Title

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The Program on Advanced Technology for the Highway (PATH), has been established in response to funding by the United States Congress and the California Legislature to demonstrate how "high technology" might be applied to improve highway transportation. PATH's goal, in the short run, is to implement technologies which promise significant relief of acute problems including traffic congestion, air pollution and energy use. Alternative systems of vehicle guidance and control, navigation, propulsion, and communication will be studied and/or developed. The impacts of these systems on highway travel, transportation, the economy and society will be predicted. Researchers envision a new generation of highway transportation ultimately evolving out of these experiments and others like them.

PATH is motivated by perceptions on the part of legislators, transportation professionals, and highway users that highway system performance has deteriorated and will continue to do so. Evidence supports the belief that the steady rate of improvement in performance to which we have become accustomed has slowed and will continue to do so; evidence also suggests that levels of service on some parts of the system have actually deteriorated. Three measures of overall system development - automobile registrations, automobiles per capita, and highway mileage deployed - are illustrated in Figures 1, 2 and 3. Each shows a pattern of slow initial growth, followed by a period of rapid change, tailing off to another period of slow growth. Deployment of high surface pavement (asphalts and concrete), for example, proceeded slowly until 1920, grew quickly from 1920 to 1970, and has been relatively unchanged since 1970. This pattern is the S-shaped technology development process described by Garrison, reproduced as Table 1. He characterized the automobile-highway technology system as near or past the end of its growth dynamic in 1979, and noted that interest in new technologies is characteristic of this late stage of development.

Mature technological systems invite and resist technological innovation. On one hand, new systems are essential to economic growth; the end of one technology's life cycle must become the beginning of the next's. On the other hand, the old technology has evolved into a tightly connected set of subsystems interacting with each other and with the rest of the economy in complex but well-defined ways. Standards created to facilitate the deployment of the system, and the rules governing the interaction of its parts, now constrain both the pace and scope of change, maintaining the system's inertia. Subsystems formerly able to innovate independently now infringe upon others. Many innovations fail to gain a foothold, although they are technically feasible and would clearly benefit a part of the system.

A cursory familiarity with successful innovations suggests that a viable new technology - one which will gain a foothold - must have the following properties, beyond technical feasibility. First, it must provide a service that is needed and wanted given its cost. If the service is a familiar one, it must be provided more economically by the new technology than the displaced one. If the service is new, enough people must want it enough to pay its cost, especially initially when it is likely to be most expensive. Second, the innovation must fit with the rest of the system into which it is introduced. It may replace a product or process, but it must work with other products and processes, some of which will themselves be changing. A successful, "inertia overcoming" innovation (the automobile in the early

1900's, for example) will have enough potential to cause the surrounding system to accommodate it eventually, but it must fit in when it is new, and provide a "pathway" to the ultimate opportunities it offers. Finally, an innovation must be capable of engendering consensus and therefore financing among those who control the existing system. Actors in the subsystems that will adopt the innovation, and those in other subsytems who perceive that they will be affected by the innovation's adoption must be convinced of its worth. Consensus seems to be dependent on perceptions of immediate and potential opportunities afforded by the innovation, immediate "fit" with the subsystems individual actors represent, and judgments as to how much the system will adapt to the innovation. Not least, consensus depends on the abilities of the innovators to influence these perceptions.

These "system considerations": economy, fit,and ability to attract consensus, are especially important for successful innovation in transportation, as compared to more autonomous industries. Within the transportation system, and especially the highway transportation system, proposed technologies must be assessed in light of their appeal to numerous constituencies. Examples include automobile producers and users, those involved in providing and maintaining highways, traffic operations officials, truckers, and shippers. Transportation is also highly integrated with other sectors of the economy, and highly integrated into the political system. Innovation must appeal to actors in these systems as well.

Economy, fit, and ability to attract consensus can be attributes of a technically feasible innovation by accident, or by intention, or by some combination of the two. The process of innovation is not yet well understood: it is not clear, for example, how the characteristics of economy, fit and consensus attraction have helped successful past inventions catch hold. Neither is it clear how the complex interactions of modern systems have changed the requirements for successful innovation, or how the institutionalization of the innovation process has changed the supply of innovations. In the absence of more refined knowledge about the innovation process, however, it seems reasonable to suggest that considerations of economy, fit, and ability to attract consensus should be part of a new technology research effort.

Innovators can enhance their prospects of success if they are familiar with technology subsystems and "intersecting systems": how they operate, their histories and prospects, their current problems and opportunities for improvement, and how they interact with the rest of the system. The benefit of this perspective to managers - who, in effect, specify innovations, and are charged with implementing them - is obvious. Less obvious, perhaps, is the advantage to be gained by informing designers about the conditions and requirements of other systems from the outset. Relatively minor design modifications can often eliminate problems requiring expensive and time-consuming negotiation and re-design if not anticipated.

PATH research tasks programmed to date concentrate on designing technical mechanisms to electrify guideways and control passenger vehicles. This is a natural starting point given the program's roots in transit-bus automation and propulsion. Intentionally designing for economy, fit, and consensus, however, will require identification of other highway transportation subsystems that might benefit from automation, consideration of how automating passenger transportation might affect other transportation systems, and "intersecting systems" potentially affected. The PATH management program recognizes some of these opportunities, and it is expected that the PATH research agenda will be broadened substantially .

The remainder of this paper presents background information on the goods movement industry,one transportation subsystem relevant to PATH. It is intended to provide managers who will design the research agenda with a general perspective on freight transportation and the opportunities and problems associated with automation. The information should also be useful to researchers whose involvement with PATH is limited to engineering isolated components, who seek to understand the relation of their tasks to the transportation system as a whole.

Economic Importance of Highway Freight Transportation

Freight transportation is of critical importance to the U.S. economy. As illustrated in Figure 4, national expenditures for freight movement amounted to approximately $ 272 billion in 1985. Transportation as a whole accounted for 18.6% of the Gross National Product, and the freight bill for 43% of this total, about 7% of the GNP.

Table 2
The 1985 U.S. Transportation Bill
All Modes
(billions of dollars)

Passenger Transportation	$ 483.3	12.1% of GNP
Freight Transportation	$ 271.7	6.8% of GNP
Total Transportation Bill[1]	$ 742.0	18.6% of GNP
Gross National Product	$ 3998.1	

The preponderance of freight dollars is spent for goods moved over the highway. Expenditures for trucking accounted for seventy-six percent of the 1985 freight bill (Figure 5). Highway shares of domestic intercity tonnage and ton mileage (Figures 6 and 7) indicate that a disproportionate share of relatively lightweight, high-value goods move by truck. Trucks carried 2139 million tons of freight in 1985, accounting for 38% of the nation's tonnage. Taking into account length of haul, trucks accumulated 610 billion ton-miles during the same year, 20% of all freight ton-miles. Average length of haul measured 538 miles for less-than truckload operations, and 244 miles for truckload hauls.

