the prescribed sequence of courses he must take in order to qualify for a degree. The choices have been made basically by the management in line with their judgment of what everyone needs. The other approach to curriculum development is a cafeteria approach. Under the cafeteria approach the university lays before the student an array of courses from which he can select his own program. In this way the student can tailor his program to achieve a very close fit to his personal goals and objectives. There is, of course, some danger that the student may select an unhealthy combination.

At UWM the approach used is basically a cafeteria approach combined with a strong advisory input. This approach has enabled accommodation of students with a broad range of interests and backgrounds. In general most students will take a common set

Table 6. Nature of research involvement of centers responding to questionnaire.

Research	Type of Center: General Transportation	Urban Transportation	Highway	Total
Transportation planning	6	5	2	13
Urban planning	4	6	2	12
Transportation administration	5	4	3	12
Transportation impacts	5	5	2	12
Traffic engineering	7	2	3	12
Transportation engineering	6	2	3	11
Urban systems	3	4	2	9
Environmental engineering	4	2	3	9
Highway engineering	4	1	2	7
Transportation materials	3	2	2	7
No. of centers	7	7	3	17

Table 7. Nature of academic involvement of centers responding to questionnaire.

Type of Activity	Yes	No
Degrees are offered under auspices of the center	3	10
Center offers classes and seminars	6	7
Center coordinates individual student academic programs with advising responsibilities	9	4
Center refers students to respective disciplines for academic programs	11	2
Center provides financial support such as graduate assistantships	11	2
Center provides financial support in the form of fellowships	9	4

Table 8. Degrees granted in transportation at 10 schools with access to transportation or traffic engineering center.

Degree	1967-68 No. of Schools	1967-68 No. of Degrees	1969-70 No. of Schools	1969-70 No. of Degrees	1971-72 No. of Schools	1971-72 No. of Degrees	Estimated 1973-74 No. of Schools	Estimated 1973-74 No. of Degrees
Bachelor's	13	2	15	3	21	3	34	3
Master's								
Part time	1	1	3	1	4	2	5	2
Full time	34	5	92	9	83	9	118	8
Doctorate	10	3	26	7	13	6	34	6

of courses with the opportunity to select electives from highly divergent areas identified as professional breadth courses. Probably no two students have taken exactly the same program, but then again nearly all of them have backgrounds in a basic set of core courses. One mechanism for achieving a high degree of flexibility in a program is to establish a "Topics in Transportation" course. Under such a course it is possible to offer students certain material on a demand basis without having to go through an extensive course approval process. It also gives the opportunity to offer material of current interest without filling up a catalog with courses that are never taught. The "Topics in Transportation" course should be frequently taught and in a seminar format.

Another important issue in curriculum development is that of offering programs at a suitable level. University transportation programs could be offered to terminate in a 2-year associate degree, a bachelor's degree, a master's degree, or a doctorate degree. In addition these degrees could also be offered on a full-time or part-time basis. Other efforts could include continuing educational programs in terms of short courses, institutes, seminars, or professional degree programs. A school needs to make some decisions on the potential market and which of these levels to emphasize. Experience at UWM has indicated that efforts to attract part-time graduate students and to offer continuing education programs can have very positive benefits. These benefits accrue to the part-time student and to the community because of the greater expertise he acquires through taking courses at the university. Benefits also accrue to the full-time student and to the faculty members from their contacts with part-time students in giving them a greater understanding of the practical aspects of the problems that exist in the real world and the constraints that exist in dealing with them. Providing programs to accommodate the part-time student may cause scheduling and other problems. However, the benefits can easily outweigh the costs if such programs are consistent with the overall goals of an academic institution.

OTHER MECHANISMS

Beyond the visibility that can be provided by a transportation center, a need exists to develop curricula consistent with the current interdisciplinary approach to transportation problems. Other techniques are also available including seminars, team teaching, class projects, sharing of physical facilities, and use of operational gaming.

Joint seminars can be used as a mechanism for bringing together people from different disciplines by providing a forum for discussion of problems of mutual interest. At UWM such seminars have taken two basic forms. The first type is a community seminar with sessions held in the evening and open to the general public. Usually the seminars involve speakers brought in from outside to discuss problems of general interest. The second type of seminar is an in-house, zero-credit seminar. This seminar is intended as a point of informal discussion for the students and faculty involved in transportation projects at UWM. There are no requirements for any of the participants other than attending the sessions. The program is largely developed by the students and can consist of discussions of ongoing and anticipated research projects, films, or outside speakers. Such activities can be quite useful in encouraging persons from different backgrounds to interact. A related tactic that can be applied is to have persons from different backgrounds share the same physical facilities. Through such sharing, the amount of contact can be increased, and a better knowledge of different viewpoints can be developed.

Another form of interaction between faculty and students of different disciplines can be developed by promoting joint activities of one type or another. These activities might involve the joint teaching of a course by faculty members from different departments, the participation of a number of students from different areas on a joint class project, or simulation gaming of a transportation project. Each of these activities has been tried at UWM, and they all have been successful. A course dealing with environmental impacts was taught jointly by faculty from engineering and architecture. In conjunction with this course and other courses, students have worked together on semester-long group class projects. These projects serve as a technique to illustrate concepts and procedures that are subjects of course materials and as such give the students experience in working together on a realistic project. Among the projects developed in this way have been rapid transit studies, TOPICS studies, analysis of the transportation problems of the elderly, and development of environmental impact statements. One project of note was the development of a "route location game." This game simulates the activities that are involved in the location of a highway facility through a public hearing. The students assume roles ranging from design engineer to concerned citizen to elected official. The interaction provided through such a process can be highly effective in gaining an understanding of the many facets of a transportation decision.

Activities that bring together persons of different backgrounds to work on a common project that cuts across a number of areas should be encouraged if an interdisciplinary effort is to be developed. These activities may go much further than formal measures such as the establishment of a center in developing a program of a true interdisciplinary nature and can be experimented with at a low cost.

CONCLUSION

This paper has discussed some mechanisms currently utilized for developing interdisciplinary programs in transportation. Attention has focused on the concept of a transportation center, curriculum development, and other techniques. The main thrust of the paper has been to present alternatives that might be considered in the development of a transportation education program. This paper is best summed up by presenting these alternatives as a series of questions. Each question must be addressed by an institution seeking to establish an interdisciplinary approach. However, it must be clearly asserted that interdisciplinary effort does not occur naturally; it requires extensive and continuing efforts, and many alternative procedures exist to assist in implementing an interdisciplinary research and training program in transportation.

1. What are the overall goals and philosophy of the program in transportation? What needs are being addressed?
2. Should a transportation center be developed?
3. At what point in time should a center be developed—at the beginning or when the program reaches a certain size?
4. What will be the functions of a center?
5. What will be the sources of support for a center or a program?
6. What academic disciplines will be involved with a center or program? What is the nature of their involvement?
7. How will a center or program function administratively? Who does it report to?
8. In what educational or training activities will a center or program be engaged?
9. At what levels will training efforts be offered? What is the potential market?
10. What is the balance between research and teaching?
11. In what directions should the curriculum be directed—a menu or cafeteria approach?
12. Should joint seminars and the like be offered, and how will they be operated?
13. What are the opportunities for team teaching, joint projects, or gaming in the program?
14. How will reward structures be established?
15. How interdisciplinary do you want to be?

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UNIVERSITY RESPONSES TO MULTIDISCIPLINARY EDUCATION

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This paper considers two facets of the response by universities to multidisciplinary education in transportation systems planning. The first deals with the educational content of training programs, and the second discusses the mechanisms for carrying out effective transportation planning education within the university.

•THE EDUCATIONAL OBJECTIVES of programs in transportation systems planning are first to transmit the state of the art and second to develop a capability to analyze and evaluate alternative transport solutions. On the one hand, education should teach the fundamental concepts, theories, methodology, practice, experience, and research results so that the student can begin professional practice. On the other hand, because the field is so rapidly changing in both methodology and scope, formal education is soon outmoded and specific planning techniques and methods become less vital than is the ability of the transportation planner to respond to changing environmental conditions.

As an illustration of the dichotomy between state of the art and obsolescence, it was not many years ago that transportation planners were taught how to locate highways on the basis of least cost solutions by considering costs and benefits to the users of the system. Today that approach is outmoded; we have become greatly concerned with the quality of our environment and the way in which transportation facilities influence that quality. Furthermore, we have learned that gross benefits conceal the distribution of benefits. Some sectors of society have experienced negative beneficial effects from freeway locations both in terms of housing relocations and in terms of the reduction in mobility, which has created problems for persons without access to an automobile.

Further, transportation planning has considered primarily needs at the regional level, and approaches have been developed principally to determine locations for freeway corridors and major transit systems. That level of planning, however, is highly ineffective for the day-to-day decisions that must be made at the local level, and we are now seeking ways to make the transportation planning process more responsive to the immediate problems of urban areas and to reflect the short tenures of policy-makers. In the next decade, as transportation planners become more concerned with short-range planning they should be more effective in communicating the professional advice that is so sorely needed.

The transportation planner has the task of developing alternative plans and measuring the effectiveness of these alternatives such that the implications of each are clearly understood by the decision-makers. Education can serve the roles of developing an awareness of the issues that are relevant to the decision-making process, including the political, social, and economic environment within which the planner operates; of coupling these with the conceptual and quantitative tools that are necessary to evaluate their consequences; and of presenting these in a manner so that decisions can be made.

