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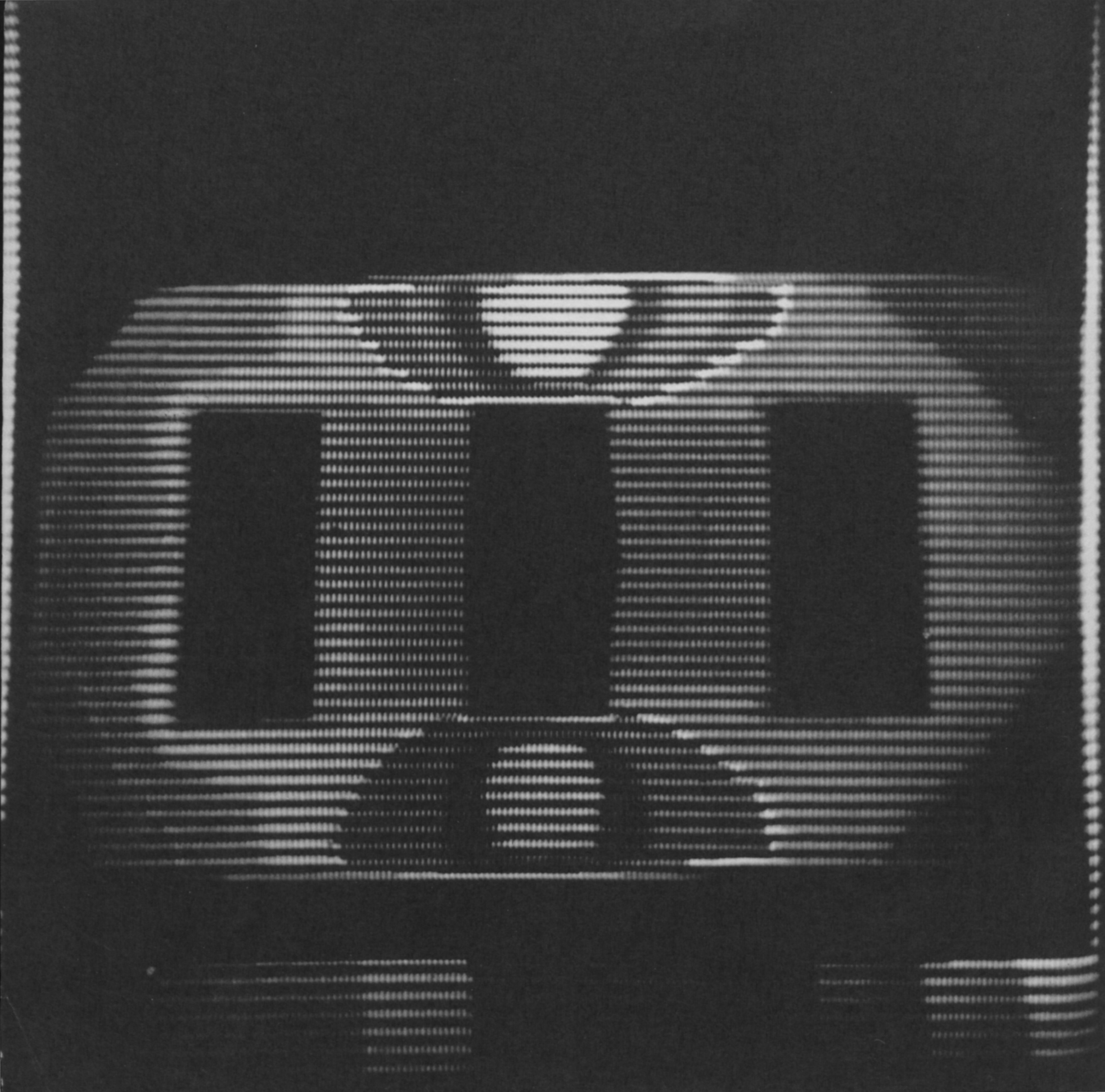
SHAPING OUR TRANSPORTATION SYSTEM



IN THIS ISSUE

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Opposite: The pattern of an infrared thermogram showing induced eddy-current patterns in a magnetic levitation track element for a possible high-speed train system. The train would carry a rectangular superconducting magnet above the conducting track. Bright areas show high current intensity in the center of the track edges. The bottom strip is the color code for the temperature scale.

THE ROLE OF MASS TRANSIT IN URBAN TRANSPORTATION SYSTEMS

by Arnim H. Meyburg

Mass-transit systems and automobiles are generally viewed as competitors in urban transportation. Whether one alternative ought to be supported at the expense of the other, and which should have preference in spatial allocations, are controversial issues. Discussions of these matters, however, are based mostly on emotional or psychological attitudes, or even ideological and philosophical ones. Rational argument is rare even among professionals, who frequently have difficulty suppressing their bias for one or the other transportation mode. And of course, the situation is in no way helped by the fact that almost everyone considers himself or herself a transportation expert on the grounds that virtually everyone is involved in the transportation process.

Concern with problems relating to the dichotomy of urban mass transit and private automobile transportation is by no means new in this country. Problems derived from automobile transportation—notably urban congestion, and noise and air pollution—have fueled the debate for a long time. It was not until World War II, though, that the issue became one of financial and political concern to the Federal government. Urban transportation traditionally had been regarded as a local affair, but the explosive increase in automobile ownership and use after the war led to problems too great for the local governments to handle. With decreasing revenues, privately operated public transit systems began to falter, and their relative attractiveness to passengers was further diminished by the deferral of maintenance and equipment renewal programs. In many cases, local governments had to take over the operations in order to prevent a complete collapse of urban transportation systems, and as a result experienced financial difficulties themselves. Pressures from hard-pressed local governments made evident the need for Federal legislation providing financing for urban mass-transit equipment and, more recently, operations.

MAJOR FEDERAL LEGISLATION CONCERNING MASS TRANSIT

The Housing Act of 1961 was the first result of Congressional efforts to deal with the problems of urban mass transportation. Federal responsibility for assisting urban mass transportation was initially assigned to the Housing and Home Finance Administration (HHFA). The first major effort of the HHFA in this area was the Federal Mass Transportation Program, which was designed as an emergency stop-gap measure to aid the financially sagging rail commuter services by providing loans. After a few years, however, it became obvious that the resources provided by this program were not capable of handling all of the mass-transportation needs, and in 1964 Congress passed the Urban Mass Transportation Act. This established a program of Federal grants (on a matching two-thirds to one-third basis) for the preservation, improvement, and expansion of urban mass-transit systems.

The responsibility for administering the 1964 Act lodged in the HHFA until the functions of that agency were absorbed into the Department of Housing and Urban Development (HUD). In 1968 the Department of Transportation (DOT) took charge and organized the Urban Mass Transportation Administration (UMTA).

"An important change... is the emerging perception of public transit as a public service."

The Federal Aid Highway Act of 1970 constitutes another step in the direction of improved mass-transit facilities. This act authorized the use of certain Federal-aid highway funds for improvements in urban mass transportation. However, these funds were restricted to use for highway-based mass-transportation service.

Among the many subsequent pieces of legislation pertinent to mass-transit funding, the National Mass Transportation Act of 1974 is particularly significant in that it authorized for the first time Federal operating assistance, in addition to capital grants, to local and regional mass-transit operations.

COMPONENTS OF THE URBAN TRANSPORTATION SYSTEM

It goes without saying that the automobile is here to stay as an essential component of the national transportation picture, although we may see substantial modifications in its use. The automobile has made valuable contributions to our society by improving individual mobility, extending opportunities for choice of work place and residential location, and, in general, providing accessibility to virtually any destination that can be reached by highway. But its large-scale use has also led to a number of serious problems, some dramatic, some more subtle, that argue against the unlimited use of individual transportation. Problems of congestion frequently turn the mobility we have come to appreciate into frustrating immobility during peak-period traffic jams. Other major problems include pollution from vehicle emissions and, of course, depletion of our natural resources at a rapid rate.

Among the less dramatic but equally significant problems are the mobility restrictions of the so-called transportation-disadvantaged. Because of the assumption of ubiquitous availability and use of the private automobile, we tend to forget that significant segments of society—for example, the very young, the old, the poor, and the mentally or physically infirm—have to rely on means other than their own private automobiles for the mobility they need. Mass transportation now available is very limited in terms of areal and temporal coverage. It is obvious that our present system discriminates against those who depend on public transportation service, either because of necessity or for reasons of principle and conviction.

It is also obvious that there is no panacea for eliminating the economic, social, and environmental problems associated with transportation. There is no one technology, operation, or system that could provide a satisfactory solution. But urban mass transit, implemented carefully and imaginatively, could play a beneficial role in overcoming the problems. It is appropriate to take a closer look at what might be done.

ALTERNATIVES FOR URBAN MASS TRANSIT SYSTEMS

If mass transit is considered to include all passenger modes except individual transportation by private automobile, it includes a wide variety of possible means for both interurban and intracity travel. Even if the term is restricted to *urban* mass transit, as it commonly is, there is a whole spectrum of options,

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Light-rail transit vehicles are an alternative to bus and subway systems for urban mass-transit development.

1. The famous San Francisco trolley has never lost its appeal to passengers. Today modern versions of the good old streetcar are appearing on city streets.

2. This light-rail vehicle is one of two kinds to be put into operation this year in Toronto. It is regarded as an advanced state-of-the-art vehicle offering improvements in performance, maintenance, energy savings, noise reduction, and passenger comfort.

3. A degree of the mobility and privacy that passengers have come to appreciate in automobile transportation may be provided by "personal rapid transit" (PRT) vehicles. This limited-version PRT vehicle services the Dallas–Ft. Worth airport. The idea of PRT is to provide computer-controlled small vehicles that can be summoned by a user and ridden to a destination with no intermediate stops and then become available to other users. The development of PRT prototypes is being funded by the Urban Mass Transportation Administration.

ranging from car and van pools all the way to fixed-rail commuter and subway lines. These options include a group, known as paratransit systems, that are oriented largely toward operations rather than technology, and whose development reflects a recent change in the attitudes of planners, operators, and decision makers. A major trend at the present time is to develop effective operational uses of available facilities and rolling stock (cars, station wagons, minibuses, and buses) rather than to devise technologically new systems.

An immediately apparent function of mass transit is to meet those kinds of travel demands that arise in a repetitive fashion, both temporally and spatially. Travel to and from work is the overwhelming element in this category—and peak-period congestion is the familiar result. During the rest of any twenty-four-hour period, automotive transportation facilities are substantially underutilized (exceptions may occur during the vacation season), but they can rarely meet the demands placed on them during the peak periods.

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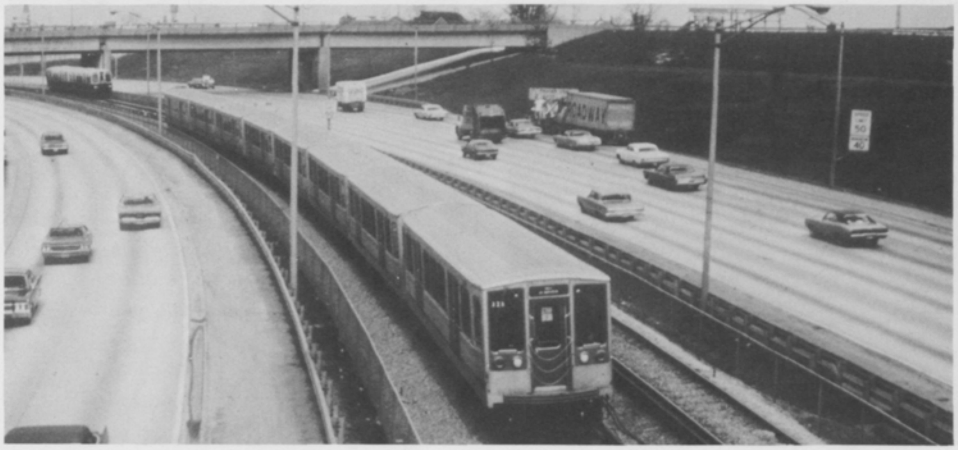

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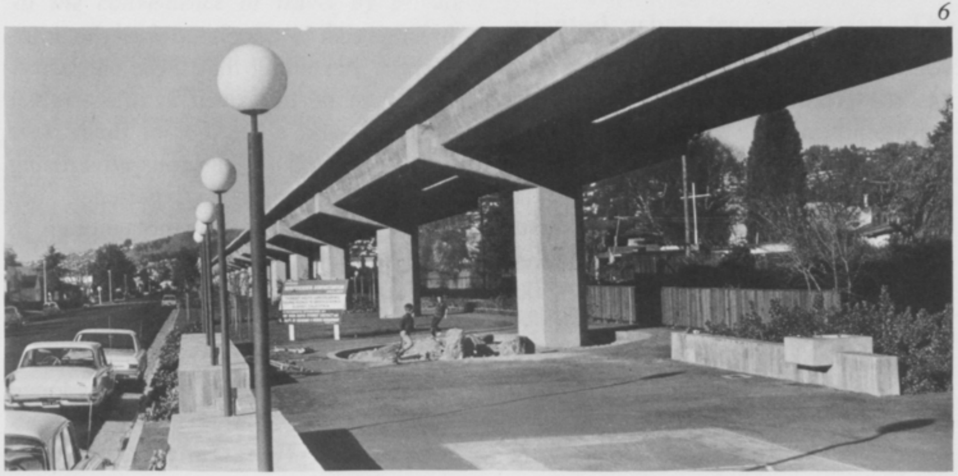

4. The San Francisco BART System provides first-class rapid transit service.

5. Parts of the Chicago rapid transit system share the right-of-way with urban freeways.

6. Providing right-of-ways that are safe and nondisruptive is an important aspect of urban rail transit planning. This neighborhood park area is located under an elevated track of the Bay Area Rapid Transit System in California.

One of the most effective ways that has been found to meet this problem is to provide rail rapid-transit service during peak-demand periods along high travel-demand corridors; the capacities of rail rapid-transit systems are unsurpassed by any highway facility accommodating private automobiles. The work trip, with its characteristic of repetitiveness and predictability, is a logical target for mass-transit system development.

A different kind of problem is encountered in attempts to provide transportation service when there is low demand density distributed over time and over geographical area. The passengers who need to be served are those we have described as the transportation-disadvantaged. The object in this case is not to provide an attractive alternative in order to effect modal shifts, but to institute primary mobility for those who do not have a mechanized means for getting around. Demand-responsive passenger transportation is one very suitable means of accommodating these travel needs, since fixed-route, fixed-schedule service or any kind of high-capacity service would obviously be

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wasteful and misplaced. The design of appropriate systems for low-demand situations constitutes another major target area in the development of public transit systems.

BRINGING ABOUT NEEDED CHANGES IN THE SYSTEM

The accomplishment of these major goals in developing mass-transit systems depends on public acceptance and on the availability of adequate financing.

The first requirement is that the public transport system be conducive to voluntary use. As long as the traveler has the freedom of choice between a private automobile and mass transit, it will be necessary to design the alternative system so that it is seen as the preferable mode of transportation. Pricing mechanisms alone have proven not to be the answer in effecting modal shifts. A number of relative advantages of the private automobile have to be met or overcome, among them convenience, privacy, comfort, flexibility, security, and the image, status, or prestige that is associated with the automobile. Assuming that these characteristics can be improved in mass-transit systems—and a number of them have been upgraded—a vigorous advertising effort is necessary. Experience has shown that it is simply not enough to offer attractive service if the public is not aware of it and if the service is not promoted in such a fashion that it can overcome the serious image problem that urban mass transit has developed during many years of neglect and almost exclusive attention to auto-

The improvement of bus service is a major objective of urban mass transit planning. Federal funding is available for a variety of programs.