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1. Sum of freight and passenger bills less double counting.

The highway freight transportation industry is a nearly mature one, having experienced most of its growth between the end of World War II and the late nineteen-sixties. While trucking's shares of revenues, ton-miles, and tonnage have increased since this rapid-growth period, the rate of increase is decreasing. This is evident in Figure 8, which illustrates intercity ton-miles of all modes between 1940 and 1984. A similar trend is seen with other measures, including share of the freight bill and share of tonnage. As this growth dynamic plays itself out in trucking, opportunities for performance improvements have become increasingly hard to identify and increasingly expensive to realize. As with passenger transportation, innovation is becoming confined to marginal changes in the established technological systems, greater efficiency in supplying existing services, and deployment of equipment and services aimed at specialized markets.

Like other near-mature industries, trucking is seeking productivity-enhancing and cost-reducing innovation. Peculiar to trucking, however, are a set of circumstances which have vastly increased the competitive character of the industry since 1980.

Changes in the national economy continue to test the abilities of many industries to adapt and maintain profitability; trucking has been especially challenged. The rapid growth of non-freight-intensive sectors of the economy, service industries for example, has meant extremely sluggish growth in overall freight demand. Figure 9 illustrates this by comparing expenditures for freight transportation to those for passenger, and to the GNP. Growth and decentralization of markets, changing labor costs, and an increased emphasis on flexibility and specialization in the economy as a whole have produced changes in the temporal demand for truck transportation, in spatial flow patterns, and in commodities transported, size of shipments, and levels of service desired. The serious recession of the early 1980's complicated truckers' responses to these trends, and its effects contribute to the industry's financial instability. Fuel shortages of the 1970's and fluctuating prices since then have contributed to this instability.

Maturation and economic change have made even more volatile an industry which has historically been highly competitive. Industry structure is dictated primarily by the character of the technology - relatively inexpensive, rather low-tech units operated more or less independently on public roadways. Most evidence indicates that economies of scale are relatively unimportant, even in the larger less-than-truckload sector of the industry. Trucking, therefore, even under regulation, has been highly fragmented and specialized. Economic deregulation, beginning in 1980, has further increased competitiveness, on the basis of service and price, and has blurred the formerly well-defined distinctions between private and for-hire operators.

The changed operating environment has resulted in low or negative profit margins for many trucking firms, and mergers, consolidations and reworked corporate strategies. A record number of firms have gone bankrupt since 1986. While the shakeout shows signs of abating, cost-reducing innovations and productivity improvements continue to be highly sought by firms desiring to stay competitive, and by shippers. A number of measures have been taken or are being considered.

- Both for-hire and private truckers are undertaking to reduce expenditures for driver labor and fringes, which constitute 50-60% of for-hire carriers' costs. The Teamsters' truck driver membership has decreased over 30% since 1980.

- Larger vehicles with higher carrying capacities have been allowed under the Surface Transportation Assistance Act of 1983, and have been adopted resulting in significant productivity increases.

- Fuel conservation equipment and fuel efficient driving techniques have been shown to provide an increase in miles per gallon from 5.5 (the for-hire industry average) to over 9. Since fuel expenses account for almost 9% of these operators' costs, this savings would be significant if realized on a large scale.

- Advanced communications technologies have been applied extensively by truckers, for everything from on-board fuel usage recording systems and "smart" dashboards, to improved routing and navigation, to sophisticated simulation of truck configurations prior to purchase of new rolling stock.

- Use of logistics is increasing the industry's backhaul opportunities, and streamlining route structures, terminal configurations, and warehouse operations.

This short but varied list gives a flavor for the industry's interest in innovation.

PATH and Trucking Productivity

PATH envisions applying 'advanced technologies' to the highway transportation system to bring about congestion reduction, capacity increases, and improvements in fuel efficiency and air quality. In addition to these immediate benefits, longer term effects on demand for transportation and economic productivity are anticipated from proposed systems, which would allow types of travel now difficult or impossible or difficult to be undertaken with ease.

A system under discussion, for example, would embed markers encoded with location information at closely spaced intervals in the roadbed. Sensors on-board individual vehicles would be capable of reading these coordinates, and controlling the vehicle's speed and lateral positioning.

Additional sensing equipment could control the vehicle's spacing relative to other vehicles. A separate system might take advantage of unique identifiers attached to vehicles, collecting real-time information on which route choice and traffic control information decisions might be based. Current weight-in-motion concepts under development in the "Crescent" project, for example, would take advantage of automatic vehicle identification technology. Pricing schemes differentiated by time, space, and vehicle-type also might use this system to bill drivers for road use.

Communications technology applications would seem to be of great interest to truckers in their search for lower cost and higher productivity. Potential impacts on freight transportation might range from marginal changes in current operating procedures, to entirely new ways of doing things.

- The pavement marking system introduced above could be used to assist in controlling the way trailers behave in Longer Combination Vehicle (LCV) arrangements (tractor plus at least two trailers). Drivers have described handling of these double- and triple-bottom combinations as "tricky", adding to concerns about the safety of these units and likelihood of even longer combinations being allowed on the highways. Significant productivity increases and driver cost reductions in the less-than-truckload for-hire segment of the industry would result from longer LCV's controlled by a single driver.

  The pavement system could also be used to control speeds and lateral positioning of all trucks. On-board units could, for example, be programmed to limit the truck to a certain maximum speed; or, with the help of pre-recorded route profiles, to optimize fuel efficiency. Lateral positioning capability could reduce lane encroachment and running off the road.

  Identifiers attached to vehicles and read by roadside computers might be used for shipment tracking, in lieu of systems now in use by some trucking firms. Costs may be lower if the system is publicly available.

  Real- (or short-) time information describing road usage could be used by truckers to fine-tune their routes in time and in space, resulting in lower travel times, higher productivity, and higher service for shippers, lowering their costs. Timely service is especially important for just-in-time delivery systems, gaining popularity rapidly.

  Road-use information might be used to apportion road costs in a different manner. Information availability and quality is a major drawback of weight-distance taxes now used by several states.

> Automatic vehicle control and route selection might ultimately eliminate the need for drivers altogether, dramatically lowering freight costs. The need for backhauls would be reduced or eliminated.