UNIVERSITY RESPONSES IN CONTENT AREAS

University responses to transportation systems education have occurred in both content and organization. Three elements in transportation systems planning education are selected to illustrate university responses in content areas. These are emphasis on a multimodal framework, systems analysis for evaluation of alternative designs and policies, and the focus on mathematical modeling and computer analysis.

Multimodal Network Analysis

The emphasis on a multimodal framework for the examination of alternative systems contrasts with the more traditional approach in which individual components, modes, or pure technologies such as railroads, rapid transit lines, highways, airports, and waterways are analyzed separately. The single-mode viewpoint considers a set of alternatives within a limited framework and seeks to select that alternative for which a least cost solution can be defined. For example, earlier education in highway design and location placed heavy emphasis on the balancing of cut and fill in order to ensure the least cost solution from the perspective of moving materials, without taking account of other related factors that were ignored or considered to be outside of the system. In a multimodal approach to the problem, a wider range of alternatives is developed because the interaction of modes is considered as is the possibility of altering operating policies. Accordingly, the interfaces of modes become an important consideration because often the most critical and complex problems will occur at these points.

Systems Analysis

Systems analysis has become widely accepted and, in the context of transportation systems planning, represents a definition of the goals and objectives to be achieved by the system; development of the means for measuring the effectiveness of candidate plans; formulation, description, testing, and evaluation of alternatives; and selection of an alternative for implementation. The systems approach as a formal educational tool is valuable in that, aside from its logic, it serves to make explicit each of the fundamental elements in the planning process and as such develops a basic awareness of the major issues involved in the selection process. We are not able to develop optimal plans in a mathematical sense in transportation systems planning, and, accordingly, systems techniques will not replace the need for judgment, intuition, compromise, and common sense. On the other hand, applying the systems approach to transportation planning has the effect of improving the student's ability to understand problems and to develop solutions by clarifying primary objectives, key assumptions, important parameters, and the sensitivity of each alternative to major policy variables. Nothing is more difficult to accept than the knowledge that the problem is not clearly defined and that the measures of effectiveness are not fully understood; yet it is the precipitous plunge into the problem that can cause major difficulties for the profession.

Mathematical Models and Computers

Transportation planning education has perhaps evolved most rapidly in the area of mathematical modeling and related computer capabilities required to carry out the results. Advances in transportation planning, which have permitted the solution of large-scale problems, have drastically changed the way in which we think about problem-solving: these would not have occurred without computer capability. Mathematical models for trip generation, trip distribution, and travel assignment were perhaps the earliest breakthroughs in transportation planning, and the resultant computer programs compose an integrated package for transportation analysis. Intensive development of these computer models has produced a counterreaction, which indicates that there may be too much emphasis on model development and data gathering and not enough on generation and evaluation of alternatives or on quickly producing usable results. These shortcomings are evident both in regional transportation studies, which often consume extensive resources—money and time—before they are able to produce a regional plan, and in small-scale studies in which the models and computer programs are unintelligible to decision-makers at the local level. Education must develop a mechanism for coupling the abilities of computer models with immediate needs to produce usable plans and relevant information for decision-making.

A working familiarity with mathematical techniques such as probability theory, linear and dynamic programming, mathematical statistics, and economic models is an essential part of transportation systems planning education, and these tools combined with a strong computer capability in the analysis process are a fundamental element in the transportation planner's education. They complement the systems approach by broadening the spectrum factors and alternatives that can be considered in the planning process, by requiring a quantitative coupling of the objectives of the plan and the means for measuring them, by incorporating the appropriate mathematical techniques for selecting alternatives, and by developing a clear understanding of the relevant issues for decision-making.

Thus, from a substantive point of view it appears that educational programs in transportation systems planning have emphasized multimodal network analysis, which considers the transportation system in terms of its performance characteristics; systems analysis, which views urban transportation planning as an integrated process rather than as a set of isolated problems; and, finally, mathematical modeling and computer applications, which represent the fundamental tools of transportation systems planning.

UNIVERSITY RESPONSES IN ORGANIZATION

How are elements of transportation systems planning education integrated within the university so that the student has access to the appropriate academic programs as well as interaction with a variety of disciplines that these programs represent? Several approaches are discussed below.

Multidisciplinary Courses

In addition to the appropriate academic course offerings, an effective means of partially achieving an integration of disciplines is through project-oriented multidisciplinary courses. To be successful, however, these courses should meet certain criteria:

1. Coherent integration of projects and a group of students who are motivated to work well together,
2. Adequate but manageable problem statements, and
3. Careful coordination of the efforts of a large group within the structured framework of an academic course.

Centers and Institutes

Another and more flexible technique is to provide students with the opportunity to work on multidisciplinary research projects with groups from economics, political science, social science, urban planning, engineering, and the like. Exposure on an operational level to the interrelated inputs of other disciplines is an essential ingredient in educating the student to make the necessary adjustments in perspective and viewpoint in order to contribute to the product of a diverse group. Interdisciplinary projects can be made more effective through an organizational structure within the university but external to traditional departments that function within a workshop framework with access to problem statements from interdisciplinary technological areas. Accordingly, transportation centers and institutes have been created in universities with the goal of providing an organizational framework within which faculty and students of diverse academic disciplines can join together to effectively deal with educational and research aspects on a particular problem. The difference between the interdisciplinary research institute and the more traditional mission-oriented special-purpose research institute is that the former has been created to enable the university to effectively operate on a problem area basis regardless of academic disciplines, whereas the latter has usually been more closely associated with one of the traditional disciplines, and, except for a marginal loss to the academic community, their primary purpose is not impaired if they institutionalize and drift away from the university.

The primary purpose of the interdisciplinary institute, however, is education, and its bonds with the faculty and graduate student body are weakened as it becomes institutionalized. The interdisciplinary institute also provides a link between the university and the outside world by providing the framework to aid in identifying and organizing research projects such that immediate problem areas may be brought into the school and such that diverse disciplines needed to make an organized attack on the problems can be mobilized.

Advantages of Multidisciplinary Approaches

There are many advantages to the multidisciplinary approaches that have been incorporated in transport systems planning programs. Among these are the following:

1. Provide students with experience in dealing with large-scale and complex problems;
2. Focus educational experience on problem solving for which there is no "right" answer and illustrate the difficult task of trading off conflicting objectives;
3. Expose the student to the task of developing recommendations with inadequate or insufficient data and severe time constraints;
4. Familiarize the student with the capabilities, viewpoints, and approaches of other disciplines;
5. Develop a sensitivity and respect for the limitations of a group effort a d what it can accomplish; and
6. Encourage students to organize and to share responsibility and credit.

Organization of Traditional Departments

From the point of view of transportation planning education as it relates to university departments, such as civil engineering, we have seen a variety of organizational approaches. For example, some departments have been considerably restructured along less traditional lines by embracing other professional areas relevant to urban transportation planning such as economics, public policy, geography, and traffic engineering. On the other hand, some transportation planning programs have developed along independent lines, resulting in the creation of separate departments or divisions that accept students from diverse backgrounds such as engineering, science, architecture, and the social sciences, usually with the requirement that the student have a quantitative orientation. Another means of accomplishing the multidisciplinary requirement is simply to offer courses to the student on a wider range of subject matter to permit him to become more conversant with the many fields relevant to his primary interest, transportation planning.

SUMMARY

This paper has outlined university responses to multidisciplinary education for transportation systems planning both in terms of the content and approach to subject matter and in the ways in which universities have become restructured to meet new demands and changing conditions. The approaches that have been described are being implemented in programs at both the graduate and undergraduate levels. At the graduate level emphasis is placed on professional training as it relates specifically to transportation systems planning; at the undergraduate level there is increased awareness that an incoming student must be motivated early in his academic career by becoming involved in real problems that allow him to see the manner in which his career will develop. For example, in many curricula, course offerings at the graduate level soon filter down to the senior level and later become available to freshmen and sophomores. We have been experimenting with course offerings in systems engineering and various introductory courses in transportation, systems, and planning in an attempt to provide undergraduate students with a sense of the relevance and connection with professional objectives.

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ROLE OF SYSTEMS ANALYSIS IN TRANSPORTATION CURRICULA

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This paper suggests some guidelines on how systems analysis should be used in transportation and on which techniques should be developed for what research. Six hypotheses are presented, and the implications of these hypotheses for curriculum development are discussed and related to current experience at M.I.T. The paper defines the multidisciplinary approach to systems analysis, and the difficulties involved in establishing a multidisciplinary effort in problem solving are pointed out.

•THE SYSTEMS APPROACH and the many techniques associated with it are increasingly being integrated into the planning and design of public facilities. Yet their role in transportation is not clear. Worse, there is actually considerable question on how systems analysis should be used in transportation systems planning. Faculty members in transportation quite legitimately wonder which of these new tools they ought to select for emphasis and how they ought to integrate this field into their curriculum.

An already substantial and increasing number of professionals in practice, government, and universities believe that the systems approach has a significant role in the planning, design, and operation of transportation facilities and networks. The number of firms using these approaches, the extent of governmental support, and the range of universities either offering or planning courses or programs in transportation systems are strong evidence of the endorsement of the systems approach.