1. Models of Transbus, an improved kind of city bus, have been built by three manufacturers under sponsorship of the U.S. Department of Transportation. Transbus is designed to provide improvements in passenger loading and unloading, speed, noise levels, comfort, esthetics, and maintenance cost.

2. This bus-stop shelter in Ithaca, New York (where Cornell is located) is an example of improvements that can help make public transit competitive with private transportation. A capital grant from the Urban Mass Transportation Administration will enable Ithaca to replace its bus fleet with modern diesel buses, as well as to install shelters such as this at all major stops. This local improvement program is a spinoff of Cornell research on mass-transit system operations.

3. Exclusive bus lanes help speed vehicle movement in urban areas. This photograph shows a reversible lane for buses; plastic posts, overhead directional signals, and changeable signs are used to separate the bus lane from traffic flowing in the opposite direction.

4. "Dial-a-Ride" bus service offers much of the convenience of travel by private automobile. In systems now in operation, mini-buses function more like taxicabs than like ordinary buses. Instead of running on fixed schedules and routes, the buses are "custom" routed: dispatchers receive telephoned requests for service, plot routes, and radio instructions to drivers who pick up and drop off passengers at the places they have designated, thus providing door-to-door service.

5. Federally funded urban transit systems will be providing new conveniences to accommodate elderly and handicapped passengers. This mini-bus is equipped with special doors and a wheelchair lift.

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oriented urban transportation. The predominance of automobile transportation was generated and sustained to a significant extent through powerful lobbying of automobile and highway-related industries.

One of the conceptions that must be refuted if substantial numbers of passengers are to be attracted is that urban mass-transit systems are designed mainly for those who are captive riders —those who are in one way or another dependent on the use of such systems. The BART System of the San Francisco Bay Area has in many ways achieved the development of an image for first-class commuter service. In that case, however, the pendulum swung too far in the direction of exclusive and superior service: Largely because of decisions about station location and spacing, as well as the rate structure, the population of large low-income areas has rather limited access to and use for the BART System.

The experience gained through the San Francisco BART System and also the Washington METRO System has

"A number of relative advantages of the private automobile have to be met or overcome."

led to, among other things, a reassessment of priorities and suitable technologies for urban mass-transit systems. Since the formation in 1965 of the Federal Department of Transportation, which was designed to integrate all transportation-related functions of the Federal government, a number of shifts have occurred in national policy as it concerns priorities in urban mass-transportation systems. For some time, great hope was placed in the role new mass-transit technologies could play in solving the so-called urban transportation problem. But eventually it became recognized that (1) there was not and is not *one* urban transportation problem, but rather a whole array of problems and symptoms; and (2) sophisticated mass-transit technologies are too costly and difficult to implement on a broad scale. Vacuum-tube transit facilities, tracked air-cushion vehicles, "personal rapid transit" systems, magnetically levitated vehicles, and a whole array of other technological innovations might look attractive in research laboratories and at test sites, but recognition of the cost and short-run applicability problems in the urban context tends to put a severe damper on the excitement. For example, TRANSPO-72, an international transportation hardware exposition in Washington, D.C., included displays of four different Personal Rapid Transit (PRT) systems, all sponsored in one way or another by the Urban Mass Transportation Administration; but since then, except in connection with the disappointing local system in Morgantown, West Virginia, very little has been heard about that particular technology.

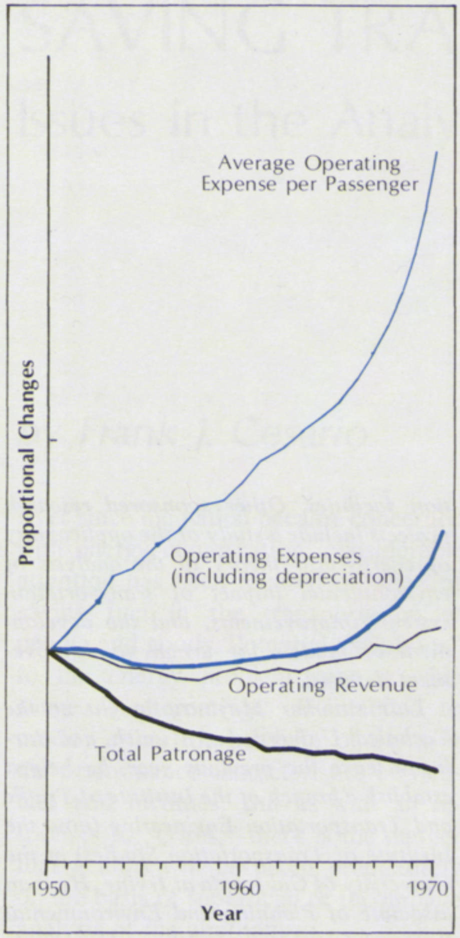
We have finally come to realize that a much more cost-effective way of using the limited resources that appear likely to be allocated to urban mass transit is to improve the quality of service available through existing technologies. The possibilities include operational improvements such as the designation of traffic lanes exclusively for buses and other multiple-occupancy vehicles; the organization of car and van pools; the introduction of "dial-a-ride" systems; and measures to improve passenger comfort and convenience. In addition, the need for marketing campaigns should not be neglected.

RECENT TRENDS IN PUBLIC MASS TRANSIT POLICY

The most recent shift in Federal policy regarding transportation service in metropolitan areas is a reorientation toward light-rail transit (the good old-fashioned tram under the guise of a new name) operating on an exclusive right-of-way at or below grade. This shift implies a change in priority from the construction of full-fledged subway and commuter systems such as BART and METRO; interest in heavy-rail systems was short-lived, mainly because of sky-rocketing construction costs.

Small urban, suburban, and rural areas face somewhat different problems in their attempt to provide transportation service for those in need of mobility and accessibility to jobs, medical service, shopping opportunities, and social or recreational activities. These low-density areas have long been the stepchildren of Federal transportation policy and funds. Yet their problems, though of smaller magnitude, are no less significant than those of metropolitan areas.

Figure 1



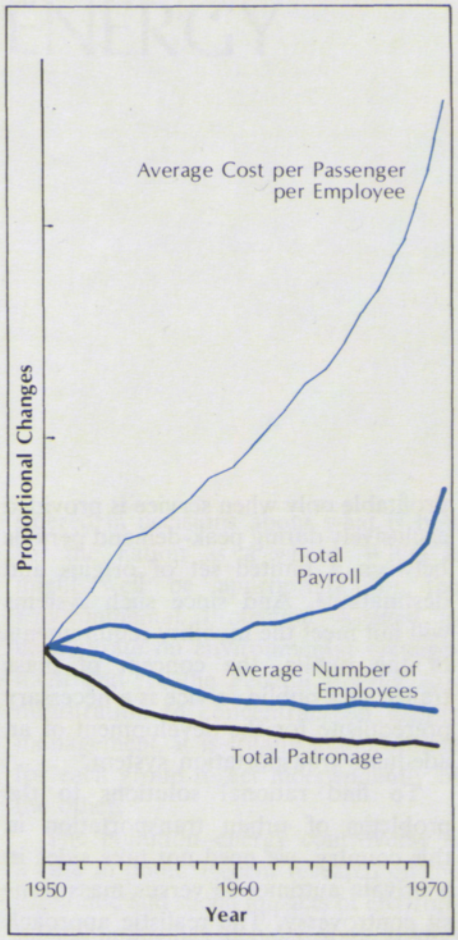
A problem common to both kinds of communities is the fact that travel-desire lines, or travel patterns, bear very little relationship to political and administrative boundaries. When political obstacles prevent area-wide transportation planning and service, the result tends to be a highly fragmented and uncoordinated public transportation service. It is obvious that inefficiency is the penalty when many separate agencies and communities in the same geographical area run separate transportation systems with separate

The familiar story of rising costs and declining revenues contributed to the decline of urban mass transit service in the United States. Figure 1 shows operating revenues and expenses, and Figure 2 shows data for patronage and transit employment. Figures for the year 1950 are used as the base. The average operating expense per passenger, for example, increased more than two hundred percent in twenty years, and the average cost per passenger per employee increased even more. Source: George M. Smerk, Urban Mass Transportation—A Dozen Years of Federal Policy *(Bloomington: Indiana University Press, 1974.)*

vehicle fleets, maintenance facilities, administrative and driver personnel, and routing and scheduling schemes. Recently, concern over these inefficiencies and inadequacies has resulted in the formation of area-wide transit agencies encompassing a number of communities. Capital and operating subsidies for both local and area-wide public transit systems have been made available.

Another way in which mass transit development has been encouraged is through the allocation of research funds for investigations of ways to plan and provide improved service. Cornell, for example, is involved in a three-year DOT-sponsored study, "Mass Transit Development for Small Urban Areas," which addresses the problems faced by small and low-density urban as well as rural areas in providing public transportation service. This study will culminate in the publication of a manual for mass-transit planning in small urban areas that should be a significant resource for local transportation engineers and planners. In addition to addressing issues of marketing and

Figure 2



monitoring, the manual will identify data requirements and techniques for obtaining the needed information, and will identify suitable travel-demand forecasting models and alternatives for the financing, administration, and operation of public transit systems.

An important change in attitude reflected in recent developments is the emerging perception of public transit as a public service rather than as an enterprise guided exclusively by profit-making considerations. Public transit systems are and will be financially profitable only when service is provided exclusively during peak-demand periods between a limited set of origins and destinations. And since such systems will not meet the mobility requirements of the public, the concept of mass transit as a public service is a necessary prerequisite for the development of an adequate transportation system.

To find rational solutions to the problems of urban transportation in this country, we need not take sides in a private automobile versus mass transit controversy. The realistic approach is to work toward the development of a balanced transportation system in which basic mobility exists for all, yet where travel choices are available for those who are willing to pay the price.

Arnim H. Meyburg, associate professor of civil and environmental engineering, is a specialist in urban passenger and goods transportation. His particular interests are in behavioral travel-demand modeling aspects of transportation planning, mass-transit systems operations, and goods-movement analysis for urban areas.

He was born in West Germany and attended the University of Hamburg and the Free University of Berlin, which awarded him a baccalaureate degree in linguistics in 1965. He did his graduate work at Northwestern University, earning the M.S. in quantitative geography in 1968 and the Ph.D. in civil engineering in 1971. He joined the Cornell Department of Environmental Engineering in 1969.

Meyburg is active locally, nationally, and internationally in his area of research and practice. An ongoing study sponsored by the U.S. Department of Transportation is concerned with mass-transit development for small urban areas and has involved a case study of Tompkins County, New York, where Cornell University is located. Meyburg is also involved in a study, sponsored by the National Science Foundation, of the possibilities for complementary use of transportation and mobile communication facilities. Other sponsored research projects include a study of the applicability of energy-flow theory to the analysis of environmental impact of transportation systems improvements, and the development of models for urban goods-movement demand.

Last summer Meyburg taught at the Technical University of Munich, and during a leave the previous year, he helped establish a branch of the Institute of Traffic and Transportation Engineering (now the Institute of Transportation Studies) at the University of California at Irvine. He is an associate of Planning and Environmental Research Consultants of Ithaca, New York, and has been a consultant on transportation projects in Illinois, North Carolina, California, New York State, and Australia. He served as co-chairman of international conferences on behavioral travel-demand modeling in 1973 and 1975.

Meyburg's publications include numerous articles and two books, Urban Transportation Modeling and Planning *and* Transportation Systems Evaluation, *written with Peter R. Stopher and published in 1975 and 1976, respectively, by Lexington Books of D. C. Heath. He is active in the Transportation Research Board and is a member of several other professional and honorary societies.*

SAVING TRANSPORTATION ENERGY

Issues in the Analysis of Alternatives

by Frank J. Cesario

Ever since the nation became concerned with energy conservation, considerable attention has been focused on ways of saving fuel in the transportation of people and goods. Potential "solutions" to the energy problem span a wide range of alternatives, all intended to modify either the behavior of users or the performance characteristics of vehicles and facilities. But as with all responses to "crises," there is the danger that actions will be taken prematurely on the basis of superficial or incomplete analysis of the alternatives.

In this article, some of the issues in transportation energy conservation analysis will be examined in the hope that future studies will take them into account. Among the important needs are:

- recognition of the fact that energy conservation is but one of our national concerns and should be considered in terms of its interactions with other goals;
- consideration of the nature of the interactions between the movement of people and the movement of goods;
- the use of appropriate measures of transportation output;
- careful compilation and use of data to ensure that information is appropriate to the problem at hand;
- comprehensive evaluations of alternatives, with attention to marginal costs and benefits.

ENERGY CONSERVATION AS ONE AMONG MANY CONCERNS

In our national life, we tend to become concerned about problems as crises arise and then treat the consequent issues as if nothing else mattered. When safety on the roadways became a political issue in the early 1960s, unprecedented attention was directed to making vehicles more durable; when environmental quality became an issue in the late 1960s, attention was focused on reducing or eliminating vehicular emissions of noxious pollutants; now, when energy appears to be the major issue, attention is concentrated on figuring out ways to save fuel. All of these concerns are, of course, legitimate, provided that they are not acted on independently of each other or of competing problems. The interacting aspects of different policy areas need to be considered in decisions about what is best for the nation as a whole. While it might well be appropriate for the Environmental Protection Agency to concentrate on environmental management and for the Federal Energy Administration to concentrate on energy management, it is totally inappropriate for each group to act independently of the other.

The pollution–energy controversy is a case in point. Recent research on the economic and social impacts of environmental policy has included some studies of industry response to the legislation that culminated in the Clean Air Act of 1970 and its Amendments. The consensus of the findings is that the original 1975-76 deadlines for meeting emission standards and the one-year delay that was later approved led the industry to develop only marginal improvements of the conventional internal combustion engine because more radical technologies would have required at least three or four additional years to develop. The compromise "bolted-on additions," as they are called, initially resulted in poor fuel economy, high maintenance and

Figure 1

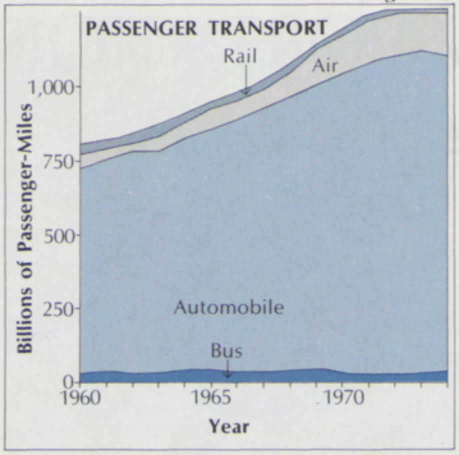


Figure 1. Passenger-miles of intercity traffic by mode. This graph shows clearly the dominance of the automobile in transporting people between cities. Of the more than 1.4 trillion passenger-miles registered in 1974, approximately 88 percent were by automobile, 2 percent by bus, 9 percent by air, and 1 percent by rail. Inland waterways account for a negligible percentage of the traffic. The decrease in automobile passenger-miles in 1974 has been attributed to the fuel shortages and increased prices resulting from the Arab oil embargo of 1973. (Source: U.S. Department of Transportation, Summary of National Transportation Statistics.)