These suggestions are purely speculative, but indicate the range of questions relating specifically to freight transportation to be investigated.

The speculations above seem at first glance to be clearly beneficial to the operation of the freight transportation and the highway systems. These and other possible impacts, however, will not necessarily be considered benefits by many trucking organizations, and will likely engender substantial controversy and opposition. The ton-mile tax is mentioned, for instance. It is a financing mechanism which apportions highway fees on both vehicle (or preferably axle) weight and distance travelled. Trucking - the American Trucking Associations in particular - are opposed to this tax and any other plan which would increase the share truckers pay for highways. It is likely, then, that any system which would expedite adoption of such mechanisms would draw some opposition. Full knowledge of the likely costs and benefits of proposed projects will be necessary. The trucking lobby is formidable, well prepared, and well financed; thus ongoing communication will be necessary.

There is reason to believe that advanced technology systems might be more likely to gain a foothold in freight transportation than among non-commercial drivers, provided truckers and shippers believe that benefits will be significant. While direct labor expense is largely irrelevant to passenger transportation (for other than the small number of mass transit vehicles, a small proportion of which will be affected), labor expenses are by far the largest component of highway freight costs. Any advanced technology system so far envisioned will have immediate impact on labor costs. The same argument applies to fuel costs. Further, the costs of on-board automation units will be relatively small in comparison with the costs of commercial trucks, but will larger initially relative to passenger cars. On the basis of lifetime miles travelled, the difference increases, as it does if automation results in a higher proportion of LCV's in the fleet. Should the automation units be designed to be compatible with on-board monitoring units already widely in use by truckers, the incremental cost of automation might be even further reduced.

It is inevitable that impacts on freight transportation be debated long before implementation of any significant alterations to the highway system is seriously proposed. The freight industry - transportation providers and shippers - is too important in the economy (and too vociferous) for it to be otherwise. This will probably be true even if the proposed alterations are intended solely for passenger use. Because passenger cars and trucks share the highways, any significant change in one will likely affect the other. Automation of the passenger fleet may affect speeds and densities of passenger vehicles, and therefore highway capacities, operating protocols and possibly highway design. In the longer term, passenger travel patterns may change, as may land use and therefore freight flows. Freight providers and shippers will be keenly interested in these possibilities (particularly the shorter term ones).

Recommendations for a PATH Freight Research Program

Several conclusions follow from the preceding discussion. First, it is inevitable that PATH consider the impact of advanced technologies on freight transportation at some point, whether those technologies are aimed exclusively at passenger vehicles or not. Second, advanced technologies are potentially of great benefit to the trucking industry, given the competitiveness of the industry and the need for productivity improvement. There is also reason to think that implementation of automation technologies to goods movement will be possible sooner and on a wider scale than will be initially possible with passenger transportation. Explicit consideration of the organization, operation, needs and concerns of the freight industry early on by PATH researchers will improve the likelihood that new technologies are designed to provide maximum benefit to both the passenger and freight transportation systems, and that PATH resources are used most efficiently. Freight transportation providers, shippers, and industry associations should be made aware of PATH, and encouraged to become involved in research. This would be consistent with PATH's philosophy of industry involvement and with facilitating implementation of advanced technology research.

As an implementation-oriented program, then, PATH's questions are **when** and **how** to initiate study of the highway freight mode. The evidence that automation may potentially be of greater immediate benefit to commercial as to private transportation, coupled with the uncertainty that the same technology can adequately (much less optimally) serve both the freight and passenger systems suggests that the two sides of the study be brought along together, from early on.

Several research tasks are suggested.

- The Freight Component should begin with an effort to outline the structure and economic organization of the California and U.S. Trucking industries, with the objective of understanding how trucking services are provided; describing the trucking fleet and its distribution, supply and ownership; and identifying key players in the industry. Much of this work was begun as background for this paper.

- The agenda should include a study of current and proposed applications of advanced technology within trucking and shipping firms. As mentioned above, many trucking firms have been aggressively adapting information technologies to their operations. There may be lessons directly relevant to PATH to be learned; there may also be opportunities to combine PATH hardware with existing systems.

- Possible contributors to and sponsors of research among trucking and shipping concerns should be identified. Contacts within the trucking industries, shippers, industry organizations, large fleet owners, and equipment manufacturers should be established. The California Trucking Associations and the American Trucking Associations in particular should be contacted.

- Questions posed in this paper should be researched in more depth. What problems might automation solve for the freight industry?, How might systems designed for this purpose differ from those under consideration for passenger vehicles? How might highway design be affected?