In a general way, the systems approach implies a comprehensive attack on the problems of designing and operating complete sets of facilities. The current emphasis on this overall planning is almost certainly to some extent a reaction to an earlier focus, almost exclusively on detailed analyses of particular projects. But, and most importantly from our point of view, this trend is reinforced and accelerated by our rapidly expanding technical capacity for dealing with an accuracy and rapidity previously impossible with large-scale problems.

At present, the concept of the systems approach is specifically and inextricably attached to the new planning process and design procedures made possible by the computer. Indeed, the development of this technology has engendered an extensive catalog of powerful computer-based techniques. These permit the consideration, explicitly and analytically, of more alternative designs and of more concepts for operation than ever before. The opportunities offered by these new analytic methods have appeared very great.

Consequently, industry, government, and universities have each devoted considerable effort to the development of capabilities in transportation systems analysis. Substantial computer facilities and large computer-based models are in evidence throughout the transportation planning field. No "respectable" regional or urban transportation plan is complete without substantial expenditures for the accumulation of extensive files of data and for their manipulation with one of the many variants of planning models. FHWA rban transportation programs are a typical example of what has been done so far.

All these investments of time and resources might, mistakenly, lead one to believe that there is a high level of confidence in the validity of the new methods of analysis now associated with the systems approach. Actually, however, there are simply not many examples of particular cases in which systems analysis and the systems techniques have been applied with especially beneficial results to real-world problems in transportation planning and design. Many of the applications have been failures, and the majority of these have probably generated fairly trivial results at great expense. Only very few good examples of the use of systems analysis in transportation are available (3).

Although one would hope for a substantial body of evidence justifying the confidence and the resources dedicated to transportation systems analysis, it is not yet available. Such evidence is needed to justify (or refute) confidence for the directions that have been taken. Secondly, this evidence, these lessons of practical experience, should also help us define more precisely what these directions should be.

One of the important intellectual questions before the profession is, What is the role of systems analysis in transportation? I propose that we address this question as we should any research proposition, by formulating and testing specific hypotheses. Experience would indicate that this is really necessary to accumulate firm knowledge, and it certainly would be desirable to know how we should employ systems analysis before we devote substantial further efforts to it and in particular before universities expend the great effort needed to establish new curricula.

The basic issue before us can be stated in terms of three specific questions:

1. To what classes of transportation problems can the various techniques of systems analysis be applied profitably?
2. Which of the many techniques available are appropriate to particular problems?
3. Which techniques deserve emphasis in practice and in a transportation systems curriculum, which should be deemphasized, and what new ones are needed?

It is important for all transportation planners to be able to answer these questions accurately so that time and effort are not wasted. It is quite likely and is often suggested by practicing professionals that systems approaches are frequently applied where they may not be especially useful or to improperly formulated problems. We should learn to avoid this. Likewise, a clearer understanding of what specific approaches are really useful would do a great deal to rationalize the wide variety of subjects that are now offered in transportation systems curricula throughout the country. More insight into the strengths and weaknesses of alternative approaches would, finally, also permit the universities to form more capable and resourceful planners and designers.

CURRENT STATUS

Before an appropriate curriculum in transportation systems analysis is formulated and discussed, it is useful to understand what people perceive systems analysis to be and how they are using it. To establish this, the M.I.T. Civil Engineering Systems Laboratory undertook a national assessment of the status of systems approaches in civil engineering in 1971-72. This review consisted of two parts: a direct questionnaire and a consideration of past surveys of activities and published discussions.

Practicing professionals in both industry and universities were polled to determine how they felt about systems analysis. Faculty members were identified first by compiling a list of those who were known to be using either of two recent texts on systems analysis or engineering (1, 4). Secondly, prospective faculty respondents were identified through catalogs and lists of universities offering degrees in systems analysis and transportation systems in particular. Similarly, a broad range of practicing professionals was identified from a listing of U.S. consulting firms, which contained brief descriptions of their interests.

The evidence obtained from the questionnaires was supplemented by the results of surveys of Vidale (13) and Johnson (8). In addition, the articles by Eldin (6), Gross (7), Kavanagh (9), Tabak (12), and Wagner (14) were consulted. The overall results are presented below.

The Concept of Systems Analysis

In general, there was remarkably widespread agreement that the systems approach is a comprehensive attack on problems, which applies appropriate technological knowledge and economic and other theory, in a rational and systematic manner, to generate optimal plans and designs. The analysis itself is to be done by using whatever tools are appropriate but, at present, particularly by exploiting the new computer-based methods.

It is also widely believed that the skills and knowledge needed to carry out transportation systems planning and design are not, now, to be found in any one academic department or discipline but must be taken from several. This suggests the need for multidisciplinary activities that, somehow, transcend individual disciplines.

The overall agreement on the general definition of systems analysis does not imply a common understanding of how the methodology can or should be used to attack real transportation problems. Quite the contrary is actually true. There is, apparently, little specific agreement on the strengths, weaknesses, and relevance of the particular techniques or approaches available. Although it is, logically speaking, possible for this disagreement to arise because there might really be little to choose from among the techniques, such does not seem to be the case. Individual experience appears to indicate, again and again, that many particular approaches are, in fact, much more applicable to certain classes of problems than to others. It therefore appears reasonable to conclude that the evident disagreement about which methods should be used arises because we have not yet, as a profession, thought through this question clearly.

Optimization Versus Modeling, Evaluation, and Implementation

If we were to predict the future from the published evidence in transportation literature and journals, we would be forced to conclude that transportation planners are nearly universally agreed that optimization methods are at the core of transportation systems analysis. Yet this is not the case.

Our questionnaires and the surveys of others suggest that respondents feel that as much emphasis needs to be placed on modeling and evaluation as on specific forms of optimization. Prime areas of concern are the causal modeling of individual and collective behavior, as represented by demand functions and the evaluation of transportation projects in light of the multiple objectives of the different communities affected by any set of projects. Further, the actual practice of transportation planning indicates that far more attention is paid to various forms of simulation, such as traffic assignment, than to any form of optimization. Johnson's survey shows that the experience in water resource planning is quite similar (8): Practitioners much more commonly prefer simulation approaches to optimization.

It is also relevant to note that both practitioners and faculty are agreed that there is a paucity of systems texts relevant to transportation systems analysis. This is in the face of the well-known abundance of excellent texts on optimization and operations research, both pure and applied to traffic operations and transportation methods. This is further evidence that optimization procedures, linear programming specifically, constitute only a limited portion of the methods required in transportation systems analysis.

These results confirm the impression that the prevailing predominance of optimization approaches in academic circles is not due to their overwhelming importance but to their mathematical elegance and tractability. Many faculties, for example, appear to have a solitary "systems" person, who is forever searching without much success for easy problems to knock off to prove his worth. Because optimization work can normally be carried out within a theoretical framework on an individual basis, much of the academic effort is directed toward optimization problems. Many of these problems are continually being rediscovered in the literature, are largely solved, and were not of much interest in the first place.

The other analytic elements that appear to be important to transportation systems analysis, such as modeling and evaluation, are much more subjective than optimization procedures. This implies that it is difficult to make progress along these avenues. We should not only be able to compare our judgment with that of colleagues but also, and even preferably, be able to give our opinions a real test by applying them to actual situations. This is an argument for the need for large-scale implementable studies within universities that wish to develop the systems approach. It is an argument for the desirability of a critical mass of faculty before one attempts serious research and curriculum development in transportation systems.

When individual efforts are combined, moreover, and preferably focused on specific projects, not only does it seem likely that it will be possible to develop an understanding of modeling and evaluation in transportation systems planning, but it also seems likely that we can get beyond the relatively trivial applications of optimization. Furthermore, by engaging in large-scale studies that may be implemented, faculty members will be obliged to give real concern to the problems of validation of assumptions and especially to implementation.

Multidisciplinary Programs

Because of the particular orientation of established departments within a university, it is generally reported that multidisciplinary efforts are difficult to establish. Members of any discipline, e.g., economics or political science, usually find that their immediate rewards are oriented toward that discipline. Consequently, whenever a member is forced to choose between a disciplinary activity and a multidisciplinary activity of uncertain potential, the multidisciplinary effort inevitably suffers. Worse, established departments often refuse to approve broader programs that would, inevitably, reduce their own influence and power.

The question is, then, How should we go about implementing a program in transportation systems analysis with its requisite multidisciplinary flavor? In attempting to answer this question, we should define what, precisely, we mean by a multidisciplinary effort. For example, suppose we define a multidisciplinary effort as one in which all the skills needed to attack a problem are brought together. If we agree that this is reasonable, as appears plausible, then we should recognize that engineering disciplines have long been multidisciplinary. In particular, for example, civil engineering has traditionally combined mathematics, mechanics, geology, hydrology, and thermodynamics in amounts considered sufficient to address problems the profession was confronting. In this case, there is now no problem in establishing a multidisciplinary effort.

The point is that the short-run problems of forming a multidisciplinary group, which are quite real, may evaporate over the long run. The difficulties faculty members may encounter in getting a multidisciplinary group together are not inherent to the multidisciplinary aspect of the endeavor, which we cannot change, but to its novelty and unfamiliarity, which we can eliminate.

This perspective suggests that a key ingredient to establishing a program and a curriculum in transportation systems analysis is a cogent rationale for the role and intellectual value of other disciplines. To be successful, this rationale must be convincing to the other disciplines and must ensure their support as partners in the enterprise. All too often, however, the effort devoted toward really trying to incorporate disciplines such as economics, political science, and sociology are too slight or too superficial. Much work and a precise understanding of what is important are required to establish a viable multidisciplinary effort.