Figure 2

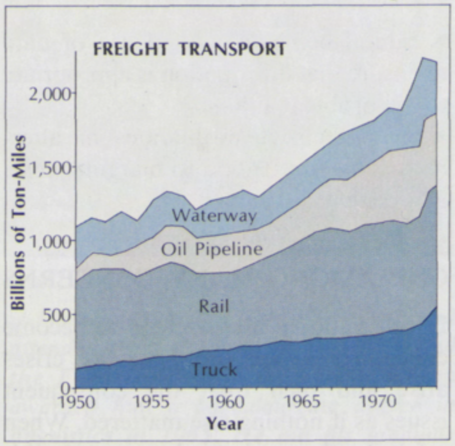


Figure 2. Ton-miles of intercity freight by mode. In addition to the four basic transportation modes that pertain to passenger travel (highway, rail, water, and air), there is also pipeline transport for oil, liquid petroleum products, and natural gas. Of the more than 2.2 trillion total ton-miles carried in 1974, approximately 23 percent were carried by truck, 39 percent by rail, 15 percent by inland waterways, and 23 percent by pipelines. Less than 0.2 percent of the total was carried by air. (Source: Motor Truck Facts, *Motor Vehicle Manufacturers Association.)*

operating costs, and questionable operating stability, and it probably would have been more effective in the long run to take the time to develop better technological alternatives. In these studies, it was recommended that interim, weaker standards be invoked until 1980 and that during the delay period, the government take steps to ensure that the development of more efficient technologies be undertaken. This might be accompanied by the structuring of a more realistic system of fines and subsidies that would apply to both users and manufacturers of automobiles. (The Clean Air Act is also criticized on the grounds that the penalties for violations —a ten-thousand-dollar fine for each vehicle that fails to meet the standards —are unrealistic, leading manufacturers to argue that compliance is impossible, and are therefore ineffective.)

It is interesting to note that the deadlines have, in fact, been rolled back, although the extension was prompted not by environmental issues, but by concern about the availability of fuels. In this particular case, the net effect will probably be positive, since the delay may well encourage and hasten the development of unconventional propulsion technologies such as the Wankel engine, the stratified-charge internal combustion engine, the Rankine cycle engine, the gas turbine engine, and electric drive.

Another policy area that is interrelated with energy and environmental policy is public safety. Prior to the passage of the Highway Safety Act of 1966, the automotive industry had no incentive for improving the safety of its products; the Act forced the automakers into providing such equipment as collapsible steering columns and crash-proof bumpers. But although safety was improved, the modifications (which increased vehicle weight) resulted in increased fuel consumption, and the Highway Safety Act therefore worked in direct opposition to energy conservation policy.

These examples demonstrate that the implications of alternative policies in different areas should be examined in such a way that all relevant impacts can be considered simultaneously. The final decision may not represent the best result for each concern, but it will be optimal with respect to the joint objective, which is to obtain the best overall solutions at the least cost. Although our current institutional framework discourages extensive collaboration, some progress is being made. For example, several agencies recently cosponsored a study which explicitly considers the joint nature of environmental and energy conservation measures in the area of transportation. Further studies of this kind should be encouraged.

"...energy conservation is but one of our national concerns and should be considered in terms of its interaction with other goals."

COMBINING MOVEMENTS OF PEOPLE AND FREIGHT

Even within the single policy area of transportation energy conservation, there are interactions that need to be taken into account. The major one is between the movement of people and the movement of goods, which take place over the same facilities. Congestion in urban areas is caused not by automobiles or trucks alone, but by the combined use of the roadways by cars, trucks, buses, and all other conveyances. Amelioration of congestion and a concomitant reduction in fuel consumption can be accomplished by bettering the situation with respect to any one or a subset of these various kinds of vehicular movements. For example, complete or partial elimination of automobile traffic in downtown Manhattan would probably serve to improve the flow of trucks in and around New York City (although it might not). Combining goods movement and passenger movement in single vehicles would probably serve to reduce energy consumption (although it might not). Other possibilities for combining services can be imagined.

There are, however, some fundamental differences in the transportation of people and of goods. The choice of transportation mode is more complex for human beings than it is for commodities. In deciding how to make a trip, the individual traveler, subject to constraints, presumably weighs the advantages and disadvantages of each available mode and route. In general, if financial costs are equivalent, the traveler will choose the alternative that involves the least expenditure of time or is the most pleasurable to travel on, or both. In goods movement, by contrast, individual commodities do not determine their own destinies. In general, the shipper, subject to constraints, will choose the transportation system that provides acceptable pickup and delivery for the least outlay of money. The cost of shipping a commodity does not include a time-cost component (a commodity has no preference for the use of its time) or a comfort and convenience component (a commodity is indifferent to the style in which it is transported). Of course, time and a parallel to comfort and convenience are not unimportant, and they act as constraints on shipments. If a perishable commodity cannot be delivered before it has begun to deteriorate, the result is a high cost to the producer; the shipper of a fragile commodity would prefer a mode of transport that provided the special handling required.

These considerations have a signicant bearing on analysis for transportation energy conservation. The possibilities of joint strategies for the transportation of people and goods should be explored, but with recognition of the differences between the two kinds of movement. Most studies to date have dealt with each type of transportation separately.

PITFALLS IN THE USE OF THE TON-MILE UNIT

One difficulty in considering energy conservation and other aspects of the movement of goods and people is that the commonly used units of transportation output—the ton-mile and the passenger mile—are deficient. Compari-

Table I

ENERGY CONSUMPTION BY SECTOR

Data for selected years show the percentages of energy consumed in the United States by three major sectors. The figures show that the transportation sector accounts for about 30 percent of the total consumption of energy, and more than one-half of the petroleum used. Both the total energy consumed and the quantity of petroleum used rose steadily until 1974, when there was a substantial decline (as a result of the effects of the oil embargo). Total transportation fuel use increased at a rate of about 4.7 percent a year between 1965 and 1972, increased 3.3 percent from 1972 to 1973, and decreased by 3.2 percent between 1973 and 1974. (Source: U.S. Department of Transportation, Energy Statistics.)

Year	Household and Commercial		Industry		Transportation		Total	
	All Energy	Petroleum	All Energy	Petroleum	All Energy	Petroleum	All Energy	Petroleum
	%	%	%	%	%	%	(Trillions of BTU's)	
1960	29.9	24.5	41.7	23.8	28.4	51.7	38,220	20,067
1965	30.4	24.2	41.5	23.4	28.1	52.4	45,320	23,242
1970	30.4	21.8	40.1	25.6	29.5	52.6	55,911	29,614
1973	29.6	19.2	39.4	28.7	31.0	52.1	60,977	34,851
1974	29.3	18.2	40.0	28.8	30.7	53.0	59,320	33,414

sons between the two kinds of movement is hindered by the obvious fact that a given number of passengers is not the economic equivalent of a ton of freight.

The ton-mile is particularly troublesome. The biggest single problem associated with its use is the implicit assumption that the transportation service is homogeneous. On the supply side, the implication is that transportation service is continuously available, like electricity, and that facilities are continuously interchangeable. On the demand side, use of the ton-mile unit carries with it the erroneous assumption that all shipments are alike—that carrying one ton of coal a distance of one mile is the economic equivalent of transporting one ton of gold or oranges a distance of one mile. The ton-mile is a statistic that fails to take into account the quality of service, the resources required to provide it, the value added, or any other factor germane to the proper measure of output.

The major problem, of course, is in measuring the real economic cost of transportation services under different circumstances. In a smoothly functioning, perfectly competitive economy, relative prices would reflect the relative marginal costs. But it is well known that the production of transportation services is not conducted within a competitive environment; complex governmental regulations developed over the years have distorted the relationships between prices and costs of the different modes and have engendered a misallocation of resources in transportation. Many observers feel, for example, that highway, water, and air transportation have been overdeveloped in relation to rail and pipeline transportation. Pricing that reflected the real costs (including the scarcity value of fuel) would go a long way toward helping us deal with energy-use problems.

Use of the ton-mile statistic can lead also to erroneous conclusions about the fuel-consumption characteristics of different transportation modes. For example, for high-volume, long-distance movements over smooth terrain, rail transport will show greater energy efficiency than trucks in terms of ton-miles.

Table II

AIR POLLUTION EMISSIONS IN 1970 AND 1974

These emissions data, in millions of tons per year of pollutants, show that transportation is a major cause of air pollution. Overall, it contributes about 54 percent by weight of the total annual amount of pollutants. Reductions in carbon monoxide and hydrocarbon emissions between 1970 and 1974 are a result of emissions control techniques developed in response to the Clean Air Act Amendments of 1970. (Source: Statistical Abstract of the United States.)

Year	Pollutant	Fuel Combustion, Stationary Sources		Industrial Processes		Transportation		Miscellaneous	
		Tons $X10^{-6}$	%	Tons $X10^{-6}$	%	Tons $X10^{-6}$	%	Tons $X10^{-6}$	%
1970	CO	1.1	1.0	11.8	11.0	82.3	76.7	12.1	11.3
	HC	1.6	5.0	2.9	9.0	14.7	45.8	12.9	40.2
	NO_X	10.1	49.5	0.6	2.9	9.3	45.6	0.4	2.0
1974	CO	0.9	1.0	12.7	13.4	73.5	77.7	7.5	7.9
	HC	1.7	5.6	3.1	10.2	12.8	42.1	12.8	9.8
	NO_X	11.0	48.9	0.6	2.7	10.7	47.6	0.2	0.9

But trucks are still needed to perform the high energy-consuming parts of the complete job of transporting a commodity from one place to another. In considering energy efficiencies, one must be careful to compare, say, total truck movement from location A to location B with the equivalent truck–rail combination.

A true measure of output would reflect not only the real monetary cost of the transportation, but also the value of the kind of service provided. The "value added" by transportation service is a difficult quantity to measure, but ways should be found to incorporate it into the designations of transportation output.

THE DEFICIENCY OF ANALYSIS BASED ON AGGREGATE DATA

Obtaining meaningful data is, in various ways, a troublesome aspect of transportation energy conservation analysis. A common practice is to base recommendations on aggregate, or average, information. Aggregate data for energy consumed per ton-mile, for example, show that rail and water transport have much higher energy efficiencies than truck and especially air transport; and the usual conclusion is that shifts to rail and water and away from truck and air carriage should be encouraged. Such a deduction, however, cannot be made without more information. Average figures for energy efficiency neglect the fact that fuel economy is affected by the type and condition of equipment used, the load factor, the length of haul, and many other factors. A freight mode that exhibits high energy intensiveness in the aggregate (that is, averaged over all situations) may actually be the most energy-efficient in a particular situation.

What is needed are recommendations based on disaggregate information, rather than on a broad policy which might make a particular situation worse rather than better. Research in this area is just emerging and should provide useful guidelines for future analyses. For instance, in a recent study, Edward Morlok showed that goods movement by conventional train is generally more energy-efficient than piggyback trans-

Table III

SHORT-TERM ALTERNATIVES FOR TRANSPORTATION ENERGY CONSERVATION

Technological Objective	Administrative Alternatives
1. *Improve the flow of high-occupancy vehicles*	• Bus-activated signals • Bus-only lanes on city streets • Reserved freeway bus or bus/carpool lanes and ramps • Bus priority regulations at intersections
2. *Improve total vehicular traffic flow*	• Improved signal systems • One-way streets, reversible lanes, no on-street parking • Elimination of unnecessary traffic-control devices • Widening of intersections • Driver advisory system • Ramp metering, freeway surveillance, driver advisory display • Staggered work hours
3. *Increase car and van occupancy*	• Carpool matching programs offered by employers • Public information programs on carpools • Carpool incentives • Neighborhood ride sharing
4. *Increase transit patronage*	• Service improvements • Fare reductions • Traffic-related incentives • Express bus service from parking lots • Demand-responsive service
5. *Encourage pedestrian and bicycle modes*	• Pedestrian malls • Second-level sidewalks • Bikeway system • Bicycle-storage facilities • Pedestrian-actuated signals • Bicycle priority regulations at intersections
6. *Improve the efficiency of taxi service and goods movement*	• Improvement in efficiency of taxi service • Improvement in efficiency of urban goods movement
7. *Restrict traffic*	• Auto-free or traffic-limited zones • Limitation of hours or location of travel • Limitation of freeway usage
8. *Adjust transportation pricing*	• Bridge and highway tolls • Tolls at congested areas and road cordons • Increased parking costs • Fuel tax • Mileage tax • Vehicle-related fees
9. *Reduce the need to travel*	• Four-day work week • Zoning • Home goods delivery • Communications substitutes
10. *Restrict energy use*	• Gas rationing without transferable coupons • Gas rationing with transferable coupons • Restriction of quantity of sales on a geographic basis • Ban on Sunday and/or Saturday gas sales • Reduced speed limits

port, which in turn is more efficient than transport by trucks with twin trailers. However, it was also found that trucks are much less affected by undulating surfaces than trains are, especially at higher average speeds, and that the lighter the load, the more favorably trucks perform in comparison with either of the rail modes. The study concluded that the amount of fuel that can be saved by shifting freight from road to rail is probably overestimated and that, in fact, there may be no savings at all under some circumstances.

In this study, only line-haul movements were considered; to make an analysis complete, the ancillary services performed to produce line-haul movements should be included. In a recent study by Robert S. Reebie and Associates for the Federal Highway Administration, for example, an attempt was made to calculate the total energy required for transportation movements in the Portland–Los Angeles corridor. Fuel-consumption rates for forty-foot container equivalents were compared, taking into account tare weight, empty equipment movement, and circuitry in the corridor, and it was found that in the exceptional terrain of this corridor, "the most efficient rail service feasible with currently available equipment would use as much fuel per transportation unit as single trailer trucks do."

Studies such as these have only scratched the surface of the problem of assessing the energy-consumption characteristics associated with alternative transportation services. But already one major finding is emerging: Fuel conservation may be more effectively

Figure 3

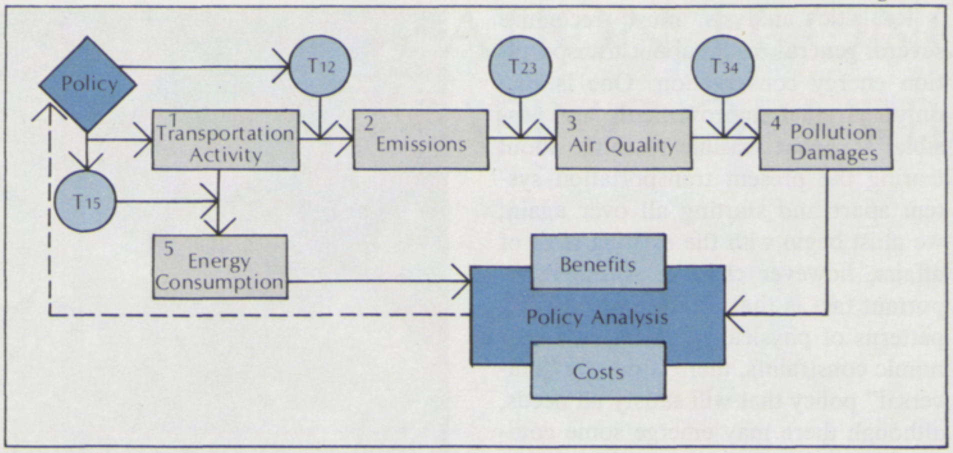


Figure 3. Schematic diagram of an idealized framework for analysis of the consequences of alternative environmental and energy management policies. This scheme is based on the idea that analysis for the establishment of national policies should take into account the interactions among the various objectives, and should have as its purpose the achievement of the best overall result at the least cost. Regional differences, not explicitly indicated in the diagram, are also important factors.