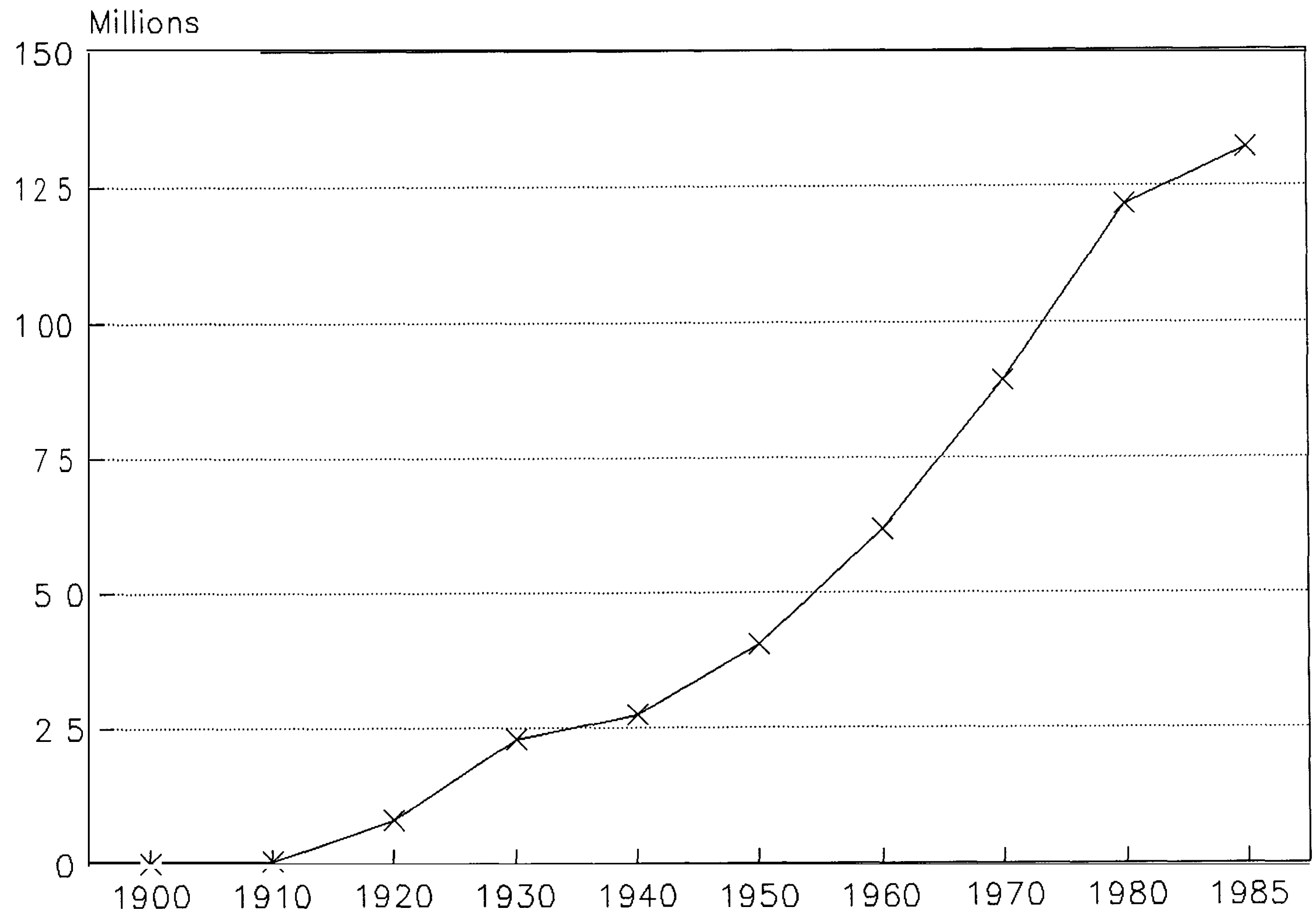
Finally, it would be desirable for PATH researchers, on both the passenger and freight sides, to strive for familiarity with the intricacies and histories of the highway transportation systems to the extent possible. PATH is likely to design and recommend major and expensive modifications to the highway system, to be implemented over many years. A "moving-target" problem is inherent here: PATH researchers are attempting to design a vehicle-guideway-operating protocol system which will serve, at some time in the future, freight and passenger transportation needs evolving even as the system is on the drawing board. "Static" data (a slice in time) is needed for design, yet change has been so rapid of late that such data taken now are likely to be obsolete by the time a the new system is deployed. This moving target problem is inevitable, it being impossible to predict the future, and therefore to generate data describing it. The productivity-eroding, expensive obsolescence associated with missing the moving target can be reduced through good design, though - design which recognizes that the target is indeed moving, and builds in flexibility to accommodate a range of movement. PATH participants can enhance their design capabilities by studying the paths taken so far by the passenger and freight systems, and by recognizing that many technological systems of the present and past exhibit similar patterns.

Table 1. Characterization of Transportation Innovation and Technology Deployment

Status of Transportation Technologies and Their Institutions	Innovation and Technology Activities
Near the end, at, or past their growth dynamic -- mass transit, rail freight, automobile.	Frenetic search for technologies to reduce costs and to meet constraints including: political requirements for service in high cost markets, regulatory, labor, capital, and institutional; much government involvement in technology matters; technologies of limited scope (e.g. improved ways to empty fare collection boxes, better rail wheels, lightweight automobile hoods); there are narrow (e.g. technology is needed for filling potholes) and sometimes suboptimal views of technology needs; some interest in new systems when the technology is well past its growth dynamic. e.g., personal rapid transit; interest in technologies to protect traditional markets, e.g. TOFC and COFC
In rapid growth phase -- truck highway, pipelines, inland waterway, air.	Alternative technological and/or institutional forms continue development from early growth dynamic phase, e.g., specialized contract carrier trucks, new aircraft, product and slurry pipelines, and the United Parcel Service; technology responding to safety and environmental regulation, other constriants may be pushed aside by productivity gains, although they affect the technology, e.g., Air Line Pilots Association work and pay requirements; search for technologies for system expansion, e.g., efficient short range aircraft.
Near the beginning of their growth dynamic--slurry pipelines; container, roll on, roll off, and large bulk ships	Search among technological and institutional forms for old and new markets; high productivity pushes aside constraints other than environmental and safety; little government involvement; industry actors seek standardization.

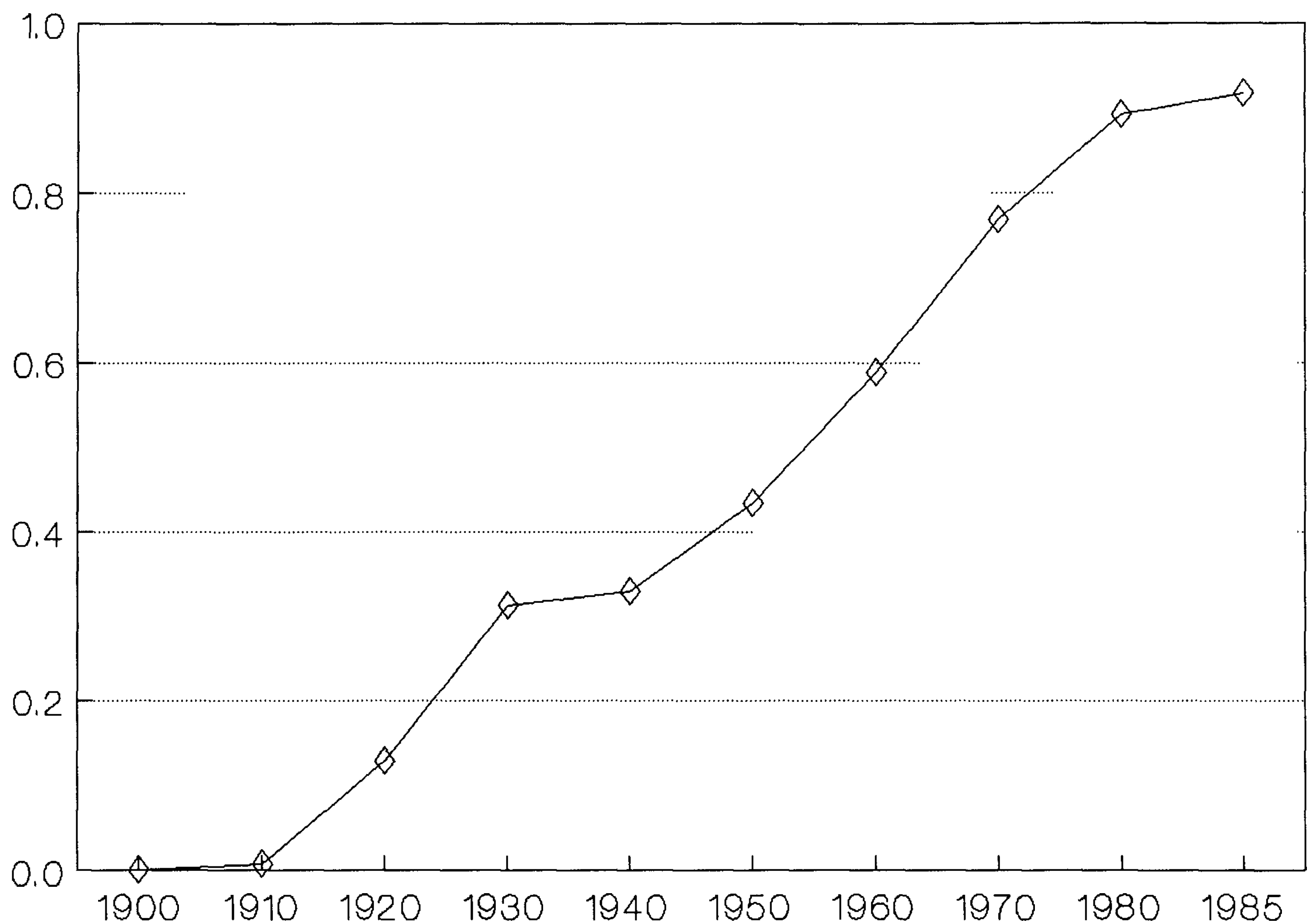
From W.L. Garrison,
Innovation and the Structure of Transportation Activities, 1979.