HYPOTHESES ABOUT TRANSPORTATION SYSTEMS ANALYSIS

The experience so far in the use of systems analysis in transportation leads to certain conclusions about this process. Inasmuch as the evidence is still far from conclusive, these statements are cast as hypotheses. These tentative axioms are of interest both in themselves and because they imply distinct policies for undergraduate and graduate curricula in transportation systems planning and design.

Although these hypotheses appear to be true, the fact that they might not be defines some fairly specific questions for research. More attention should be specifically directed toward how and where the systems methods can be successfully implemented. Existing emphasis on research on prime systems techniques should be reduced, at least as far as transportation is concerned. Rather, it would seem more fruitful to concentrate on identifying classes of problems to which a systems approach is useful, i.e., on verifying that we know what we are doing overall.

Six hypotheses are suggested. The first two speak to where and how the systems approach should be used in transportation. The remainder focus on the kinds of skills that should be developed.

Hypothesis I

> The systems approach will make the greatest contribution in complex problems that involve many interdependent projects and the links that connect them, in particular network problems.

This hypothesis is principally motivated by the experience that indicates that the computer-based methods of systems analysis are most powerful in dealing with highly combinatorial problems. Such problems are not, of course, the only interesting problems, but they may well be the only ones that would be meaningful to include as part of transportation systems analysis.

According to this hypothesis, problems of detailed design would be unsuited for the systems approach. This appears to be confirmed by efforts to date. The evidence would indicate that, in general, attempts to use some systems analysis in this area have not led to any significant developments.

Hypothesis II

> The systems approach is most useful in planning for the overall configuration of programs and the definition of regions of optimality.

It is easy to observe that the techniques of systems analysis derive their capability to sort rapidly through highly combinatorial problems by imposing definite restrictions on the mathematical description of the problem. These assumptions consist, for example, of linearity and additivity for linear programming, of independence for dynamic programming, and so on. The techniques that use them are, thus, necessarily approximative and inappropriate for precise final design. The systems techniques are, however, most useful in sorting through many combinations and determining the dominant kinds of solutions that can then be explored in further detail.

This hypothesis implies that the analyst dealing with real problems should not waste time on a more sophisticated mathematical analysis, which probably can remove the limitations of the simpler methods (such as linear or dynamic programming) at the expense of their computational power. Rather, the analyst should devote significant effort to sensitivity analyses, both of the physical parameters of the problem, to discover areas of potential redesign, and of the evaluation criteria, to indicate how different public groups may be satisfied.

Hypothesis III

> Optimization and the more detailed simulation techniques should be used hierarchically and interactively.

This is almost a corollary to the previous statement. Because the optimization techniques are inherently approximative, they require mechanisms for examining overall plans and designs in more detail. Simulation techniques are well-suited for this purpose. They can not only easily incorporate nonlinearities and discontinuities of all sorts but also be programmed to take into account the effects of probabilistic and stochastic variations.

The relationship between optimization and simulation in a practical analysis would seem to be much more, however, than one being the backup to the other. Optimization or some other method that defines regions of overall desirable design is itself almost a necessary prerequisite to effective simulation: It provides an experimental design specifying what kind of simulation experiments ought to be performed. Conversely, the knowledge gained from testing simulation models can, by indicating which parameters are critical, help improve optimization models.

This hypothesis indicates that relatively simple optimization techniques may be appropriate for most situations. By extension, it implies that a curriculum in transportation systems analysis should, in general, not emphasize advanced programming techniques or queuing analysis. Whereas these may be elegant and appealing to mathematical sophisticates, they may have little to do with real planning and design.

Hypothesis IV

> An effective systems approach must include the skills necessary to the definition of a problem both deductively, through the use of engineering production functions, and inductively, by means of systems modeling and econometrics.

Although it is a truism that any analysis depends on the quality of the model being used, few transportation curricula now seem to deal effectively with the issue of how good modeling skills are to be developed. This hypothesis makes two specific suggestions of how this should be done. First, it recognizes that any systems analysis inevitably deals with multiattribute problems and suggests that the well-developed procedures of economics for estimating production and cost functions be exploited. Second, because a transportation system cannot be brought into a laboratory, it proposes that the economic and social science procedures for dealing with nonexperimental situations be adopted. Actual knowledge of and experience with the particular systems or problems are, of course, key to the effective use of these techniques.

This hypothesis implies that a transportation systems curriculum should incorporate some quite specific elements of microeconomics, econometrics, and causal modeling of behavior. It also provides a specific rationale for the role of economists, for example, in a multidisciplinary effort in transportation. If this rationale is accepted, economists would be seen as a central and important contributor to the effect, rather than, as often appears to be the case, as dispensable adornments to a proposal. The latter role is naturally unappealing and effectively would dissuade almost anyone from participating in a multidisciplinary effort so conceived. The role suggested by the present hypothesis, however, may be quite attractive.

Hypothesis V

> An effective analysis must be skillful in specifying evaluation criteria: Knowledge of how individual and societal preferences are developed, as through utility theory, welfare economics, and sociology, and of how they are applied in specific cases via decision analysis or game theoretic analysis of collective choice is necessary.

The motivation for this hypothesis lies in the failures of the standard benefit-cost analysis of engineering economics to deal adequately with public choice of transportation projects. These failures have been demonstrated internationally, not only in regard to urban expressway systems in the United States but also, for instance, by the evaluation for the third London airport. The reason for the failure of the standard benefit-cost analysis lies in its assumptions that

1. People have a constant value for a good, whereas they actually have a diminishing marginal utility;
2. They are indifferent to risk, whereas they are in fact generally significantly risk-averse; and
3. All elements of the public share a common system of values, which is certainly not true for large projects with important differential consequences on different communities.

To devise an evaluation procedure free from these defects requires that we learn both how to assess individual preferences and how to describe how they will combine around a preferred solution. It appears that the methods devised for measuring utility and for associating them are appropriate to this task. As might be suspected, these approaches derive substantially from political and social sciences.

As with the previous hypothesis, this statement implies that a complete transportation systems curriculum should include elements of the social sciences in key positions. In this case, however, the specific subjects to be recommended are much less clear, inasmuch as these procedures are relatively new and there is much less of a tradition for dealing with these problems.

Hypothesis VI

> The implementation of transportation systems plans requires an understanding of the power of different structures of political and governmental organizations and the effect of different management control systems.

It is reasonable to suppose that transportation systems planners should really be concerned with problem solving rather than merely with problem analysis; thus it seems clear that we must be concerned with implementation. Judging from the results of transportation systems analysis that are available so far, it would appear that the profession has not been eminently successful in this regard. Those who are concerned with the problems of implementation would ascribe such difficulties to a lack of understanding of the political dynamics on the one hand (5, 11) and to a failure to establish an adequate budgeting and control apparatus to ensure that optimal plans or designs actually get executed (10).

It would appear, consequently, that a complete curriculum in transportation systems ought to allow space for subjects dealing with state and local politics and bureaucracy as well as with the specific management techniques of program budgeting. Naturally, any reasonable graduate program soon runs out of time to offer all subjects that might be desirable. Yet, if these hypotheses are correct, these last subjects are not simply peripheral but also central to transportation systems analysis. Consequently, they should be included in the pool of core subjects that a student can choose among in defining his program.

M.I.T. EXPERIENCE

After having suggested what elements might be desirable in a curriculum for transportation systems analysis, the question remains: Can all these pieces be put together coherently? The answer appears to be yes, although the task is not simple. The M.I.T. experience is instructive in this regard.

Structure of M.I.T. Program

The program in transportation systems analysis at M.I.T. has centered around the Civil Engineering Department, where it is sponsored by the Transportation Systems Division and supported by the M.I.T. Civil Engineering Systems Laboratory. The laboratory provides a focus for work on the development and application of systems analysis in engineering planning and design. The division has been responsible for substantial work in transportation in particular.

As of early 1973, M.I.T. formed the Center for Transportation Studies embracing portions of several other departments: the Flight Transportation Laboratory, an airline operations analysis program in the Department of Aeronautics and Astronautics; the marine transportation group from the Department of Naval Architecture; elements of the mechanical and city planning departments; and the Transportation Systems Division. This new center institutionalizes the fairly close associations that have developed between these groups for research and teaching. The new center will specifically be responsible for a joint, interdepartmental program in transportation systems.

The academic program in transportation systems analysis proposes to develop the student's capabilities in three complementary areas:

1. The nature and performance of transportation systems,
2. The theories and methods of systems analysis, and
3. The understanding of the social and economic forces inherent in the environment in which transportation systems will be complemented.

As suggested by the hypothesis concerning the desirable nature of a curriculum in transportation systems, the M.I.T. program explicitly attempts to blend an understanding of transportation problems with a strong analytic competence as well as a broad sensitivity to key tools and issues in economics and social sciences.

Because no student could possibly take all the subjects that might be useful, the program is deliberately devised to be very flexible. The student is, at most, encouraged to take three or four specific core subjects in transportation and systems analysis. The other two-thirds of his program can be selected from a broad list of recommended subjects. This procedure has several advantages. On the individual level, it permits the students to grow professionally in the areas that are most productive for them. For the M.I.T. group as a whole, it provides a diversity of students who are used to attacking problems from different perspectives and who not only find it easy to work on multidisciplinary problems but also have the skills to do so.