The five basic "quantities" of potential relevance are (1) the level of transportation activity, usually measured as number of vehicle miles per unit time; (2) the level of emissions, measured, say, in tons per day or year of CO, HC, and NO_x; (3) ambient air quality at a given point in time and space, usually measured as parts per million of pollutant; (4) pollution damages (social costs such as health effects), measured in dollars per year; and (5) energy consumption measured, say, in gallons per unit time or in the equivalent number of barrels of oil. The mathematical relationships of the system involve a set of transformation functions: T_{12} converts activity levels to emissions; T_{23} converts emissions to air quality; T_{34} converts air quality to damages; and T_{15} converts activity levels to fuel consumption.

achieved by adopting energy-saving measures *within* transportation modes than by focusing attention on strategies that emphasize shifts *between* modes.

EVALUATING ALTERNATIVES FOR ENERGY CONSERVATION

All of the many ways of coping with energy (and related) problems represent partial solutions. Most of the long-term alternatives for transportation energy conservation involve the development of new propulsion technologies or alternative fuels, and some require large amounts of capital investment. The major short-term options (shown in Table III) rely mainly on administrative decisions on how to implement technological objectives. A sensible approach to the formulation of an overall policy is to begin with a systematic and comprehensive analysis of the benefits and costs of each alternative, including distributional consequences.

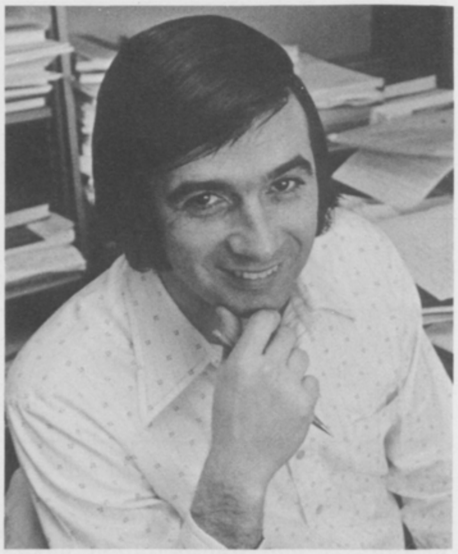
In performing the requisite evaluations, three important considerations must be kept in mind. First, technological alternatives need to be distinguished from administrative ones. As shown in the table, the alternative ways of implementing each technological objective are administrative; they can be called upon in any combination in order to effect the desired change. The problem is to select an appropriate mix of technological and administrative alternatives—a strategy—within the specified constraints.

A second requirement is that engineering feasibility must be distinguished from economic feasibility. Administrative alternatives frequently include low-capital options for accomplishing the same objectives that high-capital options would accomplish. Too much emphasis is sometimes placed on sophisticated and expensive technology (for example, new mass-transit systems) when less capital-intensive alternatives would suffice.

Finally, care must be taken to define costs and benefits in a broad social sense rather than in terms of the narrow economic criteria usually used in such evaluations. A good example is the issue of what speed limit should be established as a national standard. Those who favored reducing the speed limit on major highways to 55 miles per hour (a low-capital option) based their enthusiasm on the claim that not only is a substantial amount of fuel saved, but also substantial reductions in accidents and fatalities are achieved. There are also negative aspects of the policy, including the added amount of time required for both personal and business travel. Although the cost to industries and businesses as a result of upset schedules, overtime payments to drivers, etc., has never been calculated, it is surely substantial. An informed policy judgment cannot be made without comprehensive calculations of both the benefits and the adverse effects to society (or a segment of it).

A useful form for presenting information to decision makers is an impact–incidence matrix. Impacts can be divided into at least four categories with respect to any incidence (social, economic, or residential) group: (1) those that can be estimated in dollars (such as fuel savings and administrative costs); (2) those that can be estimated in dollars only indirectly (for example, the value of time); (3) those that can be estimated quantitatively, but not in dollars (for example, the number of lives saved or change in pollution concentration); and (4) those that can be expressed only in qualitative terms (such as required organizational or institutional changes, esthetics, or public reaction). Needless to say, there are many operational difficulties associated with such a tabulation for any given problem, but this does not mean that the analyses should not be attempted and carried as far as possible.

Realistic analysts must recognize several general truths about transportation energy conservation. One is that only marginal improvements are possible. It is not feasible to think about tearing the present transportation system apart and starting all over again; we must begin with the existing state of affairs, however chaotic. Another important fact is that because of differing patterns of physical, political, and economic constraints, there is no one "universal" policy that will satisfy all needs, although there may emerge some commonalities in the way problems are dealt with in different urban areas and geographical regions.



Frank J. Cesario, a specialist in urban transportation planning and public systems analysis, became an assistant professor of civil and environmental engineering at Cornell in 1974. He is a member of the transportation group in the Department of Environmental Engineering and serves as faculty representative for the University's Graduate Field of Regional Science.

Cesario received the B.S. degree in mechanical engineering from the University of Massachusetts in 1962, the M.S. in industrial and management engineering from Montana State University in 1965, and the Ph.D. in industrial and systems engineering from the Ohio State University in 1971. He also took graduate work at the University of Rochester. For three years before his appointment to the environmental engineering faculty here, he was at Cornell as a postdoctoral fellow in regional science and as visiting assistant professor of policy planning and regional analysis in what is now the Department of City and Regional Planning. During these years, he also functioned as a research associate in the Center for Urban Development Research (now the Program in Urban and Regional Studies).

His experience includes work as an industrial engineer with the Eastman Kodak Company, as a systems analyst with the United States Forest Service, and, for six years, as a senior researcher in sociotechnical systems at Battelle Memorial Institute.

His recent professional activities include participation in the teaching of short courses on transportation energy conservation conducted at several colleges and universities. He has recently served as consultant to the National Academy of Sciences, the Canadian government's Department of National Parks, and several contract research organizations.

His current research focuses on travel demand theory and spatial interaction modeling. He is currently working on a book, Economic Evaluation of Transportation Systems, *which is scheduled for early publication.*

TRANSPORTATION, ECONOMICS, AND THE SHAPING OF URBAN AMERICA

by Richard E. Schuler

What is an economist doing on the faculty of an environmental engineering department? To understand why this is so at Cornell, consider the dilemma of a transportation planner.

Assigned the problem of locating a thruway spur from the city's central business district to the suburbs, the planner will begin by weighing the various competing considerations. Transit for already established neighborhoods should be speeded and areas likely to expand should be served. At the same time, the topography should be favorable for low-cost road construction and the land costs should be kept as low as possible. An optimal solution will certainly require systematic, computer-aided calculations and a raid on the operations research analyst's bag of optimizing techniques. And if there is to be a serious effort to identify the areas of potential urban growth so that the highway will serve future as well as current needs, a location economist might be consulted.

The question posed by the planner is: Where will economic activity—housing, industry, and commercial

properties—be expanding? The likely answer from the economist is: Tell me where you're putting the roads and I'll tell you where the economic activity will be. This is the sort of dilemma that can result when experts from different disciplines look at the same problem from opposite viewpoints. Clearly, what is needed is a way of aligning their sights on the common goal.

A cynic might say that collaboration is unnecessary because if economic activity develops wherever the roads are built, then the transportation designer might just as well locate the highways at random. Is the transportation analyst really in the position of proclaiming a self-fulfilling prophecy? A quick review of the 1950s and 1960s, a period of rapid metropolitan expansion when expressways seemed to be transformed into six-lane parking lots immediately upon completion, appears to support this view. To be sure, even in those days of apparently unbridled growth there were a few dissenters among city planners and environmentalists, and perjoratives such as "slurbs" were coined to describe the results of urban growth and sprawl. These cautionary notes have been massively reinforced in the 1970s by the dramatic reductions in birth rates and in the formation of new households, the precipitous increase in fuel prices, and the escalation of construction costs.

As a result of these forces, overall urban expansion has ground to a halt in many parts of the United States. (Individual sunbelt cities are the notable exceptions.) Certainly, in a situation of slow or no growth, there is less likelihood that new housing develop-

"... overall urban expansion has ground to a halt in many parts of the United States."

ments will cluster immediately around a new roadway, and the transportation planner's job becomes more difficult. Indeed, serious reservations might be made about the need for any new freeways. A further set of unanswered (and still partially unasked) questions surrounds the issue of the need for our society to intelligently reduce some of its public facilities—a prospect that appears a virtual certainty for many specific localities over the next decade.

The planning of transportation systems is directly connected to these questions about the amount and location of future economic expansion. In terms of wasted resources, the penalties for inaccurate assessments loom ominously. It is clear that successful solutions must entail consideration of the private market responses to public sector decisions and recognition of their simultaneous nature.

THE HISTORIC INFLUENCE OF TRANSPORTATION FACILITIES

Historically, transportation technology has played a substantial role in characterizing urban areas. Indeed, one might argue that the process of urbanization could not take place without adequate means of conveying and distributing the necessary goods and services. If the wheel hadn't been invented, society would be dispersed and agrarian, and individuals would be much more self-sufficient. Of course, the wheel was invented, the transportation of commodities did become economically feasible, and specialization in production did take place. The fact that food and other necessities could be hauled from the hinterlands to urban places fostered the growth of cities, and by the first half of the twentieth century, all industrial societies had become urbanized.

In effect, people and enterprises located in patterns which seemed to reflect their attempts to minimize transportation costs. Leon Moses and H. F. Williamson, Jr., have made an interesting analysis (in a paper published in 1967 by the *American Economic Review*) of why industry in the United States clustered near wharves or rail terminals at the beginning of the century. The determining factor was transportation costs: It was cheaper to move workers on horse-drawn trolleys from their homes to the center city than it was to move raw materials by wagon to outlying factories (and to reverse-haul the finished products). This was true even though land costs for factories would have been much smaller if they had been scattered throughout residential areas and even though lower wages might have been possible because of the shorter trips to work. Trolley systems were economical only for passenger transport because while people could walk between their homes and the tracks and from there be transported to and from work on the low-friction, horse-drawn vehicles, raw materials and commodities had to be hauled door to door and the trackage required for a widespread freight trolley system would have been prohibitive. The subsequent development of rail commuter systems in the largest, most densely populated communities reinforced this pattern of centralized employment. (It might be noted that political organization had something to do with the construction of rail mass transit; New York City's elevated and

Economic development as a result of highway-building is exemplified by this area near Cornell University, which was semi-rural before the road (Route 13) was rebuilt in the mid-sixties as a four-lane highway. After the time this photograph was taken, an overpass was added at the intersection to help accommodate the increased traffic. Near the intersection there are now three shopping centers (the construction of the largest and most recent one was a controversial issue in the county), an apartment complex, three motels, and a number of business establishments, including automobile agencies, gas stations, and restaurants.

subway lines, for example, were designed to facilitate movement between the central city and the then sparsely populated boroughs of Brooklyn, Queens, and Bronx, all of which were within the city limits.)

THE CHANGES BROUGHT BY AUTOMOBILES AND TRUCKS

The internal combustion engine disrupted these transportation patterns. The substitution of trucks for horse-drawn wagons cut the cost of hauling materials in half and provided a stimulus for decentralization of industry; this trend was enhanced by the construction of interstate highways which obviate the need for access to railways for many firms. Also, continued technological progress led to steadily rising incomes and it became possible for workers to own cars and live in suburban homes.

Rising wages also brought the realization that time is money, a fact that doomed many forms of mass transit in all but the largest cities. About a decade ago, the expectations of many advocates of intraurban rail mass transit were shattered by a simple statistical calculation. In their book *The Urban Transportation Problem,* John Meyer, John Kain, and Martin Wohl demonstrated that in order to beat the average *door-to-door* time required for workers to commute by car, a mass transit facility would have to provide an average speed of nearly 150 mph in a typical forty-minute commute.

Only in an enormous and densely-populated city like New York can sufficient subway lines be built and trains run frequently enough to keep the time required to get to, wait for, and walk from the train within reasonable bounds. In New York City the subway does effectively compete with the automobile (street congestion and high parking costs, as well as travel time, are factors). But there is only one city the size of New York in the United States—Chicago, the next largest, has a population less than half the size—and some people predict that eventually there will be none. This is why the emphasis in recent research and development sponsored by the De-

Right: Professor Schuler (at left) is a member of the faculty group involved in transportation studies at the School of Civil and Environmental Engineering. His colleagues include two other authors of articles in this issue: Professors Cesario (center) and Meyburg (at right). Below: a senior member of the group, Gordon P. Fisher, was on sabbatic leave at the Instituto de Ingenieria, Ciudad Universitaria, in Mexico, during the fall term. Fisher's main area of interest is urban goods movement. At Cornell he has served as director of the Center for Urban Development Research and is now codirector of the Program in Urban and Regional Studies.

partment of Transportation has been on flexible bus systems, and in particular on demand-responsive systems, such as dial-a-ride, which can provide door-to-door service.

THE PLACE OF ECONOMICS IN TRANSPORTATION STUDIES

Many engineering students arrive at Cornell with a preconceived notion that economics is important in the study of transportation because of the need to understand and project the costs of future facilities. Actually, economics plays a much more significant role than this. Since the basic law of economics is that of supply *and* demand, the amount of commodities consumed or services purchased and the prices actually paid reflect the coincidence of wants and available technology. Engineers have usually excelled in adapting new technologies and in developing least-cost solutions to specific problems. They really need little help from economists in lowering costs. Where technological efforts have occasionally gone awry is in the assessment of future patterns of demand and of how the characteristics of supply might in turn alter historical wants. Nowhere has this been more true than in urban transportation planning, and this is why the program for Cornell's transportation students places a major emphasis on demand analysis.

In a current Cornell research effort, for example, the investigators are attempting to analyze the various subjective ways in which travelers value the time they spend on a trip. Identification of these values is important, since it affects the traveler's demand for various alternative modes and routes. The traditional approach in such a study would be to assign travel time a dollar amount almost as high as the individual's hourly wage, on the assumption that an hour spent commuting is at the expense of an hour of gainful employment. Actually, however, it is extremely difficult to determine the earnings an individual might forfeit because of time required for commuting: some people work for a proscribed forty-hour week, and some can work as long as they like. And then there are some commuters who enjoy the ride and do not view it as having any cost other than the price of a ticket. The fact that individual valuation of travel time is reflected not only by what mode of travel is chosen, but also by where people choose to live and how far they commute, adds additional complexity. Of course, decisions on where to live are influenced by land costs, which are lower at greater distances from employment centers. But these cost differences are partially generated by an unwillingness to pay as much for distant land because individuals value time as a commodity. Once again the simultaneous nature of answers to urban transportation and land-use patterns is apparent.

In other recent graduate dissertations at Cornell, attempts have been made to interpret commuters' preferences in terms of comfort and convenience as well as the more traditional criteria of travel time and out-of-pocket cost. If population pressures are reduced in our society in the future, the concomitant increase in per capita income may lead to a greater emphasis on hedonistic pleasures and a lessening of concern over time and costs. It may be even more important in the future than it is now for planners to be able to discern and estimate the strength of comfort-related demand factors.

The integration of economic analysis of demand factors into planning strategies is, of course, important in a much broader context than just urban transportation analysis. Consider, for example, some competing concerns of Cornell's Department of Environmental Engineering, which includes both transportation and sanitary engineering specialists. Improved water supply, sewage treatment, and environmental ambiance are factors that enhance urban living, and they provide an impetus toward population concentration or at least render high-density habitation less onerous. At the same time, improved transportation facilities and speedier intraurban trips favor an offsetting tendency toward urban sprawl. The municipal manager and the public are caught in the middle of this tug-of-war. They must decide what technology to buy, and could use some advice from planners who are knowledgeable about the economic implications of the alternatives. Ultimately, engineers and designers must be concerned with the question too. The choices are sure to influence the future shape of urban America.