Figure 1 : Automobile Registrations



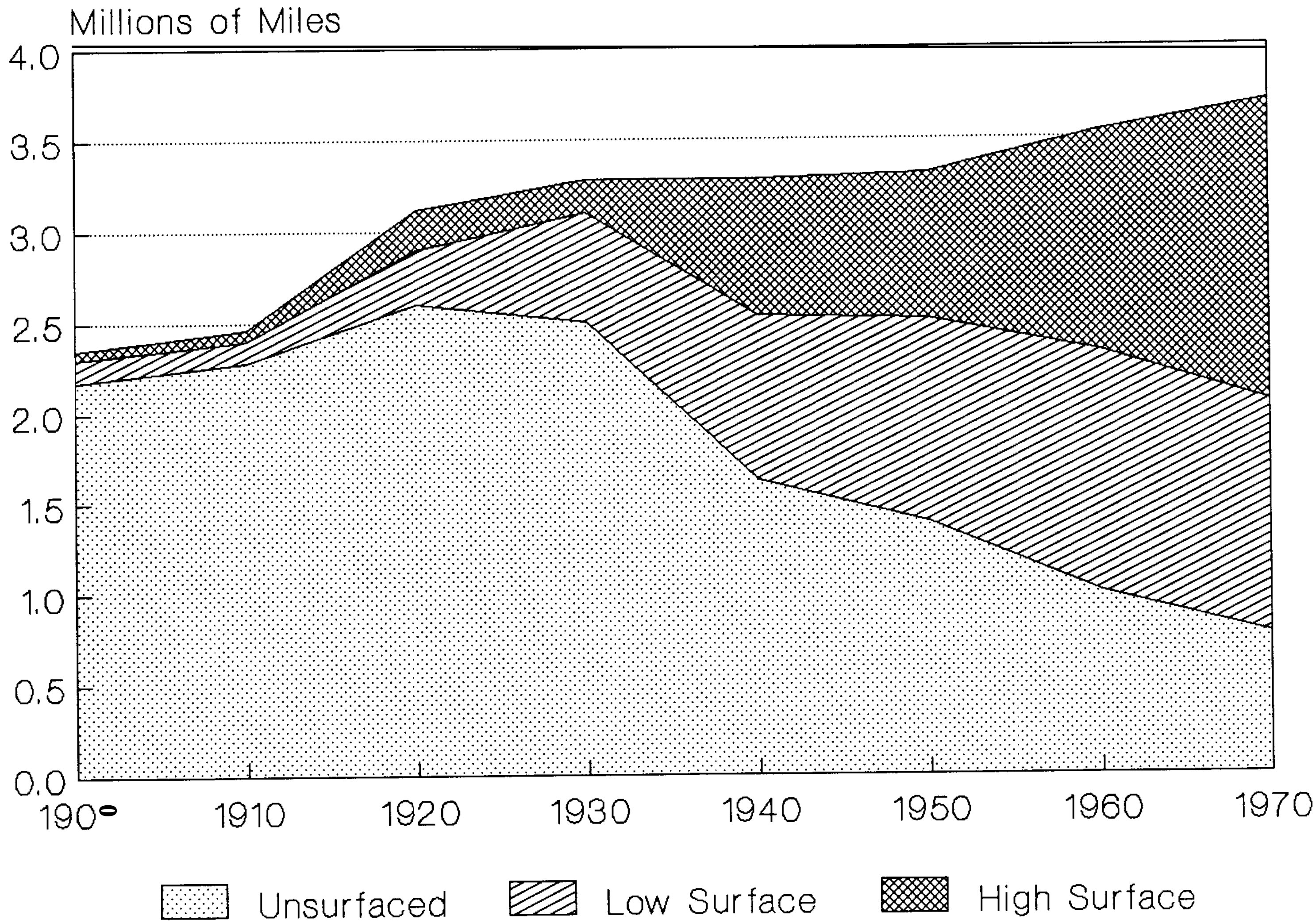
Source: Federal Highway Administration

Figure 2: Automobiles per Capita



Source: Federal Highway Administration

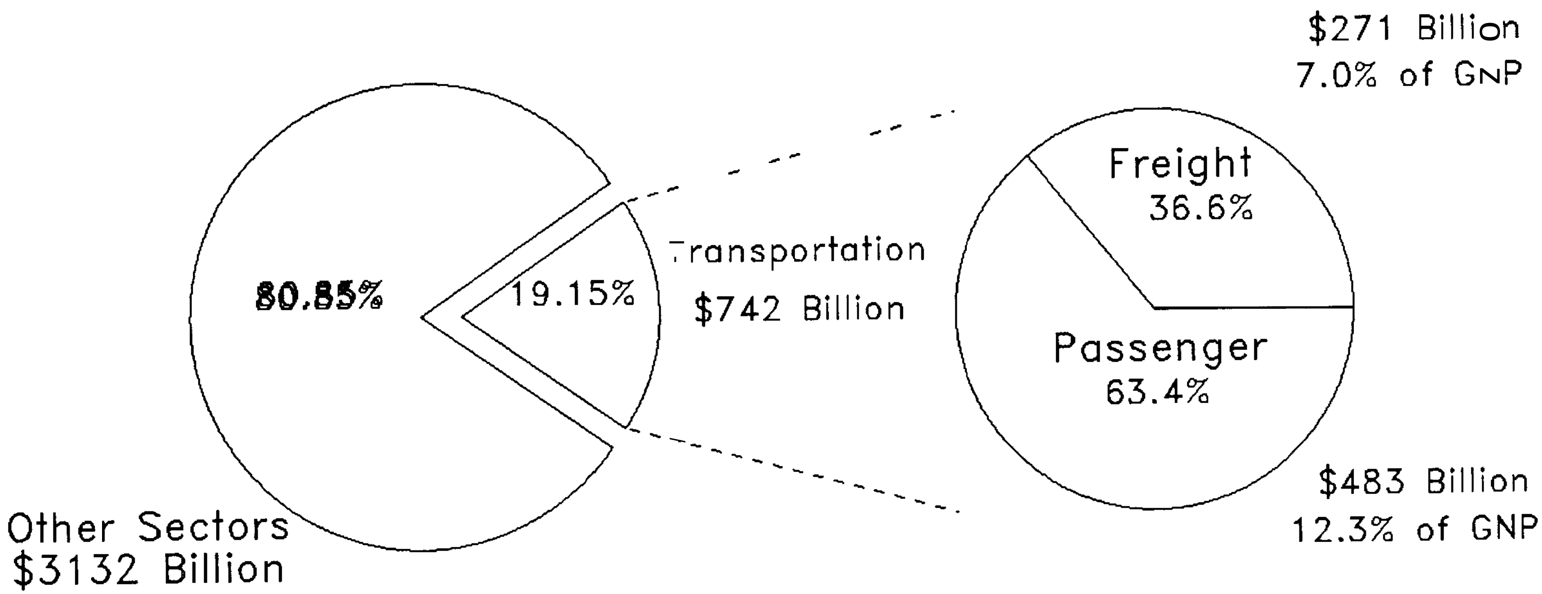
Figure 3: Highway Miles by Surface Type



Source: Federal Highway Administration

Figure 4: The Transportation Bill, 1985