It should also be added that the faculty members within the programs are not purely engineers. Many hold advanced degrees, even their doctorates, in different fields. City planners, lawyers, architects, economists, and a sociologist are all part of the staff. This diversity, plus the diversity cultivated among the students, means in effect that we are growing our own multidisciplinary program from within.

Recognizing that a thorough education in transportation systems really requires more than might be placed in an ordinary master's program, the M.I.T. program has been extended into the undergraduate curriculum. Since 1970, an undergraduate option, including several special subjects in transportation systems, has been available. This program is continually expanding so that students can, indeed, obtain full professional preparation in transportation systems in the 5 full years it requires to complete a bachelor's and master's program.

Transportation Subjects

The transportation curriculum has two special features. First of all, many of its subjects are jointly taught by several departments. Its core subjects in transportation, technology, demand, and economics are stressed in particular. Several specialty subjects, such as those in airport planning and management, are also taught cooperatively.

The second interesting feature, which relates directly to hypotheses I and II, is that many subjects are closely related to ongoing large-scale projects dealing with particular elements of transportation systems. These are Manheim's community values projects concerned with the development of guidelines for highway evaluation; Roos's projects implementing dial-a-bus in several communities; Sussman's projects on railroad reliability in association with several lines; and my own work on airport planning and design. These projects, each basically undertaken from a systems point of view, help identify just how and when systems analysis can and cannot be helpful in transportation.

Systems Analysis

Faculty members associated with the M.I.T. Civil Engineering Systems Laboratory are attempting to develop, along the lines sketched by the hypotheses, a common understanding of how the techniques of systems analysis should be applied to real problems. Specific areas of emphasis are stochastic systems and statistical inference for the development of systems models, the use of optimization and simulation, and evaluation procedures, including multidimensional benefit-cost analyses and decision theoretic approaches. These are being applied to large-scale, real-world studies in a number of fields, in particular, transportation.

The teaching in systems analysis in the M.I.T. program derives directly from this experience with practical problems. The research work has also led to the preparation of a number of texts that attempt to present the most relevant elements of the systems approach from the planner's point of view. Texts on probability and statistics in engineering (2) and on systems analysis (4) have already been published. A special effort is also made to relate the analysis to actual practice in the course work. This has generated a reader of case studies based on recent research (3).

Economics and Social Sciences

In addition to an active group of faculty members concerned with transportation economics and regulation, which is fairly usual, the M.I.T. program in transportation systems explicitly involves lawyers, managers, city planners, and a sociologist. In addition, students are actively encouraged to take a substantial portion of their subjects in these fields. Although it is difficult to provide a precise or meaningful estimate of the degree of this activity, it would appear that the M.I.T. effort has managed to develop and maintain an active multidisciplinary program. This may, possibly, be attributed to the intellectual success of our efforts and, consequently, to the fact that our colleagues from these fields feel as equals in the work in transportation systems.

CONCLUSION

Based on experience to date, six hypotheses have been presented concerning the role of systems analysis in transportation. These specify, first, that systems analysis is most useful for the definition of the overall configuration of transportation facilities, especially of networks. Second, they indicate that optimization, which has been a useful focus of activity, should be seen only as a search procedure to be used in conjunction with more detailed analyses. Finally, the other two main areas of concern, systems modeling and evaluation, require explicit use of the techniques and procedures of economics and the social sciences. This is a tall order to fill, but the recent M.I.T. experience indicates that it is possible.

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UNDERGRADUATE CIVIL AND ENVIRONMENTAL ENGINEERING AND TRANSPORTATION ENGINEERING NEEDS

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Civil engineering in general and transportation engineering are rapidly changing fields in which engineered facilities intimately interact with society and the environment. However, proper interaction can only be ensured if the involved professionals are aware socially and environmentally and are adequately trained technically. The new curriculum in civil and environmental engineering at the University of Wisconsin, while it recognizes that education is a continuing and life-long process, has as its main purpose the training of engineers who not only are technically competent but also have sufficient breadth to be able to appreciate and relate to society and the environment. The curriculum provides ample opportunity for significant study related to analysis, design, synthesis, and general engineering. Opportunities for multidisciplinary involvement are also available and encouraged. The new curriculum provides the opportunity, it is felt, for a firm foundation in technology plus the capability to weave that technology into the fabric of society.

•IT HAS BEEN SAID that "A student who can weave his technology into the fabric of society can claim to have a liberal education; a student who cannot . . . cannot claim to be a good technologist." Increasingly, civil engineers, and among them transportation engineers, are becoming more sensitive to the nonperformance consequences of their actions. For many years the profession has been concerned with the performance function only. In transportation, the major concern was the dollar costs and benefits of transportation facilities and measures of performance efficiency with little regard, except superficially, for the nonperformance social and environmental costs and benefits associated with their actions.

The emerging social and environmental concerns of engineers result partly from a new and greater understanding of man's needs and wants and of how man relates to other men and to his environment. This emerging concern has, in part at least, paralleled the rising national awareness of man's impact on the environment and the need to protect that environment. But it has also been the natural result of increased adverse public reaction to various engineering proposals. The transportation engineer, for example, is all too familiar with the crescendo of opposition to major highway improvements, particularly in urban areas. Whereas it has put him on the defensive, it has also increased his level of environmental awareness and caused him to take a new look at his engineering value system.

CREATING AWARENESS—THE START

Logically, creating greater environmental awareness and responsiveness in the engineering profession should begin with the engineering education process. This fundamental fact is recognized in the new curriculum in civil and environmental engineering at the University of Wisconsin. The basic philosophy underlying development of the new curriculum is the requirement that it embrace the concept of a broad education and at the same time permit the kind of flexibility that would allow major course groupings leading to specialization. Within this context, sufficient attention is paid to applying theory to physical phenomena, to providing significant design course work that will emphasize the application of basic principles, and to providing group problem-solving experience directed at resolving real-life problems.

CURRICULUM OUTLINE

The basic curriculum consists of 135 credit hours. Flexibility is provided without sacrificing basic science and other fundamentals by permitting a wide array of elective courses. Within each of the areas from which electives are chosen, broad guidelines ensure breadth without sacrificing the desired flexibility.

The elective credits devoted to technical subjects relate to analysis, design, synthesis, and general engineering practice and give the student an opportunity to

1. Continue to develop in the broad field of civil engineering by dividing his electives fairly equally among the five divisions of instruction (structures, hydraulics, sanitary, transportation and city planning, and surveying/photogrammetry/remote sensing),
2. Specialize in one or more areas of activity in civil engineering,
3. Participate in interdisciplinary programs, and
4. Participate in depth in elective programs in other departments of the engineering college.

The technical electives, of which 6 must be in civil and environmental engineering, permit additional technical depth and enrichment in professional and scientific training. The remainder of the technical electives can be satisfied by numerous courses of a technical nature within or outside of the College of Engineering.

TRANSPORTATION OPTION

A major advantage of the new curriculum is that it permits specialization at the undergraduate level. In transportation, several tracks are available depending on student interest.

CURRICULUM DEFICIENCIES

The potential shortcoming of the new curriculum is the omission, at a very early stage, of an environmental core consisting of courses in basic ecology, natural resources and their utilization, and technology-society-environment interrelationships. Although such a core can be developed through selection of courses in natural sciences and liberal studies, such a core might appropriately be a required part of any civil and environmental engineering curriculum.

Other areas that should be covered specifically within the curriculum because they impinge so directly on all of the activities in civil and environmental engineering include decision-making, both public and private, community/citizen goals and values, and community/citizen participation.

CURRICULUM TRANSITION

The problem of implementing a new curriculum and making a transition from the old to the new raises all kinds of new questions. A major one was to whom it applies. Junior and senior students are given a choice and can opt for either the old or the new curriculum. In so doing, so-called equivalent courses—those courses, both new and old, that satisfy the new curriculum—had to be identified. In some cases, course credit requirements were changed, old courses were dropped, and new courses were developed. Freshmen and sophomore students are required to pursue the new curriculum.

The high degree of flexibility permitted by the new curriculum and the opportunity for many choices require a very close and continuing relationship between the student and his adviser. Although all of the advising issues have not been answered, a logical approach appears to be one in which a student can select an adviser in his area of interest. Unlike the present practice where the adviser changes yearly with the student's class standing, a student would keep an adviser throughout his course of study unless, at his request or through a change of curriculum direction, it became desirable to change advisers. Under development at this time is a new advising form that will show the up-to-date status of the student as it relates to the overall curriculum and the manner in which he is fulfilling the various curriculum requirements.

PROBLEMS ASSOCIATED WITH CURRICULUM REVISION

Undertaking the modification of an existing curriculum consumes an enormous amount of time and personal energy. It required the unselfish efforts of a six-man committee (one representative from each area in the Department of Civil and Environmental Engineering and a chairman without vote) for a period of 3 years.

An initial step (after the goals were identified) required an in-depth evaluation of the topic content of existing courses to identify precise needs, areas of duplication between courses (some overlap and duplication is necessary in the learning process), and areas of deficiency. In identifying new course needs (or major changes to existing courses), detailed course outlines had to be developed in parallel with the new curriculum.