Richard E. Schuler brings a background of engineering, business, and economics to his research and teaching in the areas of public sector problems and the interaction between local government and urban development, transportation, and environmental quality. At Cornell he holds a joint appointment as assistant professor of environmental engineering in the College of Engineering, and of economics in the College of Arts and Sciences.

Schuler received the degrees of B.E. in electrical engineering from Yale University, M.B.A. in business from Lehigh University, and M.A. and Ph.D. in economics from Brown University. After graduating from Yale in 1959, he spent eight years in engineering, marketing, and administrative positions with the Pennsylvania Power and Light Company, followed by two years as a fuels and energy economist for the Battelle Memorial Institute. He joined the Cornell faculty after completing his graduate studies in 1972.

In addition to his academic activities, Schuler serves as a consultant to the Institute for Energy Analysis at Oak Ridge, to the Schenectady Community Action Program as an adviser on New York State utility rate costs, and as a referee for the American Economic Review *and the* Journal of Political Economy. *He is registered as a professional engineer in Pennsylvania.*

RAILROAD ABANDONMENT:

Can the Local Road System Take the Impact?

by Lynne H. Irwin

For more than one hundred twenty-five years our nation's railroads have been the backbone of our transportation system. They were the "highways" along which development proceeded at a rapid pace during the period from 1850 to 1910. They served us well during two world wars and several more recent "conflicts." Today they are still a major part of our transportation system.

Since 1916, however, the railroads have been in a state of gradual decline that has accelerated in recent years. Large sections of track are being abandoned, and although this may make sense from the viewpoint of the railroad companies, it may not from the perspective of regional and national economics, and of the transportation system as a whole. The place of railroads in our national system is an issue with greater dimensions than the single criterion of operational economy that is now being used as the basis for decisions on abandonment.

One of the specific issues involved in railroad abandonment is the impact it has on the highway system, which has to absorb most of the extra load. Especially important in regard to the transport of agricultural products and supplies are secondary roads, which are often inadequate for heavy use. To agricultural and highway engineers, this is a compelling problem that should be taken into account in decisions affecting the future of our railroads.

THE PLACE OF RAILROADS IN OUR NATIONAL SYSTEM

One of the most important functions of the railroads at the present time is to transport agricultural and industrial commodities not only for distribution to markets within the United States, but also to ports for export. The effect of agricultural export on our nation's financial health is clearly shown by the fact that during the period 1970 to 1974, the only year we experienced a positive trade balance was 1973, when the Soviet grain deal was consummated; examination of the statistics for that and the previous year show that all but two percent of the favorable trade balance in 1973 can be explained by the increase in agricultural exports.

In general, the railroads offer considerable savings for long-haul freight movement because of their efficiencies in terms of scale and energy utilization. It is generally accepted that railroads are most efficient when haul distances exceed two hundred miles; truck transportation offers economies for shorter haul distances. Increased utilization of containerization should encourage intermodal transport (piggybacking) for intermediate-distance hauls because of reduced transfer costs. But optimal use of these freight transport modes depends on the continued availability of railroad service.

THE PROBLEM OF RAILROAD ABANDONMENT

During the latter part of the 1880s and the first quarter of this century, United States railroad companies greatly overbuilt their trackage, extending service to rural areas through many miles of spurs and feeder lines. This overbuilding was especially prevalent in the northeastern and midwestern parts of the country.

The year 1916, when there were 254,000 miles of line-haul track in the

Table I

UNITED STATES RAILROAD STATISTICS

	1950	1960	1970	1973
Number of companies	471	407	351	331
Mileage of line-haul track (thousands)	224	218	206	201
Locomotives in service (thousands)	43	31	29	30
Freight cars in service (thousands)	1,746	1,690	1,454	1,387
Passenger cars in service (thousands)	37	26	11	7
Number of employees (thousands)	1,237	793	577	533
Net operating income (millions of dollars)	1,055	595	506	725

Source: Bureau of the Census, *Statistical Abstract of the United States* (1975)

United States, marked the peak of railroad mileage in this country. By 1973 the total mileage had decreased to about 201,000 (see Table I). Bankruptcies of the major northeastern rail companies resulted in Federal reorganization into the Consolidated Railroad Corporation (ConRail), but the trend toward retrenchment has continued. In 1972 the United States Department of Transportation recommended the abandonment of an additional 78,000 miles of track, nearly 40 percent of the present system.

Since 1920 the Interstate Commerce Commission (ICC) has been charged with the responsibility of evaluating applications for abandonment of railroad trackage. There have been many of these, and most of them have been approved. From 1960 through 1973, the ICC received 1,937 applications to abandon a total of nearly 31,000 miles of track; the overwhelming majority of these requests were granted, some were dismissed without decision, and only forty-seven were denied. In the last five years, there has been a significant increase in the number of applications received each year; pending in July of 1974, for example, were 340 cases involving 6,694 miles of track. These sections were located in nearly every state in the nation, but the largest portions were concentrated in the corn belt and the Northeast. The continued approval of abandonments on this scale is sure to cause difficulties in moving farm products to market and to ports for export, and should be a matter of concern to us all, especially our Federal legislators.

HOW SHOULD ABANDONMENT APPLICATIONS BE ASSESSED?

The procedure used by the ICC in evaluating abandonment applications involves at most a calculation of annual revenues and operating expenses for a particular section of track. When these calculations show a deficit, an economic case to support abandonment is presumed to have been made. Where a section of track is used for less than thirty-four carloads per mile annually, the railroads are relieved of furnishing proof of loss under the so-called "thirty-four car rule." This provision is based

Symbolic of an impending major transportation problem are these abandoned railroad tracks (below) and this inadequate bridge (right), which were photographed in Tompkins County, New York. Abandonments of railroad lines in agricultural areas are resulting in increased heavy traffic on inadequately constructed farm-to-market roads with narrow, weak bridges.

on a study by the Federal Railroad Administration which showed that a volume of business below the thirty-four carload level is at the lower bound of financial viability; the same study showed that where more than seventy carloads per mile per year are hauled, there is a high probability of financial solvency.

A serious criticism of this evaluation procedure is that it considers only the economics of track operation from the point of view of the railroads. It does not in any way consider the effects on regional economic development, or the availability and adequacy of alternate means of transportation. This criticism is directed at the lack of breadth in the information sought by the ICC and does not imply that the concept of considering economics is without merit. The continued operation of uneconomical portions of the railroad system for prolonged periods of time is obviously not in the best interests of the nation; but neither is it a good policy to permit abandonment of rail service where adequate alternative modes of transportation, particularly for movement of goods, are not available.

A better ICC policy would be to consider the economy *as a whole* in the abandonment evaluation. If alternate forms of transportation are found to be inadequate, approval of the application should be withheld pending improvement of the situation. If it is found that delaying abandonment would be in the national interest, then public money should be made available through the Department of Transportation to offset financial loss by the railroads and to finance the improvement of alternate means of transport. This would prevent adverse effects on both the local and the national economy, both in the short term and over a period of years.

Before such a policy could be adopted, it would be necessary to explore the capabilities of the total transportation system. While there certainly have been no definitive studies in this regard (which points to an area of needed research), it can be observed that if light-density rail lines are abandoned, most, if not all, of the freight they handled will probably have to be moved initially by truck. Increased trucking might not be a significant factor in urban, industrial areas, but in rural, agricultural regions the problems would be serious. Heavily loaded trucks would have to begin their journeys to market over what are presently light-duty, local roads, and shipments of feed grains and fertilizer to farms would probably shift to fewer, heavier truck deliveries. The secondary road system is inadequate for this kind of use and in many areas significant capital investment would be required to make the needed improvements.

Table II

UNITED STATES HIGHWAY STATISTICS (1973)

	Roads of All Surface Types		Unsurfaced or Low Load-Bearing Roads	
	Mileage	Percent	Mileage	Percent
Rural				
State primary*	409,834	11	122,935	4
State secondary	272,807	7	195,700	7
State parks etc.	27,920	0.7	22,626	0.8
County	1,727,834	45	1,575,534	53
Town and other local	521,612	14	493,811	17
Federal parks etc.	215,747	6	208,341	7
Municipal				
State primary*	64,343	2	6,271	0.2
State secondary	17,249	0.5	8,852	0.3
Local	549,537	14	333,063	11
Total	3,806,883	100	2,967,133	100

*Includes 42,748 miles (33,782 rural and 8,966 urban) of interstate highways

Source: *Highway Statistics* (Federal Highway Administration, 1973)

PRESENT INADEQUACIES OF OUR SECONDARY ROADS

The two principal shortcomings of the farm-to-market road system are inadequate bridges and weak or seasonally weak pavements. In addition, significant numbers of these roads are constructed to inferior standards, and there are many unsafe rail crossings and high-accident segments.

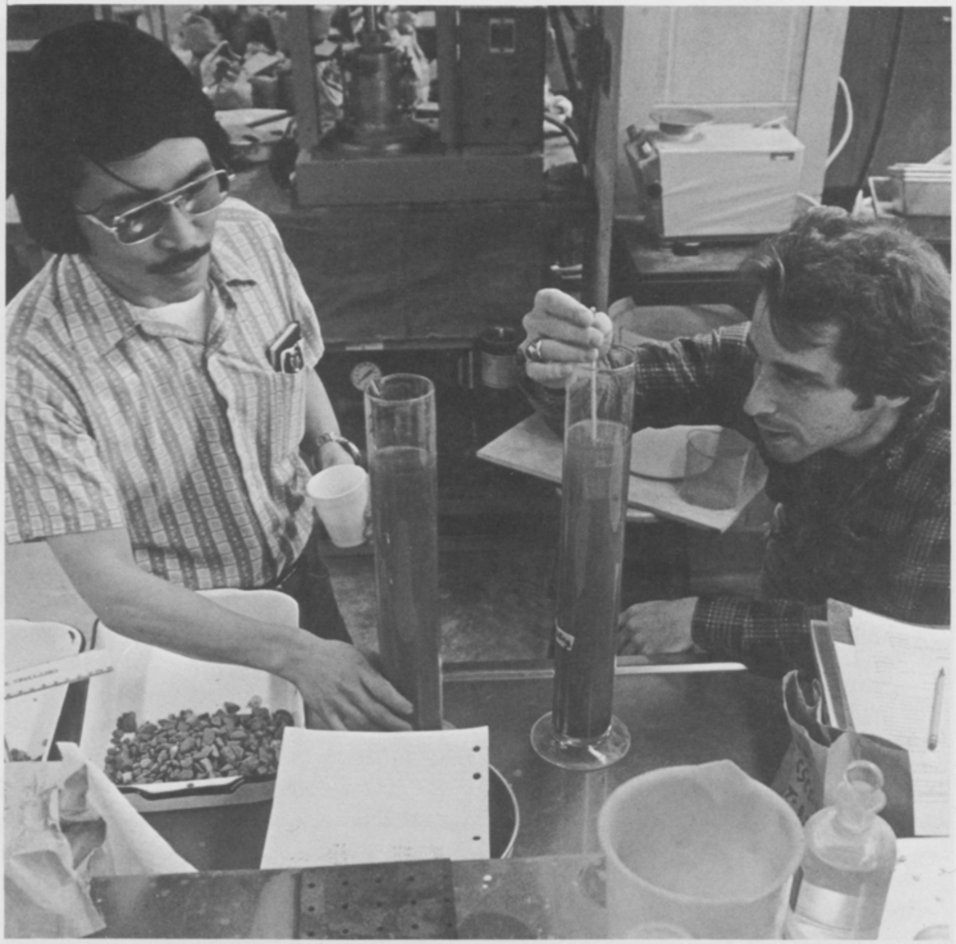
Of the 3.8 million miles of highways and streets in the United States, only about 630,000 miles are in urban areas; the remaining 3.2 million miles are rural (see Table II). County, town, township, and other local jurisdictions carry the responsibility for 71 percent of the rural system, amounting to 2.2 million miles of mostly low-volume, secondary roads; only 265,000 miles of these rural roads under local jurisdiction are on the Federal-aid program. Of the 2.2 million miles of county and local rural roads, 2.0 million have been rated by the Federal Highway Administration as being of low load-bearing quality. Thus, approximately 90 percent of the rural secondary road system could be described as structurally deficient.

In 1971 the Federal Highway Administration reported that of the slightly more than 563,000 bridges in the United States, about 89,000 were structurally or functionally deficient. About one-fourth of the inadequate bridges were part of the Federal-aid highway system, and the remaining three-fourths were in state and local systems.

One might properly ask how we let our secondary road system get into such a state of inadequacy and disrepair. While there are many facets to an answer to such a question, it certainly must be recognized that throughout most of the country, the secondary road system has evolved to its present state by continuous upgrading from an even more inferior condition. If these roads are still inadequate, it is because the money available to upgrade them has not been sufficient to keep up with the increasing loads and traffic, and with progressively more stringent standards. In those instances in which secondary roads have deteriorated from a previously adequate condition, again the reason can usually be traced to a lack of funds for maintenance and reconstruction.

METHODS TO IMPROVE SECONDARY ROADS

In many areas of the United States, the supply of good quality road materials is rapidly diminishing, partly because of actual depletion of gravel deposits and partly because of restrictive environmental-protection legislation which may preclude the use of available materials. As a consequence, the cost of the remaining marketable supply has escalated at the same time that many highway agencies have been faced with tighter budgets because of recession and inflation. Under such circumstances, the use of soil stabilization methods becomes increasingly attractive. The addition of relatively small amounts of chemicals such as cement, lime, asphalt, and salt can improve the strength of road materials to the extent that it becomes possible to use lower quality gravels, or even to stabilize sufficiently the *in situ* road materials.



Highway research at Cornell focuses on the development of improved materials for roads and methods for evaluating highway pavements.

Above: Graduate students Steven Kaminaka (left) and David Mountner collect data on stabilized soils.

Left: Laboratory technician Charles D. Ditmars operates an automatic soil compactor in which he makes test specimens of road materials that have properties closely resembling field-compacted materials. The low-cost, hydraulic machine was developed recently by Ditmars and Professor Irwin.

"... Federal economic policy in the area of commodity transportation is not being shaped in terms of overall needs."

Research studies at Cornell are concerned with these possibilities. Current projects include the development of innovative construction techniques, study of the possible use of industrial waste products such as fly ash as soil stabilizers, and investigation of ways in which the correct amount of stabilizer for use with various types of gravel can be determined.

NEW TECHNOLOGY FOR THE EVALUATION OF ROADS

Until recently we have had only limited and inexact means of rating the structural adequacy of roads. Accordingly, the deficiencies suggested by the data in Table II are based solely on categorization by pavement type and thickness, not on any *measurement* of structural strength. Yet we know that a road founded on a well-drained soil in the southwest United States is more likely to have adequate strength than a road of the same material and thickness built on a frost-susceptible northeastern soil.

Equipment and methods of data analysis now being developed will permit highway agencies (or the ICC) to make rapid measurements of the structural strength of a road. Field test equipment includes a surface vibrator that applies a cyclic load to the pavement, generating a deflection basin; with a knowledge of the layer thicknesses, fundamental properties of the pavement can be calculated from the surface deflections using layered elastic theory computer programs. As a final step, the maximum load that can be applied without overstressing the pavement can be calculated. Because this field test equipment is easily portable, many tests can be performed along a road in a short time. Although the equipment is expensive, several consulting engineering firms are offering the testing service, thereby reducing the cost to individual highway agencies. There is a need to improve the efficiency of the computer programs to reduce the cost of the data analysis, but this should not be difficult. It is possible to foresee an inexpensive, nondestructive method of pavement evaluation which could be used to study the characteristics and diagnose the structural needs of our roads.