Source: Transportation in America, 1987 *



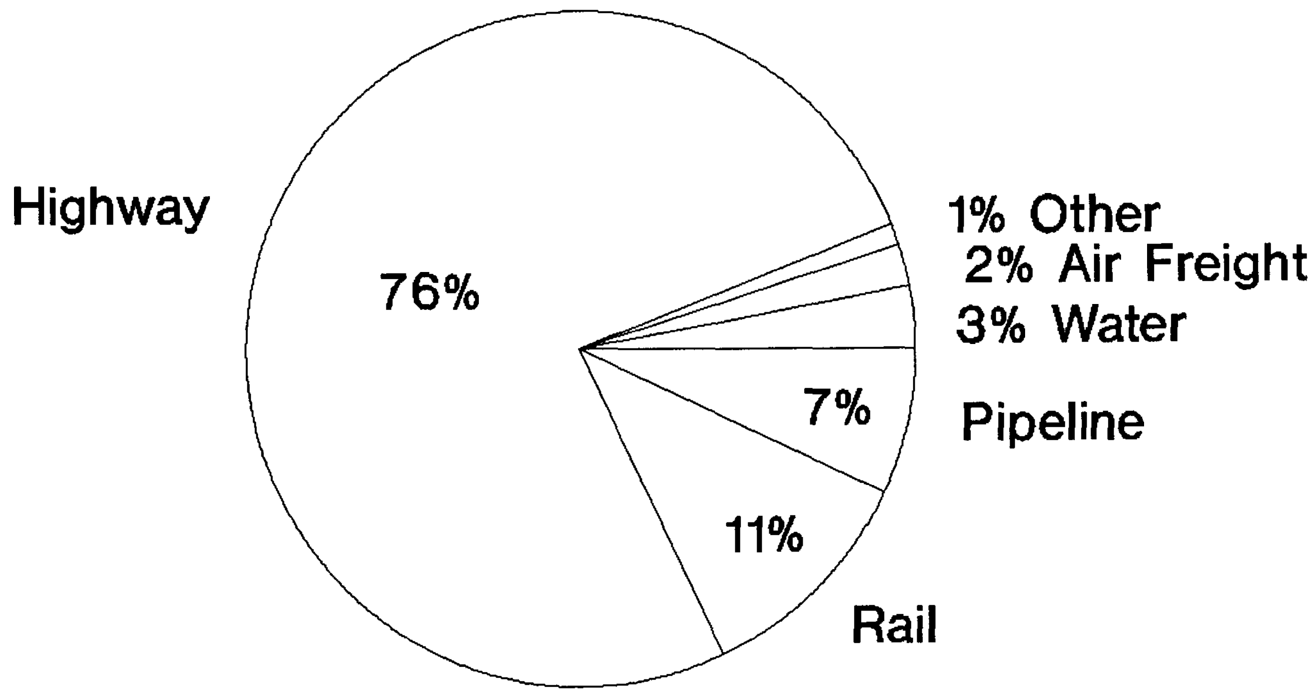
Transportation Expenditures as Share of Gross National Product (Passenger and Frieght, All Modes)

Breakdown of Transportation Bill By Passenger and Freight Expenses

* Expenses reported in source as duplications are proreted by share of non–duplicated expenses.