One of the more difficult issues was related to tradition: Were there certain things that a civil engineer should know and be able to do, and what did this mean in terms of a minimum educational experience? The subject became a burning one when it involved the question of the required summer survey camp and a fairly heavy load in structural engineering. The camp was discontinued and the structural requirement reduced by one-half, but not without much soul searching and gnashing of teeth.

The major goal of affording students an opportunity to specialize raised another serious concern. To what extent would graduate programs be diluted, inasmuch as undergraduate students could take courses that they would normally have taken at the graduate level? Offsetting this was the realization that graduate work in a given field could now permit greater breadth in fields related to the area of specialization.

Some of the other issues related to (a) the accreditation requirements, (b) whether a curriculum should prepare students for the professional registration exams, (c) implementation, and (d) problems of interrelationships with other university departments. Among the latter were things such as course cross listings, course overlap, and tailoring courses, now taught by external departments, to the unique needs of the civil and environmental engineering curriculum, e.g., whether such courses as calculus and statistics would be more relevant if taught in the department and whether university policy would allow this change.

RELATION TO OTHER UNDERGRADUATE PROGRAMS

Although most programs involving formal multidisciplinary study are at the graduate level, undergraduates are able to participate in several combined (joint) programs.

Transportation and Business

A bachelor of business administration degree may be earned in addition to the bachelor of science in engineering by proper selection of electives throughout the program. It is necessary, however, to extend the total program by two or three semesters to permit the minimum 32 credit hours in business courses.

Transportation and Law

Superior students in engineering may be permitted to register in the law school during their senior year to begin work toward a law degree.

Transportation and City Planning

Within the Department of Civil and Environmental Engineering, BS degrees can be obtained in both city planning and civil engineering (emphasis in transportation) by selection of certain additional designated courses for a total requirement of 176 credits.

Environmental Studies Minor Option

By proper selection of a 9- to 12-credit core of courses outside of the College of Engineering in the areas of basic ecology, natural resources and their utilization, and technology-society-environment interrelationships, the transportation engineer can earn a bachelor of science degree in civil and environmental engineering with an environmental minor studies option. This program option, with the environmental designation entered onto the student's transcript (it is not a degree designation) was developed to provide an opportunity for engineers to obtain greater depth in environmental areas. In other fields of engineering, the program must include, in addition, environmentally related course work that is already a part of civil engineering and transportation engineering curricula. These include 3 to 6 credit hours drawn from an approved list of courses that devote a major share of their time to the solution of environmental problems (most courses in civil transportation engineering are already on this list) and a 3- to 6-credit practicum or similar course that uses a multidisciplinary approach in which students attempt to solve a real-world problem.

Undergraduates in civil and environmental engineering as well as in other engineering areas can also obtain, through proper use of their electives, a well-rounded background in areas other than engineering, e.g., geography and political science. The reverse is also true. Numerous courses in engineering are available for degree credit to nonengineering students.

RELATION TO GRADUATE PROGRAM

Increased understanding of how technology affects the man-environment system has resulted in a proposal for the development of a series of graduate-level environmental management programs, including one in transportation. Because of the interdisciplinary nature of the program, it would be under the umbrella of the University of Wisconsin Institute for Environmental Studies (IES). The institute has a unique structure in that it can provide effective leadership, coordination, and support for carefully integrated efforts involving various units of the university. The raison d'être of the institute is to develop and encourage interdisciplinary work on the multitude of environmental problems that do not lie within the purview of a single discipline.

The transportation management program has as its goal the preparation of graduate students for work in agencies responsible for managing and planning transportation systems.

Entry to the IES Transportation Management Program will be from engineering and the natural and social sciences. Although predominantly a graduate program, a number of the courses in the program will be offered at the intermediate level and, as a result, will be available for both undergraduate and graduate students.

The staff will be from the Institute for Environmental Studies (IES has departmental status) and from graduate programs in other departments.

Programs of study in professional management or research lead to degrees administered by a committee drawing membership from IES and other departments. For the transportation management option, the committee would be composed of IES staff, staff from the transportation/city planning area in civil and environmental engineering, and possibly staff from other areas.

CURRICULA IN OTHER INSTITUTIONS

A number of other institutions, among them Purdue, the University of Illinois, the University of California, Berkeley, and Massachusetts Institute of Technology, have developed engineering curricula that permit considerable flexibility beyond a required core of fundamentals. Each takes a slightly different approach.

SUMMARY

Civil engineering and transportation engineering curricula must be designed to train graduates who have both technical competence and an awareness of how their actions affect society and the environment. This level of training requires a strong foundation in basic science and engineering and provides an opportunity to obtain a broad understanding of how man, society, and the environment function and an opportunity to gain considerable depth in a chosen field of specialization. These are not dichotomies; they can be effectively woven into a curriculum that is flexible and has depth and is interesting to students.

Because society and the environment, and how man views both of them, are changing rapidly, and because man's technology is also changing rapidly, the curriculum must be a dynamic one: continually changing and adapting to new needs and challenges.

THE TRANSPORTATION LABORATORY: TEACHING FUNDAMENTAL CONCEPTS OF TRANSPORTATION SYSTEMS ANALYSIS

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Development of an undergraduate transportation laboratory is under way as a mechanism for teaching transportation systems analysis at the undergraduate level. The transportation laboratory is in the form of (a) a workbook of exercises in transportation systems analysis and (b) an integrated set of computer programs and data for executing the exercises. The computer programs have been developed by additions to the DODOTRANS problem-oriented computer language. Each exercise teaches the use of a particular laboratory capability, develops an understanding of a specific aspect of transportation systems analysis, and poses questions for the student to explore in his own way, by using the laboratory. Emphasis has been placed on developing an understanding of the interrelationships between transportation technology and social impacts in the context of multimodal transportation systems.

•FROM THE VIEWPOINTS of both teaching and research, experiments in the socioeconomic arena (urban problems, transportation, etc.) are difficult to perform. In the physical sciences, the student can often isolate a piece of the real world in the laboratory in order to experiment with it. In transportation, however, experiments with the real-world system are very difficult to perform because they are expensive and time-consuming, and, most important of all, they have profound social, economic, and political effects. Yet, from the viewpoint of education, it is highly desirable to provide "laboratory" experience for students in transportation. Such a laboratory experience can

1. Give the student an intuitive, deeply felt perception of the interactions among the components of the transportation system and between the transportation system and its socioeconomic context;
2. Encourage the student to experiment (in the laboratory) in an exploratory, natural way with a wide range of transportation and regional development policy alternatives; and
3. Motivate the student to take more highly specialized courses in transportation techniques (e.g., demand analysis, network flow models, transportation technology, and sampling design).

To achieve this kind of laboratory experience, we can make use of the computer. In the computer, we can construct a simulation of the real-world transportation system and its interactions with its environment. Even if the student cannot easily experiment with the actual transportation system, he can experiment with the simulation. Thus the computer becomes our "transportation laboratory."

BASIC OBJECTIVES

Our basic objectives in developing this transportation laboratory have been

1. To teach the fundamental concepts of transportation systems analysis in a way that transcends the properties of particular models or techniques;

2. To develop in the student an understanding of how to go about analyzing problems systematically, whether they be transportation or nontransportation problems, with particular emphasis on how to structure the systematic analysis of a problem in which a complex simulation model will be used (such as a transportation network analysis package); and

3. To demonstrate for the student the interrelationship between technological and social choice issues by illustrating how decisions about technological alternatives—in this case, transportation alternatives—have profound sociopolitical impacts and consequences and by showing him how such decisions with social consequences can be analyzed systematically.

In a sense, the most fundamental objective of all is to give students a basic introduction to the interrelationship between technological and societal problems, in general, and to urban transportation problems in particular, in a way that also develops an understanding of how to go about analyzing such problems. Thus, the basic transportation laboratory course is an introductory course. There are no prerequisite courses, and our target audience is freshmen and sophomores. From this basis, students will go on to take more advanced courses in a variety of areas, including transportation and mathematical modeling techniques. There is a parallel graduate version of this course that is more technique-oriented and that makes less use of a computer laboratory.

In a sense, what we are trying to do is to challenge those students who are concerned about the problems of contemporary society, have a quantitative and analytical orientation (as most of the students at M. I. T. do), and are looking around and groping for a role in which they can operate professionally to work on such problems. Thus, our objectives are not only to teach transportation but also to challenge students in a more general way to deal with the problems of society.

THE LABORATORY CONCEPT

To function effectively such a laboratory must contain models, computer programs that simulate the behavior of transportation systems and the interactions between transportation and its environment; and data, representing real or hypothesized urban or megalopolitan regions and their transportation systems. For example, there would be models for simulating traffic flows over highway and transit networks in a particular metropolitan area and data for calibrating these models.

To use the laboratory effectively as a teaching environment, the following must also be provided:

1. Instructions on how to use the laboratory—how to set up and run various types of experiments; and
2. A series of carefully designed experiments.

In our development of the laboratory, we have integrated both of these components.

Our objective is a series of laboratory exercises, in each of which the following elements are integrated:

1. A basic concept of transportation systems analysis is introduced;
2. Simple examples are given;
3. Simple exercises are given to reinforce and test the student's understanding of the concepts—simple enough so that the problems can be solved without the use of a computer, generally graphically or by simple algebra;
4. The relevant computer capabilities [for example, specific DODOTRANS (3) commands and routines] are introduced and demonstrated by examples;
5. The student uses computer routines to solve a "structured" problem, that is, one for which there are "correct" answers (this tests his understanding of the basic transportation systems concept and his ability to apply it, both with and without the computer); and
6. The student is then given an unstructured problem in which he must exercise judgment in formulating the problem and in his analysis of it.