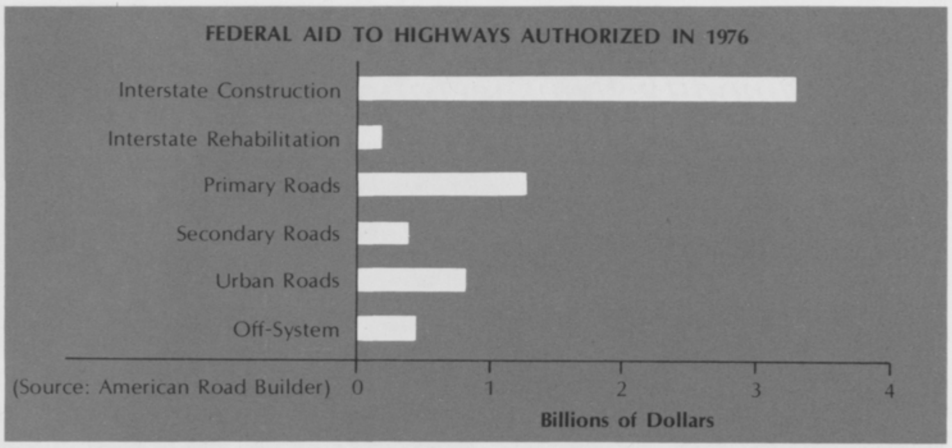
Cornell is contributing to this area of research through efforts to develop lost-cost equipment for measuring pavement deflection. If this work is successful, it will make it possible for many more highway agencies to perform their own pavement investigations.

FUNDING FOR CONSTRUCTION AND IMPROVEMENT OF ROADS

Historically, the Federal government has assumed responsibility for the nation's overall road system. The initial Federal-aid highway act of 1916 provided money for the improvement of rural roads to permit delivery of mail and to "get the farmer out of the mud." In 1921 the Congress established the Federal-aid primary road system (known as the 7-percent system), and in 1944 the Federal-aid secondary system was initiated.

With the establishment of the Highway Trust Fund in 1956, significant appropriations for the construction of an Interstate highway system became available. Between 1956 and 1974, the Federal government invested $90 bil-

Figure 1



Above: Although the nation's rural roads are carrying an increasing amount of agricultural and industrial commodities as railroads decline, their share of Federal highway funds remains low. Only 6 percent of the total authorized in 1976 was designated for secondary roads.

lion in the Interstate system, which comprises about 42,500 miles (about one percent of the total mileage of roads and streets) and which carries about 20 percent of the total traffic. During the same period, expenditures for all other Federal-aid primary and secondary road programs amounted to about $37 billion, for a total of more than 850,000 miles of road.

In the past few years, however, there has been a shift in priorities. The 1973 Federal-aid highway act required that "after June 30, 1976, the Federal-aid secondary road system shall consist of rural major collector routes." The anticipated result of this requirement is a reduction of mileage in the secondary system from 265,000 miles to under 100,000 miles. Most of the reduction will occur in county and local jurisdictions, and financial responsibility for this mileage will revert to local governments; very few miles of farm-to-market roads will remain in the reduced Federal-aid system. The problem of inadequate bridges has been recognized to the extent that since 1975, a limited amount of Federal money has been available for replacing deficient bridges that are not in the Federal-aid system; the funds are insufficient, however, to satisfy the needs.

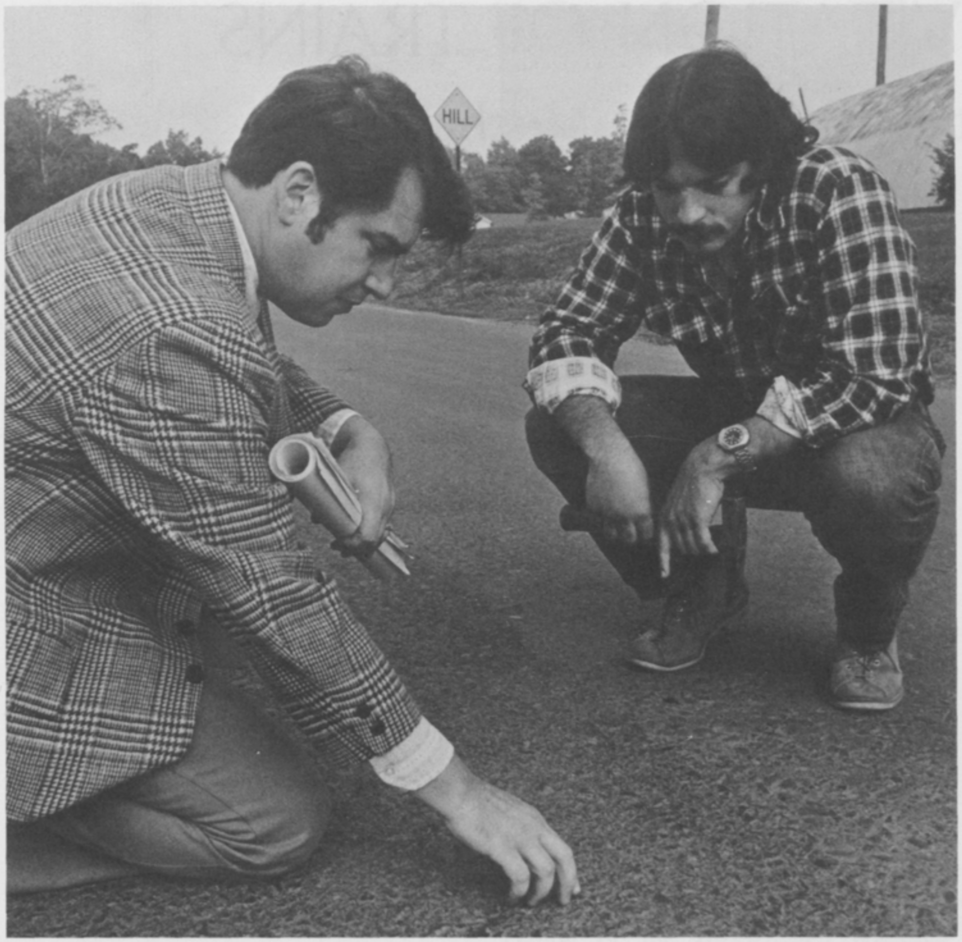
The 1976 Federal-Aid Highway Act allocates 54 percent of the total funds for the Interstate system, 20 percent for the state primary system, 12 percent for urban streets, 8 percent for off-system improvements, and only 6 percent for secondary roads (see Figure 1). A portion of the off-system funds may go for spot safety improvements on secondary roads.

Clearly, the Federal government is reducing its financial responsibility for improving local streets and roads, including low-volume, farm-to-market roads. It is apparent that financing for secondary roads is presently considered to be a local responsibility, despite the increasing importance of the secondary road system in the marketing of agricultural products as railroad abandonments proceed unabated.

PROVIDING FOR OVERALL TRANSPORTATION NEEDS

The essential problem is that Federal economic policy in the area of commodity transportation is not being shaped in terms of overall needs. The trend is actually to decrease rather than augment Federal support for the secondary road system at the same time that railroad capacity is being cut back.

As we have seen, an immediate need is for the ICC to revise its procedures for evaluation of railroad abandonment applications, delaying approval until satisfactory roads or other substitute means of transport are made available. If this procedural change is made, measures must also be adopted to protect the railroads from further loss of revenue during the interim period prior to abandonment.



At a demonstration site on the Cornell campus, Professor Irwin (left) and graduate student Michael Cowell examine the surface of a low-cost, cold-mix paving material for use on local roads. Several different types of pavement surface and base at this site show promise of providing improved riding quality and long-term economy; a further advantage of the cold-mix materials is that they require less energy for preparation. The test strips were laid during an annual conference for New York State county and township highway superintendents, held on campus last summer; the site will be inspected during this summer's conference.

Concurrently, funding policies should be adapted to ensure adequate means of transporting commodities, especially agricultural products and supplies. Specifically, Federal funds should be used to accomplish needed reconstruction of local roads as these become an increasingly important part of the national transportation network. Federal departments must recognize that since the cost of farm products in foreign and domestic markets is determined in part by the cost of transportation, the burden of financing local farm-to-market roads should not be exclusively the responsibility of local governments. In addition, studies of the unique engineering problems of low-volume roads should be encouraged through research support.

The future of the railroads in the United States is an issue that cannot be separated from other aspects of freight-transportation planning. The formulation of a more rational national transportation policy depends on a broad program of analysis and research.

Lynne H. Irwin, assistant professor of agricultural engineering, is a specialist in highway design and engineering. In recent papers and talks before national meetings, he has brought attention to the impact of railroad abandonment—the subject of this article—and to the need for more secondary-roads engineers.

His research has included work on the design and evaluation of highway and airfield pavements, soil stabilization, highway drainage design, and the use of waste materials in road construction. At Cornell he has also worked in a program on transportation policies for developing nations.

Irwin studied at the University of California at Berkeley for the B.S. and M.S. degrees in civil engineering, granted in 1965 and 1966, respectively, and received the Ph.D., also in civil engineering, from Texas A&M University in 1973. Before joining the Cornell faculty in 1973, he taught for three years at California State University at Chico. He has also worked as a consultant and served as an expert witness on problems of highway engineering and pavement design. He is a member of a number of professional organizations, including the Transportation Research Board of the National Research Council, and is licensed as a professional engineer in Texas.

MAGNETIC LEVITATION OF TRAINS

And Related Possibilities in Magneto-Mechanics

by Francis C. Moon

To skim over the ground with no visible means of suspension has long been a dream of science fiction writers and of those who believe in the power of science. Such a believer was Benjamin Franklin, scientist and statesman, who mused on the future of land transportation in the United States while the nation was still being formed. "The rapid progress true science makes occasions my regretting sometimes that I was born too soon," he wrote. "It is impossible to imagine the height to which may be carried in a thousand years the power of man over matter. We may perhaps learn to deprive large masses of their gravity, and give them absolute levity, for the sake of easy transport."

Now, less than two hundred years later, test vehicles separated a few centimeters from guideways by the magic of magnetism can carry passengers over the ground at speeds up to four hundred kilometers an hour. Revenue-producing magnetically levitated trains appear certain to become a reality in at least a few countries where intensive development is under way.

Above: A Japanese magnetic-levitation (MAGLEV) test vehicle weighing 3,250 kilograms is based on the "repulsive" lift concept. The pods on the side of the vehicle carry superconducting magnets. The "track" consists of loops of aluminum fixed to the guideway. The vehicle is propelled by a linear induction motor (LIM).

Left: A low-speed MAGLEV "people mover" was built in June, 1972, in the United States by Rohr Industries. This vehicle uses "attractive" lift magnets integrated with a LIM for propulsion and levitation.

> *"They simply ride on a magnetic field. The logistics of it work just like a railway system . . . But the tracks are magnetic, nothing at all like railway lines. The great thing about it is that it's all silent, and it's all computer controlled."*
>
> —A description of life in the year 6000, in *October the First Is Too Late* by astronomer Fred Hoyle.

INTERNATIONAL INTEREST IN VEHICLE LEVITATION

The first type of levitated vehicle actually constructed was the tracked air-cushion vehicle (TACV), which was under development in France, Great Britain, and the United States in the 1960s. These efforts died for one reason or another, including technical difficulties such as excessive noise. But part of the demise of the TACV may be attributed to the success of research on magnetic levitation (MAGLEV).

This research, conducted in the United States, Japan, West Germany, and Canada, sought to demonstrate the feasibility of using magnets to levitate vehicles and propel them at speeds up to 480 kilometers per hour (300 mph). The studies ranged from experiments in the United States in which small models were levitated on rotating wheel tracks to a full-scale demonstration in West Germany in which a twenty-ton test vehicle was suspended and propelled on a track three hundred meters in diameter. The results of this research clearly demonstrated the feasibility of magnetic levitation as a transportation option.

In this country, the main centers of research on MAGLEV were initially at the Ford Motor Company, the Massachusetts Institute of Technology (MIT), and the Stanford Research Institute. A group at Stanford, for example, built a two-meter levitated sled using superconducting magnets. My own interest in MAGLEV was sparked by an article published about ten years ago by James Powell and Gordon Danby of the Brookhaven National Laboratory, who proposed using superconducting magnets on a train to achieve levitation above an electrically conducting guideway. At the time, I was a graduate student at Cornell, working on the instability of elastic materials in magnetic fields. Later, at Princeton, I built a small levitated model and studied possible instabilities in MAGLEV vehicles.

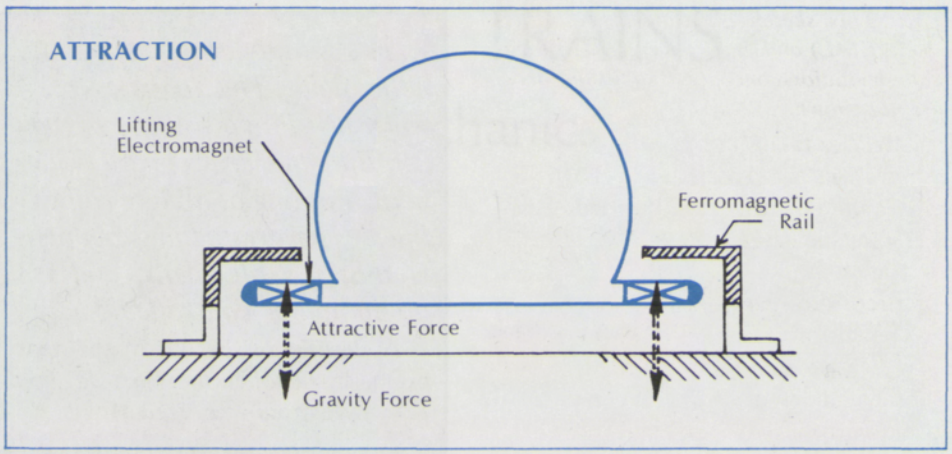
For a time, United States efforts in high-speed ground transportation were directed mainly toward a system for the Northeast corridor. However, the financial problems of the nation's railroads have preoccupied the minds of Washington planners to the point where high-speed passenger transportation is no longer a goal of the Federal Rail Administration. Except for a few paper studies and the small experimental effort here at Cornell, MAGLEV research has been sidetracked in the United States. In contrast, officials in Japan and West Germany are so convinced of the merits of MAGLEV that those countries are now spending millions of dollars on its development for future land transportation systems.

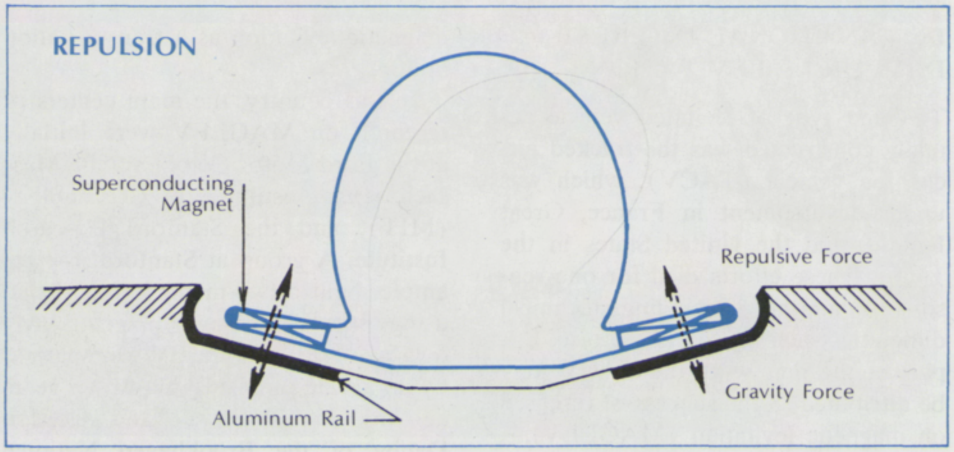
HOW MAGNETIC LEVITATION IS USED FOR TRAINS

There is a limit to how fast conventional wheeled trains can go. At speeds greater than about three hundred kilometers an hour, the interaction between steel wheel and rail causes dynamic problems, including loss of traction, and the need arises for some means of noncontact suspension. This can be provided by a MAGLEV system, in which electric and magnetic fields are used to suspend, guide, and propel a vehicle along a guideway.