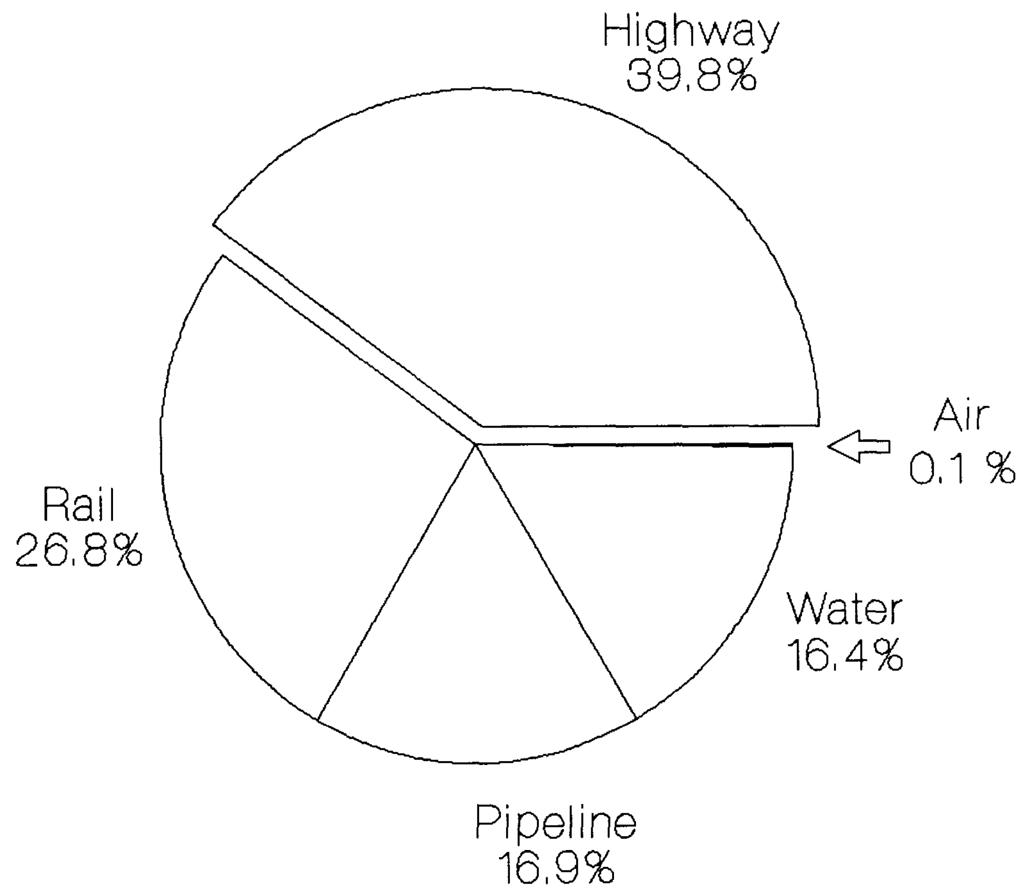
Figure 5: The Freight Bill, 1985

National Freight Expenditures by Mode



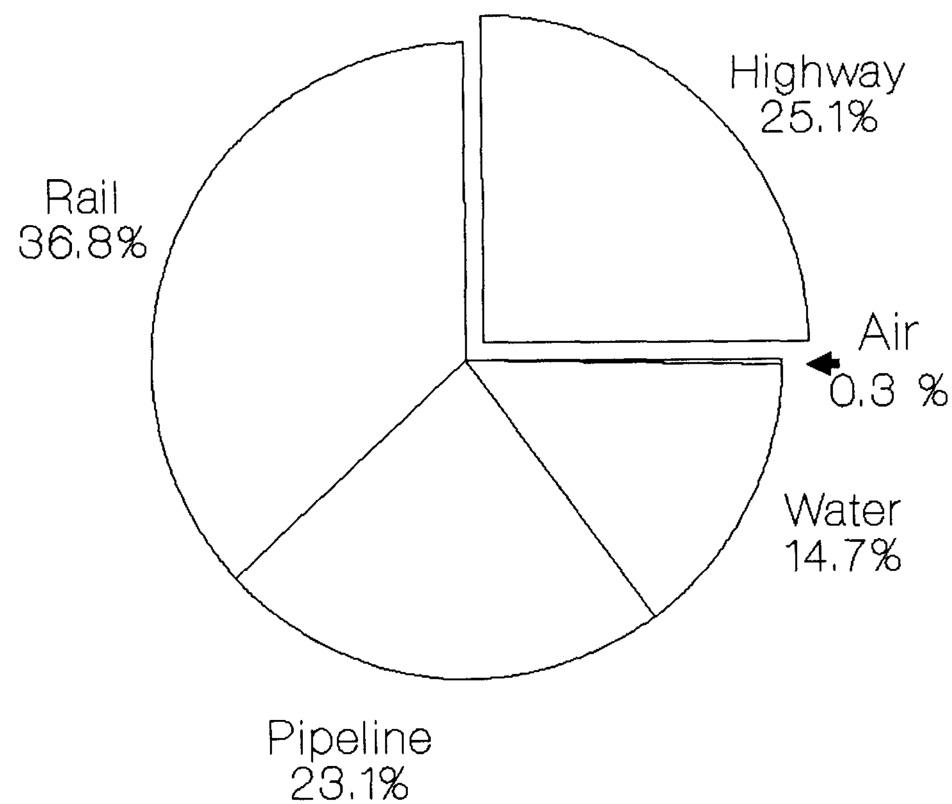
Source: Transportation in America, 1987

Figure 6
Shares of Intercity Tonnage by Mode



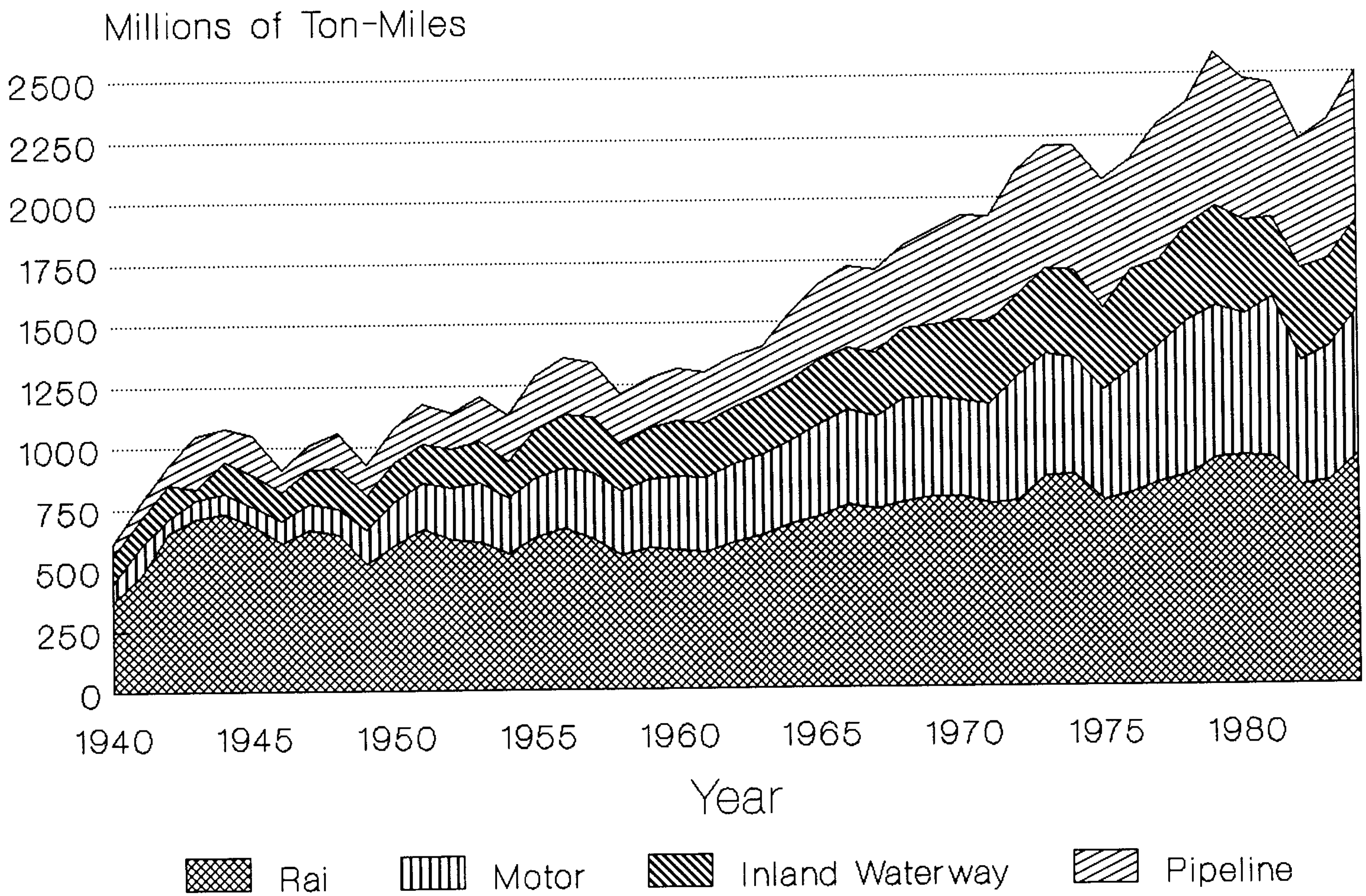
Source: Transportation in America, 1987