This description should indicate that the use of the computer is a means, not an end in itself. The DODOTRANS language is a problem-oriented computer language that is very easy to learn in the context of developing an understanding of transportation problems. To use this language, the student does not have to learn computer programming in the usual sense, as is the case with FORTRAN or other programming languages. He only has to learn how to write a description of his transportation systems problem in the relatively simple DODOTRANS commands. (We have found that students with little or no prior computer experience can master both the transportation systems concepts and the use of DODOTRANS in 4 to 6 weeks.)

For example, an exercise in the comparative analysis of urban transportation technologies might take this form: Given the data, set up and do a comparison of the cost and service characteristics of rail transit and highway in a particular urban corridor. This part of the exercise would teach use of the appropriate laboratory techniques (computer programs in the form of problem-oriented language commands), as well as provide an understanding of the relative advantages of the two modes under various conditions of demand and assumptions of cost. Develop data for some other existing or projected modes, and compare them with previous results. This would stimulate the student to think about the basic similarities and differences among transport modes. Propose some desirable objectives for a new mode to meet; suggest the form such a mode might take. This challenges the student to think about the fundamental characteristics of different possible new modes and to do analysis to compare the cost and service performance of a possible new mode with the modes analyzed previously.

BASIC TRANSPORTATION CONCEPTS

It is useful to review briefly the basic concepts of transportation systems analysis that we are trying to teach.

First of all, we begin from the perspective of analyzing transportation systems as integrated, multimodal systems, in which we consider as a single system all the transportation facilities of a region. We analyze this system as a whole, considering all components of the system, and treat flows from initial origin to final destination (2). There are a wide variety of options open to the transportation analyst, ranging from choice of technology and characteristics of particular technologies, network configurations, link characteristics, the number and characteristics of vehicles, and the way the vehicles are routed and scheduled through the system to the prices that are charged and other aspects of operating policies. The impacts to be considered in a transportation analysis are many: the impacts on users, with careful differentiation of the impact on different groups of users; the impacts on the operators of the various transport f - cilities; the functional impact of transportation, through affecting the spatial organization of social and economic activity and the time pattern of the development of a region; the "physical" impact caused by the mere presence of transportation facilities, such as air pollution, noise pollution, visual blight, land taking, and displacements of families and jobs; and the impacts on various levels of government, through changes of tax revenues, subsidies, and the like.

The basic framework of analysis of transportation alternatives is that arising from the concept of equilibrium within the transportation network. This requires that the transport system be modeled as a network with supply functions for various links in the network (links include line-haul links as well as terminals and other transport facilities) and that demand functions be developed for all the actual and potential users of transportation. The core of the problem of predicting the impacts of a particular transportation plan or policy is the prediction of the flows in the network, based on the equilibrium between supply and demand. In practice, this requires use of a complex system of models (2).

Finally, it must be recognized that the system of models used for prediction is only the first step. To actually perform transportation systems analysis requires search procedures to develop transportation and development alternatives that are worth testing in the simulation model system. In addition, evaluation and choice procedures required through alternative transportation plans can be prepared, and conclusions can be reached on the relative desirability of the several alternatives analyzed.

These ideas about the basic concepts of transportation systems analysis led to the design of the following series of concepts to be covered in a semester of approximately 15 weeks:

1. Supply-demand equilibrium over a single link—Hand and computer calculations of equilibrium are performed on a simple link connecting two points, which explores a range of demand parameters and link alternatives.
2. Supply-demand equilibrium in simple networks—Equilibrium flow patterns in various simple networks are explored to develop an understanding of how flows in networks are distributed.
3. Alternative flow distribution rules—Simple networks are used to explore different assumptions about the behavioral basis of flow distribution, by comparing such approaches as the so-called "behavioral traffic assignment" with "normative optimization."
4. Demand functions—Alternative values of demand parameters and forms of demand functions are tested against data, and experiments are made with various calibration techniques. The "best" demand models and parameter values are then used in an analysis of a simple network, and the results for different demand functions and parameter values are compared.
5. Technology—Simple models of transportation technologies (e.g., rail transit, highways, dial-a-bus, dual mode, air) are used to develop and explore significant trade-off relationships within and between modes. For example, total cost, average cost, and marginal total cost curves would be derived for different modes, for different levels of user service.
6. Network patterns—For several types of distributions of development patterns in a region and given a list of the available technologies that could be used, the student tests different network patterns to develop an understanding of how the effects of networks and alternative land use and economic policies are interrelated. For example, a student might test several transportation networks ranging from highway-dominated to transit-dominated to a system with innovative transportation technologies, each against several alternative land use patterns for metropolitan regions.
7. Differential impacts and substitutability of options—This is perhaps one of the most important blocks of exercises. The student explores a wide variety of alternatives and develops an understanding of what it means to systematically explore options and to trace out the differential impacts on various groups. For example, a student might work with an urban transit and highway corridor and vary rapid transit station spacing, the choice of line-haul transit technology, the train frequency, the choice of feeder service, automobile parking fare, automobile parking capacity, and other policy options. He then might trace out the differential incidence of costs and benefits as the options are varied.
8. Time staging of transport investment—This exercise will develop an understanding of the sequence of steps involved in implementing, in an evolutionary way, major transportation systems changes. The student evaluates the alternative time-staged sequences of transport investment and explores uncertainty about characteristics of demand and technology.
9. Case problems—In one or more case problems, for a period of several weeks each, at the end of the semester, the student does a comprehensive analysis of a single transportation problem. He assembles the necessary data, constructs supply and demand functions, designs alternative transportation plans, tests them, and analyzes the socioeconomic impacts on different groups by systematically exploring the options and finally reaching a decision on a system to recommend. The student writes up his recommendation, including documentation of his analysis.

This sequence of exercises is a projected target. It is quite likely that this will be too many concepts to try to get across within a single semester. At present, many of these concepts have been incorporated in the exercises developed to date. Before describing these exercises, however, it is useful to amplify what we hope to teach in terms of concepts about systematic analysis.

SYSTEMATIC ANALYSIS IN TRANSPORTATION

There are two major themes in our image of systematic analysis. It is often useful to describe these in terms of hypotheses. First is the calibration problem. The issue here is what models and parameter values for a particular model are most likely to simulate the real world. This is the typical thrust of "hypothesis testing" in transportation analysis: Alternative model forms and sets of parameter values are formulated as hypotheses that are then tested against the data. Various statistical tests are used to measure goodness of fit to determine the most appropriate model forms and parameter values to be used. Exercises to explore this kind of problem would stress the hypothesis-testing aspects of calibration of demand models, calibration of networks, and the like and would involve developing some elementary notions of statistics.

Second is the decision problem. Once a model is calibrated, the problem then is to use the model to analyze the decision issues, based on the assumption that the calibrated model is a reasonably valid picture of the real-world system. In this kind of analysis, the basic hypotheses concern the following:

1. What are the possible actions open to the transportation decision-maker?
2. What are the anticipated consequences of the various actions?
3. What are the key decision issues, what are the technological trade-offs open as possible options to the decision-maker, what value trade-offs are involved in making the choice, and what value judgments are required to reach a decision?

This too can be viewed as a hypothesis-formulation and -testing problem. Here, instead of hypotheses about models and parameters of models, the hypotheses are about actions and their consequences and about which actions are most desirable. The "experiments" to be conducted are the simulation model, to predict flows and other impacts in a transportation system. The approach to analysis must reflect this hypothesis-testing view: Based on the results of several preceding analyses, the transportation analyst formulates a set of hypotheses about what desirable actions might be like, what their impacts would be, and what decision issues these would illuminate; to test these hypotheses, he formulates one or several runs of the transportation model system and, then, based on the results of these model runs, revises his hypotheses.

Thus, the simulation model in the transportation laboratory is used much as a piece of "physical" laboratory equipment, and an attitude of "experiment" design is appropriate. There is a basic mode of formulating and testing hypotheses, which is essential in transportation systems analysis. Our objective is to develop exercises through which the student develops a feel not only for the hypothesis formulation and testing aspects of model calibration but also for the hypothesis-formulation and -testing aspects of exploring possible actions to be implemented in the real world.

THE PRESENT COURSE

We now turn from philosophical issues and general approach to indicate precisely where we stand in the development of this teaching material. These concepts have been evolving over several years, most especially in the context of a graduate course, 1.201 Transportation Systems Analysis I. This course has been the basic introductory course for entering graduate students and advanced undergraduate students and precedes a sequence of several more advanced transportation systems courses. The basic concepts outlined here were first implemented in teaching this graduate course in the fall of 1969, in a rudimentary way. In spring of 1970, a small experimental version of the undergraduate form of this course, 1.20 Transportation Laboratory, was conducted as a pilot experiment, and enrollment was restricted to 10 students. Since then, the course has been taught on a regular basis in the fall term and also in spring of 1971. Enrollment has been steadily increasing and is now 25 to 30 students.