At the present time there are two principal methods for suspension and two competitive propulsion systems.

In the so-called "attractive" method of suspension, ordinary electromagnets on the vehicle lift the train up toward a ferromagnetic rail. To prevent the vehicle from slamming against the rail and to maintain a distance of one to two centimeters between the vehicle and the rail, the currents in the electromagnets are adjusted automatically by a feedback control system. This is called electromagnetic levitation (EML). The "repulsive" method of suspension uses a nonferromagnetic guideway made of a material such as aluminum, and a number of superconducting magnets—perhaps eight—on the vehicle. These moving magnets, each of which carries a current of the order of 10^5 ampere-turns, electrodynamically induce currents in the guideway and produce repulsive forces between it and the magnets. This electrodynamic levitation method (EDL) has the advantage of a larger gap—up to twenty or thirty centimeters—between the vehicle and the guideway.





Both EML and EDL suspension methods have been used in test vehicles built by the Japanese and German research teams, and low-speed versions of EML-type vehicles have been built by Rohr and by General Motors in this country.

The two propulsion systems under study are based on the linear induction motor (LIM) and the linear synchronous motor (LSM). In the United States, the Garrett Corporation has developed a LIM motor that has propelled a wheeled vehicle at speeds up to four hundred kilometers per hour. A system based on the integrated repulsive levitation and the LSM propulsion concepts was developed by MIT until funds were cut off in 1974.

DYNAMIC INSTABILITIES: A POTENTIAL PROBLEM

A problem that must be overcome before MAGLEV technology can be successfully developed is that of dynamic instability. While several passenger-carrying MAGLEV research vehicles have been tested, they have been run for short distances only, and dynamic

Left: This sketch illustrates the "attractive" (EML) and "repulsive" (EDL) magnetic-levitation concepts. Propulsion forces are not shown.

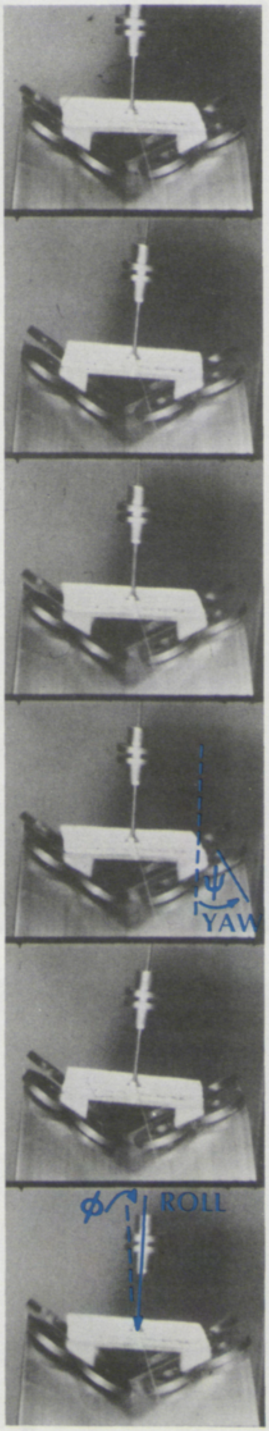
instabilities take time to build up. More research in the dynamics of magnetically levitated vehicles is needed, especially for the design of vehicles intended to travel at speeds greater than four hundred kilometers per hour.

The history of aircraft development is indicative of the problems that are anticipated with MAGLEV vehicles. Some early attempts at powered flight —by Langley in 1896 and by Santos-Dumont in 1898—failed because the aircraft had stability problems and went out of control. One of the important contributions of the Wright brothers in the early 1900s was the addition of the proper control surfaces to permit stable flight. With each increase in aircraft speed, new instabilities appeared and had to be analyzed and remedied on the basis of new research. Aeroelastic flutter, for example, was not properly understood until the 1930s and 1940s. Even in the jet and rocket age, dynamic instabilities such as the engine-wing instability of the Electras and the "Pogo" instability in the Saturn rockets continued to plague aviation.

MAGLEV test vehicles have yet to prove stable for long periods of time (although the Germans may demonstrate stable flight in tests on their 300-meter-diameter track). Furthermore, possibilities for dynamic instabilities are suggested by tests on models: films of a test model at MIT show a roll-yaw divergence, the Stanford test sled exhibited lightly damped pitching motions, and a yaw-roll flutter has been observed in my laboratory on a small model in a rotating guideway.

MASS ADDED

INSTABILITY DEVELOPS



Left: This 16-mm film shows coupled roll and yaw dynamic instability in a magnetically levitated model on a rotating wheel. An added mass (in the top frame) leads to oscillating yaw and roll motions. Model tests such as this are conducted in Professor Moon's laboratory to study the effect of magnetic forces on vehicle stability.

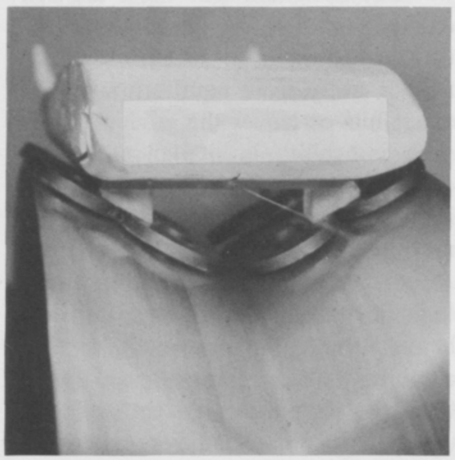
DESIGNING FOR STABILITY AND RIDE QUALITY

A MAGLEV vehicle, like an aircraft, must be designed for a particular cruise height; it must be centered over the guideway; and it must have sufficient stability to keep within the guideway and to minimize accelerations in the passenger compartment. The magnets and guideway must be able to generate sufficient restoring forces when disturbances such as wind or track irregularities move the vehicle off equilibrium.

What designers fear most are self-excited oscillations or motions that cause the vehicle to swing farther and farther away from equilibrium until it either hits or leaves the guideway. One such instability is similar to the so-called "Dutch roll" of aircraft dynamics, in which lateral, roll, and yaw motions of the vehicle are coupled. Another possible self-excited motion is the "porpoising" instability, in which heave (vertical) and pitch motions combine to take forward-speed energy from the propulsion system and convert it to pitching and vertical oscilla-

Right: In the Cornell laboratory, technician Peter Brown places a small MAGLEV model in the 3-mm-thick aluminum guideway on a 1.2-meter-diameter rotating wheel. The guideway speed is about 160 kilometers an hour (100 mph).

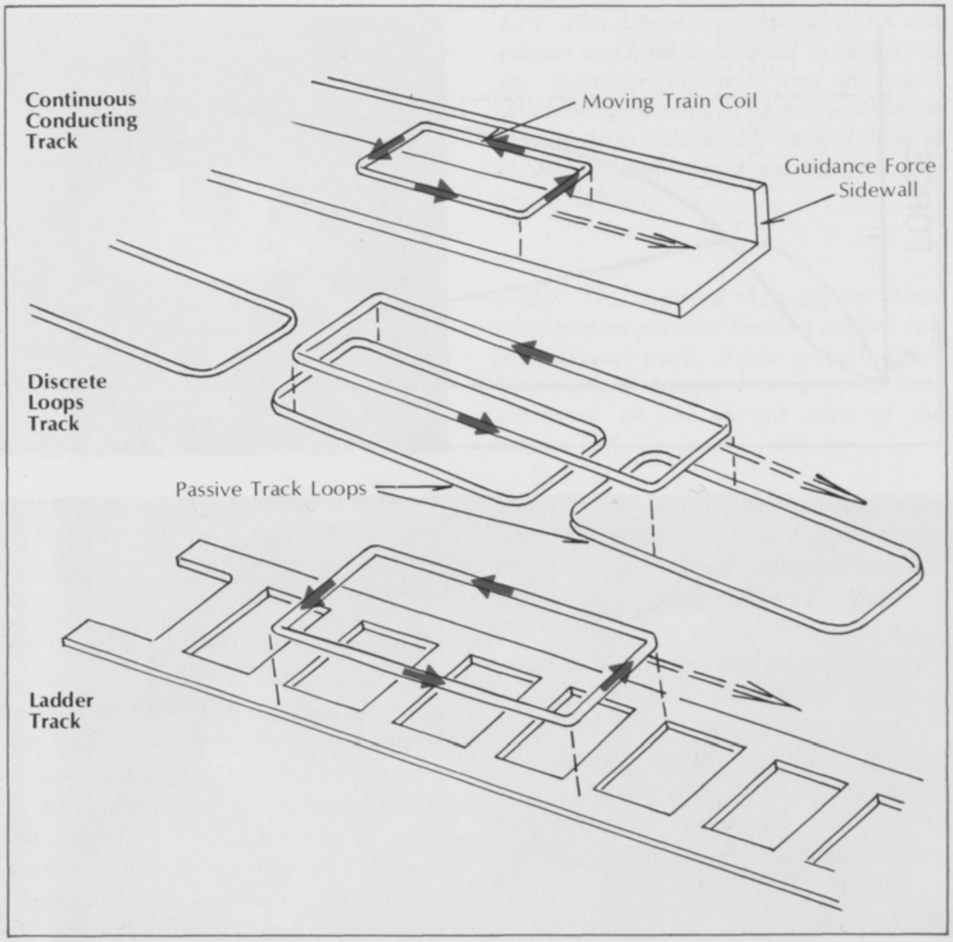
Below: This close-up photo of a MAGLEV model in a "V" aluminum guideway shows the "vehicle" in stable, full levitation. Eight permanent magnets on the one-kilogram model provide an 800-gauss magnetic field to lift and guide the model.



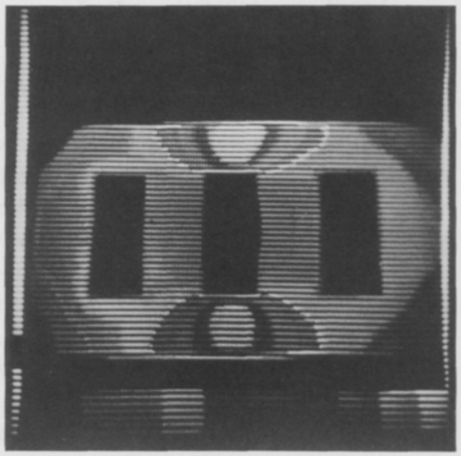
tions. Such oscillation instabilities depend on magnetic drag forces which, in addition to exerting a longitudinal force, can produce yaw, roll, and pitching moments about the vehicle's center of mass and cause it to gyrate like a top.

Both instabilities have been observed and studied in the MAGLEV laboratory at Cornell. The equipment used, a rotating aluminum wheel 1.2 meters in diameter, which serves as a moving guideway under a stationary test vehicle, is particularly well suited for investigations of magnetically induced effects, since aerodynamic forces are absent. In fact, one can think of the rotating wheel as the "wind tunnel" of MAGLEV research. Of course, combined aerodynamic and magnetic forces must be considered in analyzing full-scale vehicle motions, but it is important to understand how magnetic forces acting alone influence vehicle motions and affect stability.

Another problem that has been studied with the rotating wheel in my laboratory involves the dynamics of a linear induction motor. In such a



Above: Three different MAGLEV guideway schemes are: (top) the continuous, split-channel track (one side only is shown); (middle) the discrete-loops track favored by the Japanese; and (bottom) a hybrid "ladder" track. Removing material from the inside decreases the magnetic drag forces on the vehicle. Current is indicated by the colored arrows.

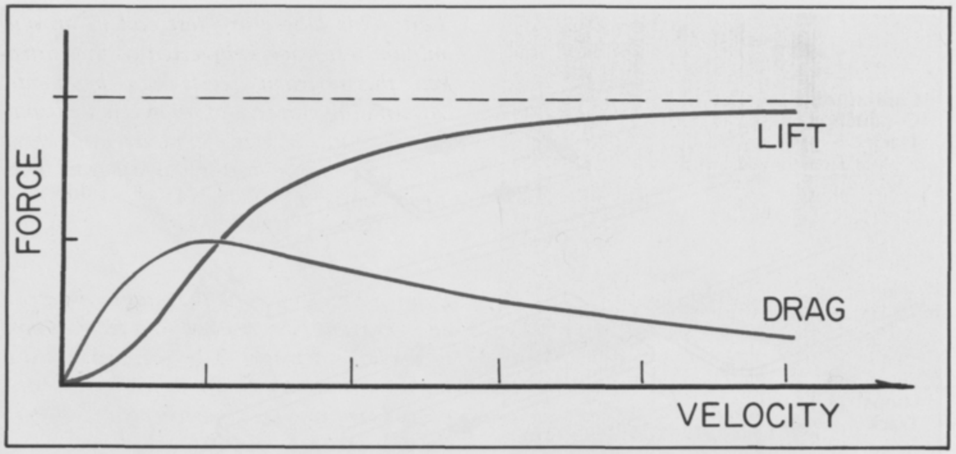


Right: An infrared thermogram shows the eddy currents induced in a ladder-track element by a rectangular current-carrying coil above the track. The bright areas represent high concentrations of current and hence magnetic lifting pressure.

motor, primary windings on the vehicle straddle a vertical conducting rail which is the secondary; the primary magnetic fields induce currents in the secondary, and these interact to produce thrust on the vehicle. Because the secondary rail is a flexible elastic plate, it is subject to dynamic instabilities or vibrations when the vehicle places moving forces on it. The rotating wheel, fitted with an attached flexible circular plate, provides a way of observing these potentially damaging vibrations without the use of a long test track.

INFRARED THERMOGRAPHY TO STUDY EDDY CURRENTS

As a developing technology, magnetic levitation requires new design tools, materials, and laboratory methods. A useful technique for MAGLEV research is infrared thermography, which we have adapted to provide information about the distribution of the induced or eddy currents in the guideway or overhead rail. The use of infrared techniques permits the "visualization" of the eddy-current patterns because circulating currents in a solid generate



A magnet moving over a conductor guideway produces lift much like that on an aircraft. A magnetic drag force is also induced.

heat, which is detectable with an infrared sensing device.

Measurements of eddy-current patterns are important for an understanding of both repulsive and attractive levitation schemes, as well as linear induction or synchronous motors. They are also important in equipment design, since lift, guidance, and propulsion forces, as well as some of the major energy requirements of the system, are dependent on the eddy-current distribution. For example, eddy currents in attractive MAGLEV systems can decrease the lift ability at high speeds, and the designer needs to know where these currents are concentrated. Design of the levitation magnets requires knowledge of the distribution of forces acting on it; in superconducting systems, for instance, the force distribution on the magnet coil determines the number and position of supports between the coil and the vehicle.

The infrared thermography technique provides a reliable way of obtaining the eddy-current patterns. It should be especially helpful where analytical methods are difficult to apply, such as in studies of out-of-plane track elements. The technique could also be valuable in studying the effect of flaws or discontinuities in the guideway, such as the overlapping but unwelded track joints required to compensate for thermal expansion.