Figure 7
Shares of Intercity Ton-Miles, 1985



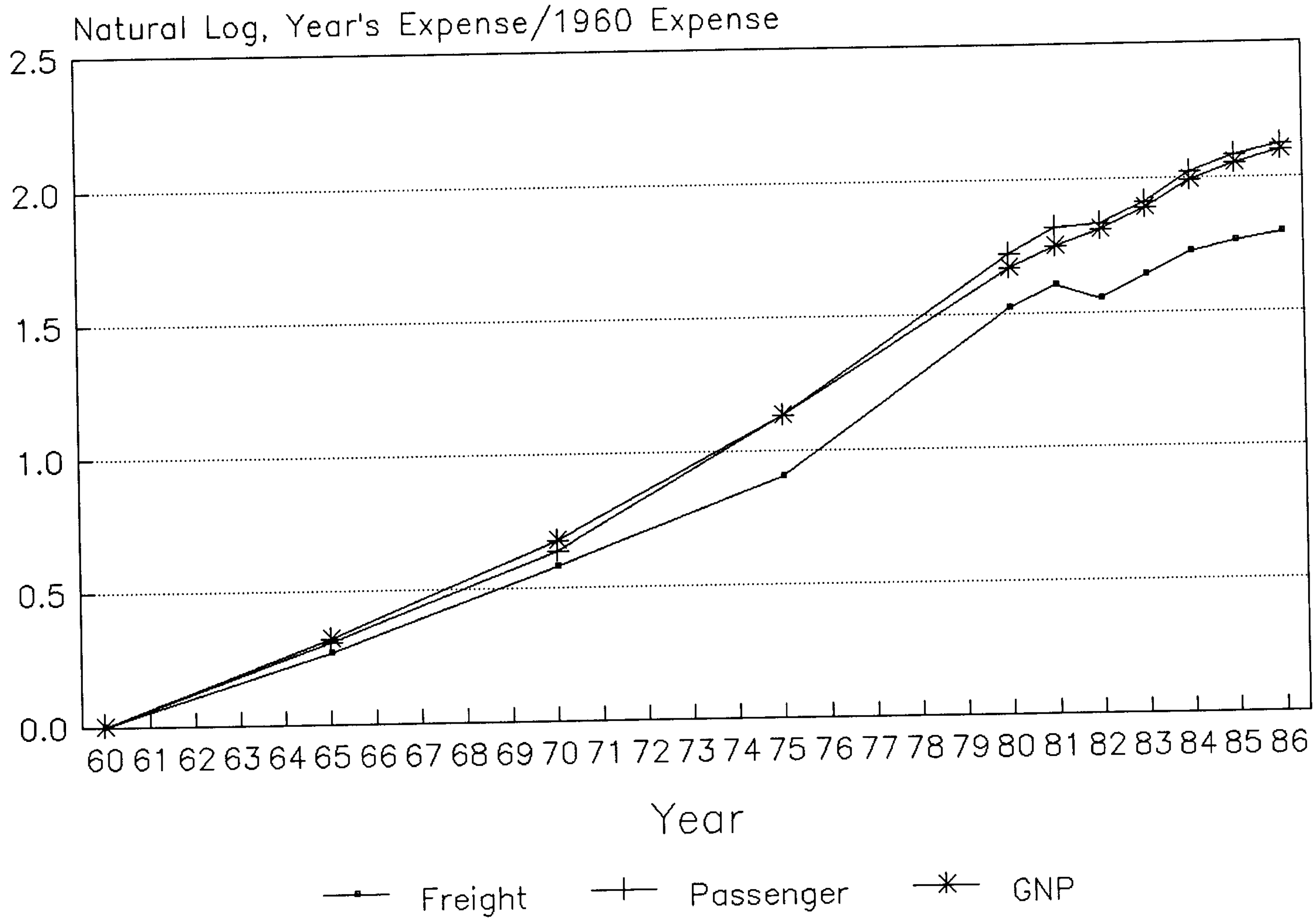
Source: Transportation in America, 1987

Figure 8: Intercity Ton-Miles by Mode 1940-1984



Data from Moody's Investor's Services

Figure 9: Freight and Passenger Expenses Relative to GNP, 1960 - 1986



Source: Transportation in America, 1987