In this course, the full flavor of the laboratory concept is explored. The experiments were initially structured into three major sections:

1. Basic concepts and techniques,
2. Project I—urban transportation corridor, and
3. Project II—airport access.

In section I, the emphasis is on developing an initial understanding of concepts and techniques: basic notions of supply, demand, equilibrium, network flows, and the like. Then, additional concepts and techniques are developed in the context of two major projects or case studies. For example, project I deals with the problem of highway and transit complementarity in an urban corridor (suburbs to central business district) using the southeast corridor of the Boston region as a case study. Concepts of multimodal demand models, substitutability of pricing and operational improvements for construction of new facilities, and exploration of new urban transportation technologies are included. Particular emphasis was placed on the differential tracing out of impacts by dividing trip-makers into two income groups as well as into radial rings of residence locations. The second project deals with access to airports and choice of access mode in an urban region. The specific exercises that have been developed are discussed below.

Part I: Basic Concepts and Techniques

Exercise 1—This first exercise introduces the basic concepts of transportation systems analysis, building around the concept of equilibrium analysis. The emphasis is on simple one-link networks, with linear supply and demand functions. Simple manual computations are included to reinforce the concepts. Then, the use of the computer for the analysis of such networks is outlined, including extracts from sample computer runs and introduction to some of the basic DODOTRANS commands. There are also explorations of how changes in the parameters of the demand functions would affect the predicted results, which demonstrates, among other things, the shift of demand over time due to population growth and income change. The exercise concludes with a simple comparison of alternatives for replacing a particular hypothetical highway link. Students also code and punch simple DODOTRANS runs, which are checked for basic understanding of concepts and DODOTRANS commands.

Exercise 2—This exercise introduces the complexities of multimodal network analysis. There is detailed instruction in the use of DODOTRANS commands for setting up and executing a multimodal network analysis. A simple case study deals with a multimodal network with three modes, highway, transit, and park-ride, for a single origin-destination pair. The student analyzes various alternatives by using listings of computer runs that have been prepared for him. Through the use of listings of runs, the basic concepts of transportation systems analysis and of the use of the DODOTRANS language can be reinforced and understanding of details can be tested, without the time lag and expense of each student's actually preparing and executing computer runs. For the last part of the exercise, students code up and run their own alternatives. In studying this simple network, students explore various alternatives that emphasize the substitutability of fare, service, and other options for the construction of transit and/or highway line-haul or terminal facilities. As an example of the approach, the following sequence of classes is held:

1. Class 1—Here is a network with predicted flows for future year X. Class discussion: Where are the "bottlenecks" or other problem areas? Why have they come about?

2. Class 2—Here is a list of possible improvements to the network (including pricing and service changes as well as the construction of new links such as expressway or parking facilities). Discussion: What effects do you think each of these possible improvements would have? Why do you think they would have these effects? Can you explain them in terms of the theoretical concepts and of the particular numerical values of parameters, such as the parameters of the demand functions? What other alternative improvements should be examined?

3. Class 3—Here are tables showing the impacts predicted by the computer for each of the alternative improvements. Discussion: Can you expect these to occur in the real world? For a different set of parameters (several are specified), how would you expect the results to be different? Why?

By the end of this block of exercises, the students know how to set up and execute a multimodal transportation systems analysis using DODOTRANS, and they have an understanding of the basic concepts of network equilibrium analysis and of the detailed commands necessary to use. This set of exercises takes about 6 weeks.

Exercise 3 deals with the calibration problem, with a concentration on demand model calibration. Basic concepts of linear and product forms of demand models and of elasticity and cross elasticities are introduced, as well as identification and other aspects of the demand model calibration problem. Simple hand-calculated exercises are used to reinforce these concepts.

Parts II and III: Projects

Exercise 4 is the first case study, The Urban Transportation Corridor, based on the southeast corridor of the Boston metropolitan area. Two modes are modeled, highway and transit; the metropolitan corridor is divided into five suburban rings and a CBD, with two groups of travelers, high income and low income. Each group has different demand functions, represented by different parameters of a single demand model. The case study has been made as realistic as possible by using the available data for this corridor to the maximum extent feasible. The students explore a wide variety of alternatives. The first several groups of explorations are in response to structured questions: The class is asked to look at the results of computer runs in which transit fares and other characteristics of the system were varied over several different levels. Each student traces out the differential impacts of these alternatives on different groups, not only from the perspective of the operators of each mode but also in terms of the ridership from different rings and different income groups. To reinforce and expand his understanding of these differential impacts, he summarizes the various runs in terms of trade-offs between the net revenue to transit and highway operators and user benefits represented by travel time, fare, and other measures (including a consumer surplus measure). At the end of this exercise, he is given the assignment of formulating his own alternatives:

"You are now on your own. Develop and study alternative solutions for the southeast corridor: (a) Develop one or more alternatives that you think will be desirable. (b) First, write down your hypotheses about what you think the consequences of those alternatives would be. (c) Then decide which ones are worth testing in detail. Write down your reasons why. (d) Set up and execute one or more runs to test your hypotheses. (e) Review your results and repeat previous steps if desirable and if there is time and computer budget left. (f) Prepare a report on the results:

1. Summarize (no more than two pages) the key choice issues. Which alternatives are most important to consider; what are the key issues in choosing among them (the trade-offs) and your recommendations?
2. Document your analysis process, including the results of the various steps above."

Exercise 5 is the second case study, an airport access problem. Whereas in exercise 4 a number of very structured questions are asked, leading the students step-by-step through a systematic analysis of the alternatives, exercise 5 is open-ended and concentrates on the design of an analysis process that will lead to answers to the problems caused by ground travel to and from airports. The student is asked, "What would you do, given a range of available amounts of time and money?"

EVALUATION

In the process of offering the urban transportation laboratory course a number of times, we have made a number of operational improvements, so that now we feel we have a working, tested course with which to introduce undergraduates to transportation systems analysis. To date, we have made the following major changes and elaborations. Although we did not do so when the course was first given, we now stress the need to prepare good, written engineering reports to summarize the work done on the various case studies. This stress has resulted in not only better reports but also better analysis by the students. Also, a role-playing game concerned with the problem of airport expansion has been developed. This was first used in spring of 1971. The students have expressed great interest in the game, stating that it helps them to see the role of transportation analysis in the real world.

More generally, a number of significant conclusions about the course and the approach as a whole have been reached.

In terms of achieving the basic objective of student involvement, the students seem to be highly involved and committed to the course each time it is taught. Several students have been instrumental in having their friends enroll in following terms. A number of students have shown their continued interest in transportation by taking advanced courses, by working as student assistants on transportation research projects, and by earning academic credit while helping to conduct the course as undergraduate teaching assistants.

Each time the course is given, the students are asked to complete a course evaluation questionnaire. These questionnaires indicate that the major attraction of the course is its relevance, combined with the analytic computer aspects: They can see the relevance to everyday transportation problems with which they are familiar (one sophomore from Long Island sees the problem that his father faces everyday in commuting to Manhattan in one exercise), and they can also see the role that systems techniques (computers, economic analysis, and the like) will play in dealing with these problems. The students also have expressed satisfaction with the case study approach, although they would prefer more and shorter studies. Many have felt that a previous economics course would have been helpful as preparation for the course.

The second major conclusion is that the development of these kinds of exercises is not simple. Data must be gathered from actual transportation studies where available; these data are difficult to find and often inconsistent and must be extracted and adjusted carefully. The theoretical concepts of transportation systems analysis must be clearly worked out, and it is surprising how much is learned by constructing simple examples for hand calculation. Several computer examples must be developed to bring out the basic issues and teach the uses of specific computer language commands. Then, this must all be integrated with a case study project. The development of carefully structured exercises, together with a series of open-ended questions, which require the student to formulate his own experiments, takes very careful thought and planning.

Third, and finally, one very important conclusion is that we, the faculty and staff involved in teaching the course, are learning a great deal from it, perhaps more than any of the students. In trying to structure and formalize the concepts of transportation systems analysis and to develop well-integrated exercises, we are forced to rethink and clarify a lot of things we have assumed as givens. Particularly important here is the way we and our students are learning to treat the computer, as a tool for policy analysis. We stress a continual comparison of computer results against theoretical and intuitive judgment, as for example the series of class discussions in exercise 2 and the discussion of hypothesis testing. We stress using the computer model as a tool to analyze policy questions, not as an end in itself. We place great emphasis on exploring the social, political, and environmental choices that must be addressed. We expect to learn a great deal from our students in constructing these exercises and have learned a lot already.

FUTURE PLANS

We are continuing development and refinement of this transportation laboratory course. The exercises described have been documented and are available for limited distribution. We hope to begin circulating these to get comments and criticisms from our colleagues in practice and in academic institutions. We look forward greatly to widespread participation in this experiment, and, as soon as it is feasible, we will attempt to make these exercises and computer programs available to other institutions.

Major directions of future work are

1. Development of exercises for problem contexts other than those that have already been developed,

2. Incorporation in the exercises of quantitative and qualitative aspects of social and environmental impacts of transportation alternatives,
3. Expansion of DODOTRANS capabilities to include representative forms of the conventional urban transportation planning model system,
4. Continued revision of previously developed material to promote better teaching effectiveness, and
5. Experiments in presentation approaches in order to reduce computer expenditures required per student.

We live in an exciting period in the field of transportation. The research problems are challenging. The problems of teaching transportation effectively are even more challenging. The "transportation laboratory" concept that we have described is one possible approach to teaching transportation systems analysis effectively.

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