Infrared thermography is based on the fact that the heat created in thin plates by circulating currents is proportional to the square of the current density, $\mathbf{J} \cdot \mathbf{J}$. The mathematical expression relating $\mathbf{J} \cdot \mathbf{J}$ to the rise in temperature T is:

$$k\nabla^2 T - c(\partial T/\partial t) = \mathbf{J} \cdot \mathbf{J}/\sigma$$

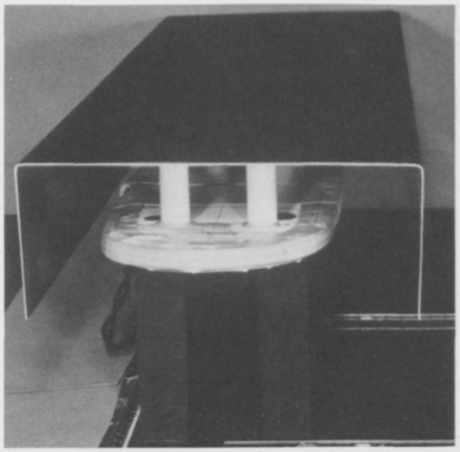
where k, c, and σ are thermal conductivity, specific heat, and electrical conductivity, respectively. For short times after the currents are induced, heat conduction can be ignored, and the rise in temperature locally is directly proportional to the square of the current density. Measurements must be made in a matter of seconds, however, with temperature variations of the order of 10°C.

The equipment we used to make such measurements is an infrared TV camera–monitor system. The device scans its field of vision with an infrared sensor and displays a color-coded picture of the temperature distribution on a TV monitor. Photographs can be taken of this image. The technique was tested on a number of plate elements and the results were found to compare well with current density patterns determined by search coil measurements.

MAGNETIC PRESSURE FOOTPRINTS FROM IR DATA

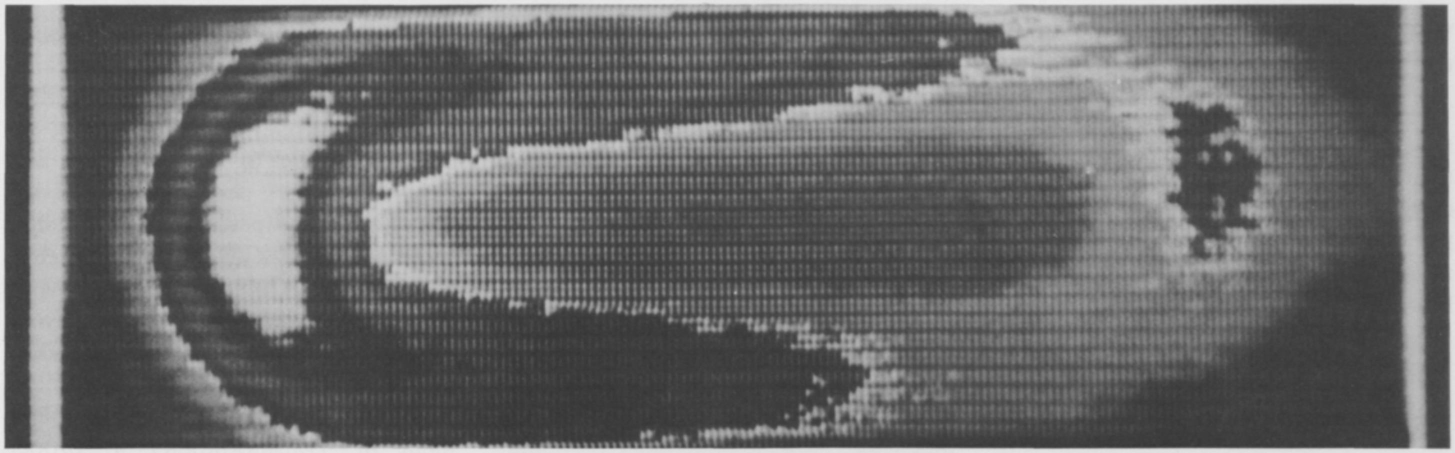
Infrared thermography can also be used to calculate the "magnetic pressure footprint" of the magnet on the conducting track.

The magnetic force on the track per unit area (the magnetic pressure) can be shown to be proportional to the square of the current density (J^2) per unit length of track. Therefore, if temperature is the analog of J^2, the infrared scan of the sheet track will show



Left: This laboratory test coil in an aluminum test track is inverted so that infrared thermography tests can be made. Alternating currents of up to one thousand ampere-turns induce eddy-current patterns similar to those for a moving coil with steady current.

Below: This infrared thermogram shows eddy-current patterns due to a pitched coil in a channel track. Bright areas indicate high current density and lift-force concentration on the curved edge of the magnet coil.



the pressure distribution. The thermograph reproduced above provides an indication of the value of this kind of information. One can see that this pressure footprint is not uniform around the circumference of the coil; by implication, the distribution of lift force along the coil itself may not be uniform. Knowledge of such force distribution patterns will become very important indeed when the present research models are scaled up to the anticipated 50-ton size of working vehicles. For example, such information would enable the designer to concentrate the lift-force supports (which connect the magnetic coils to the vehicle structure) near the points where magnetic pressure is greatest. Or the magnetic pressure footprints could be used in designing the coil and guideway so as to redistribute the lift more evenly around the coil.

The lift-force distribution is also important in determining the moment acting on the coil. The thermogram shown here, for example, indicates a higher concentration of pressure on the down edge of the pitched coil, implying that there is a restoring moment on the coil. It also implies that the forward edge of the coil must carry most of the lift, which it may not be able to do if it is not designed for this condition.

The examples touched on here demonstrate that MAGLEV technology requires considerable engineering research into the secondary design problems that will be encountered as development proceeds beyond the stage of feasibility studies.

"...by the 1990s we shall be able to ride in a magnetically levitated train at a speed of four or five hundred kilometers an hour."

WHAT ABOUT THE FUTURE OF MAGNETIC LEVITATION?

Technological crystal-ball gazing is an unreliable business. History has shown that technical achievements can outdo conservative estimates of progress, yet for new technologies like MAGLEV transportation, problems such as the looming energy and resource shortages may retard development. While four years ago I would have bet on the 1980s for a revenue-producing MAGLEV system, my current guess is that by the 1990s we shall be able to ride in a magnetically levitated train at a speed of four or five hundred kilometers an hour. Whether that ride will be on the North American continent is another matter.

Air travel will certainly continue to be the choice for trips greater than five hundred miles. But for trips of less than four hundred miles (currently about 40 percent of airline business), MAGLEV will provide an attractive alternative with comparable travel time. We are most likely to see MAGLEV in the high-density corridors of the Northeast, the Great Lakes region, and the West Coast, and in a bi-city route mode rather than a network mode similar to that of the railroads.

Energy consumption will be intermediate between that of high-speed aircraft and of modern conventional trains. It is estimated that MAGLEV at 480 kilometers an hour will use 35 to 50 percent of the energy per passenger kilometer consumed by a 727 jet, but will require about twice as much energy as a Metroliner traveling at 160 kilometers an hour.

It is perhaps ironic that in this country MAGLEV has elicited more interest from the aerospace community than from the rail industry. One of the first proposals for a levitated train was made by Robert H. Goddard, the "father of rocketry," in a 1909 article in *Scientific American*. He explored the idea of a vacuum tunnel between New York and Boston to convey airtight cars suspended and propelled by the action of magnets. After World War II, the Navy developed a linear induction motor to catapult planes from carriers. In the middle sixties, a team at Sandia Laboratories became interested in a repulsive levitation scheme to propel a rocket sled in an evacuated tube to speeds up to five thousand meters per second. And recently a NASA-sponsored team headed by Gerald K. O'Neill of Princeton University and Henry Kolm of MIT completed a study of the possibility of using a magnetic space launcher (based on the MIT Magneplane research recently dropped by the Department of Transportation) to propel manufactured materials from the moon into Earth orbit. Estimates are that the proposed MAGLEV moon launchings (at the 2.4 kilometer per second escape velocity) would cost less than one dollar per pound, as compared to the cost of several hundred dollars per pound for rocket launchings from Earth.

With prototype MAGLEV vehicles being built abroad and little interest in this country, one could ask what motivates my own continued interest in magnetic levitation research. One reason is my belief that there are still basic engineering problems, such as the achievement of dynamic stability, that are not fully understood. Also, I see this research as one aspect of the larger field of magneto-solid mechanics, an area of study with promise for near-term application in the magnetic forming of metals, superconducting devices, and high-power electric devices. Experimental and analytical tools developed in research on magnetic levitation are also useful in the study of related magneto-mechanical problems.

Besides, there is the lure of that fantastic ride in a magnetically levitated vehicle. The prospects of traveling at nearly five hundred kilometers an hour, twenty centimeters off the ground, continues to hold a special fascination for me.

Francis C. Moon, associate professor of theoretical and applied mechanics, is a specialist in magneto-solid mechanics and an expert in the magnetic levitation of trains. His research, sponsored by the National Science Foundation and the Energy Research and Development Administration, also has potential application in other areas, including the use of superconducting magnets in proposed fusion reactors.

Moon began his university education at Pratt Institute, where he earned a baccalaureate degree in mechanical engineering in 1962. He did his graduate work in theoretical and applied mechanics at Cornell, receiving the M.S. degree in 1964 and the Ph.D. in 1967. Before returning to Cornell as a member of the faculty in 1974, he taught at the University of Delaware and then for seven years at Princeton University. In 1973–74 he was a research engineer at Princeton's aerospace laboratories.

He has served as a consultant to the Boeing-Vertol Corporation (on the magnetic levitation of trains), the Rand Corporation, and the Sterling Extruder Corporation. During and immediately after his undergraduate years, he worked as a mechanical engineer in the New York Naval Shipyard. For several summers he was a visiting faculty fellow at the NASA Lewis Research Center in Cleveland.

He is active in professional mechanical engineering and scientific organizations and is a reviewer for several professional journals.

College Mourns Death of 'Dusty' Rhodes, Founder of Chemical Engineering School

Fred H. Rhodes, the Herbert Fisk Johnson Professor of Industrial Chemistry, Emeritus, and founder and director of the chemical engineering school at Cornell, died November 30 at the age of eighty-seven.

"Dusty," as he was known to thousands of chemical engineers and educators throughout the country and the world, retired in 1957 after forty-one years at Cornell, four as a graduate student in chemistry and thirty-seven as a member of the faculty. In 1971 a professorship in his name was established at the University with contributions of more than a half million dollars from alumni and friends.

Commenting on Rhodes' achievements at Cornell, Edmund T. Cranch, dean of the College of Engineering, said, "For four decades, 'Dusty' Rhodes and Chemical Engineering at Cornell were practically synonymous in industrial and educational circles. The example he furnished through his high personal standards and capacity for hard work have stood the alumni of his school in good stead. His achievements as a teacher and as an educational leader have become virtually a Cornell legend."

"Dusty" Rhodes visited Cornell during the 1971 College of Engineering centennial convocation and was photographed in the director's office at Olin Hall. On the wall is a picture of Rhodes taken while he was director of the school.

In his initial capacity at Cornell as a member of the chemistry department, Rhodes introduced chemical engineering courses into the curriculum and eventually organized a separate degree-granting department. In 1938 a School of Chemical and Metallurgical Engineering was established within the College of Engineering; Rhodes, one of two full-time faculty members in the new school, was named director, a post he held for nineteen years. In 1942 the school moved to a new building, donated by Franklin W. Olin, which was the first of the ten buildings on the Engineering Quadrangle. Today the School of Chemical Engineering has a faculty of sixteen and more than 1,700 alumni.

Rhodes, a native of Rochester, Indiana, was graduated from Wabash College in 1910 and received the doctorate from Cornell in 1917. After a year of teaching at the University of Montana and three years as a research director of the chemistry department at the Barrett Company, he returned to Cornell as professor of industrial chemistry. At about the time of the move to Olin Hall, Rhodes was named the first Herbert Fisk Johnson Professor of Industrial Chemistry; the chair had been established in 1941 by Johnson, who served as chairman of S. C. Johnson and Son, Inc. After his retirement, Rhodes was elected to a five-year term as an alumni member of the University's Board of Trustees.

During his career, he was granted a number of patents, especially for new methods of refining coal-tar products and manufacturing pickling agents for steel. During World War I he developed a needed low-cost method of making phenol. For nearly ten years he was a director of General Analine and Film Corporation, and he served as a consultant to a number of firms.

His publications, in addition to a large number of articles in professional journals, included two major engineering texts, *Technical Report Writing* and *Elements of Patent Law*.

He is survived by his widow, Ethel, of Leland, Florida, and a daughter, Clara Rhodes Rosevear of Toronto.

Fred H. Rhodes would answer the phone by saying, "This is Fred Hoffman Rhodes, director of the School of Chemical and Metallurgical Engineering, Herbert Fisk Johnson Professor of Industrial Chemistry, Professor of Chemical Engineering, and personnel officer of the School." He then would insist the caller address him as "Dusty."

Cornell University is diminished by the death of "Dusty" Rhodes. He is a Cornell legend and a chemical engineering legend. He was a leader in the establishment of chemical engineering at Cornell, in the development of chemical engineering education, and in the betterment of the chemical engineering profession. He has often been described as the "father" of chemical engineering at Cornell, which is true and to his credit, although he might have disavowed the attribution of chemical paternity. He believed chemical engineers had to be competent chemists and also competent engineers, as well as having specialized training in putting both types of knowledge into practical application in design and construction of chemical manufacturing plants. He believed the requisite competence in Cornell's chemical engineers could be achieved through effective teaching.

"Dusty" Rhodes was himself no ordinary person and he wanted extraordinary individuals as students. He wanted to teach and train superior engineers. With a humanity covered with a veneer of gruffness and mild chicanery, he built the curriculum and the program, forced his students to superior work, and then assured them of positions of status in the profession. He fought for his students, he supported them, and he defended them against incursions from alien beings. (He had a particular capacity for placing professors of physics in perspective and in place.) He continued to be concerned about them when they left Olin Hall. His continuing interest in the fate and fortunes of chemical and metallurgical engineering alumni is well documented.

"Dusty" Rhodes produced generations of talented chemical engineers. He was a positive inspiration for others, nonengineers, who took his courses. (The Nobel Prize-winning physicist, I. I. Rabi, attributes his making up his mind to become a scientist to Rhodes' chemistry lectures.) He was a negative, or reverse inspiration, for he was the catalyst which produced a large number of successful Cornellians in nonchemical engineering professions by informing them, in that less-than-subtle Rhodesian manner, of two things—they'd never make it as chemical engineers, and perhaps they should pursue their goals in another profession.

Generations of Cornellians have told and will continue to tell "Dusty" Rhodes stories. Some are filled with humor and humanity, some with a tinge of fear and bitterness, all with respect. There are the stories of the poker games, the proceeds of which went to student loans: of the Rhodes-mandated school tie "designed to look bad with any article of clothing;" and of the trembling while waiting in long corridor lines in the southwest corner of Olin to discuss a 37 average in chemistry. In all of this, there was a pride, a pride in being a "Rhodes scholar." If you made it you knew you were good.

"Dusty" Rhodes brought prestige to Cornell, to Cornellians, and to Cornell chemical engineers. His University mourns his death and our thoughts and prayers go out to his family.

–Dale R. Corson, president of Cornell University and former dean of engineering

FACULTY PUBLICATIONS

The following publications and conference papers by faculty members and graduate students of the Cornell College of Engineering were published or presented during the period May through August 1976. Earlier publications inadvertently omitted from previous listings are included here with the date in parentheses. The names of Cornell personnel are in italics.

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