that will not be subject to year-by-year budget pressures and fluctuations. Transit supporters have done this rather successfully in a number of cities through dedicated sales taxes, gasoline taxes, and other automobile user fees. However, even these dedicated taxing sources have been growing too slowly to keep up with transit financing needs. As a result, a few years after enacting one dedicated tax for transit, planners often find themselves looking for another. New York is well along in this process with some seven different dedicated taxes, ranging from a mortgage tax to a unitary tax on oil companies

Another difficulty with implementing dedicated taxes is that generous short-range fare and service policies often create long-range financing problems. In Los Angeles, for example, a half-cent sales tax was recently implemented that uses what has come to be called the "Atlanta formula." To obtain political support from lower-income groups, policymakers promised to lower bus fares for a few years, and then use the sales tax funds for rail construction. While this works well in the short run, what happens to the bus fares when the time comes for using the tax for the rail system? In all likelihood, the bus fares will have to be increased very rapidly, as has happened in Atlanta.

Effects of Energy Supply and Telecommunications on Urban Mass Transit's Future

Sarah J. LaBelle and Martin J. Bernard III

There are many recent technology and resource developments that constitute significant changes from past trends. Both the forecast reduction in the availability of petroleum and the forecast increase in the availability of efficient telecommunications devices are changes from historical trends. This paper will examine the effects of both of these developments on urban mass transportation systems.

The topics are divided into three parts: energy for the operation of mass transit systems, the use of transit systems during an energy shortfall, and an analysis of possible changes in transit system use due to telecommunications technologies. Literature in each area will be surveyed. We conclude from this review that energy shortfalls may provide an opportunity for transit systems to gain visibility and that rising energy prices will exacerbate present deficits, but that the general issues of energy availability and the rise of telecommunications devices are not developments that will make or break the success of transit systems. Instead, forecast changes in household structure and continuation of present trends toward lower-density development dominate the future for urban areas and therefore define the markets for transit.

ENERGY FOR OPERATION OF MASS TRANSIT SYSTEMS

Energy as an Operating Cost

The average U.S. transit system in 1980 spent 8 percent of its operating budget on fuels and lubricants (1). This is the most rapidly escalating cost facing a transit operator; since 1972, diesel fuel prices rose six times faster than the consumer price index. In the past decade, the share of operating cost attributed to fuel has more than tripled. Fuel for motor buses is no longer an incidental budget item; further price increases could push fuel alone to 17 percent of transit operations in 2000, based on an analysis done for the Houston Metropolitan Transit Authority (2). For that bus-only system, fuels and lubricants are about 7 percent of present operating costs. By 1989, after a period of continued diesel price increases, fuel is expected to rise to 11.3 percent of costs. Their assumed rate of price increase peaked during 1985-1990, at 7.76 percent/year. The rate of increase was assumed lower in other years, yielding a 116 percent increase in the real cost of fuel from 1982 to 2000.

Similar projections of a high rate of increase in the real cost of diesel fuel were made for the Technology Assessment of Productive Conservation in Urban Transportation (TAPCUT) project (3). Diesel fuel price was expected to catch up to gasoline prices during the 1980s, resulting in a 128 percent increase in price over 20 years in the more conservative of that study's scenarios.

The rationale behind these assumptions by two different sources of rising prices for diesel fuel is discussed in a later section of this paper. Their implications for transit are clear--that energy costs are becoming very important and will worsen the operating cost deficit if nothing else changes in the future.

Relative Energy Efficiency

Rail

Although rail transit currently carries about 40 percent of the passenger miles on all transit modes nationally (1), it is responsible for a slightly smaller fraction (35 percent) of the direct energy use for transit (3). Only 22 of the 1044 transit systems included rail in 1980 (1). These rail systems are less concerned about energy as an operating cost than bus-only systems, although regional variations in electricity prices may cause problems for some operators. Electricity is forecast by the Energy Information Administration (EIA) to be available and relatively inexpensive; the price is expected to rise to 6.29¢/kWh in 1995, compared with 4.53¢/kWh in 1980 (both figures in 1980$) (4). There is a much lower rate of increase than that expected for diesel fuel. Rail vehicles operated at full load are very energy-efficient, using only 436 Btu/passenger-mile (pax-mi) to carry 200 passengers in a car. At the average load of 22 passengers, however, their productivity is 3900 Btu/pax-mile, equivalent to 35 pax-mi/gal of diesel (5,6,36). These energy computations assume 10 400 Btu/kWh; that is, the energy content of the fuel used to produce electricity rather than just the electricity from the utility gate is included.

It is relevant to observe that only 5-15 percent of the energy for rail transit is likely to be petroleum-based, while bus as well as automobile are nearly 100 percent petroleum-fueled.

Bus and Automobile

In the mid-1970s, we argued that mass transit was energy efficient (7). In the early 1970s, with an average passenger load, an urban automobile obtained an energy productivity of 15 pax-mi/gal, while a busy urban bus got 60 pax-mi/gal (8,9). However, automobile fuel efficiency has improved since then and transit bus efficiency has not. The typical transit bus achieved 39 pax-mi/gal using vehicles that get 3.5 vehicle-mile/gal of diesel and carry 11.2 passengers. Both the vehicle efficiency and the passenger load vary by system, however. The Chicago Transit Authority, for example, currently averages more than 50 pax-mi/gal of diesel.

In 1980, with an average occupancy of 1.7, the range of the new car productivity is from 20.6 for six-passenger cars up to 30.7 pax-mi/gal for four-passenger cars, on a city driving cycle. These values are computed differently than the values cited for early 1970 vehicles. However, average fleet fuel economy has increased 9 percent from 1973 to 1980 (10). New-car fuel economy increased 25 to 40 percent in that time, depending on the estimating method (10). Table 1 displays fuel economy for urban vehicles under different assumptions of speed and passenger load.

For the automobiles and van on urban cycle, the U.S. Environmental Protection Agency (EPA) method is used to calculate fuel efficiency; that method assumes that only the driver is present and that the average speed of urban travel is 16.8 mph. In general, urban vehicle fuel consumption is calculated (5) as

$$FC = C_1 + C_2 W + (C_3 + C_4 W)(1/V)$$

where

C_1, C_2, C_3, C_4 = constants that are functions of the size, weight, engine type, and performance of the vehicle;
W = weight of the driver, passengers, and payload; and
V = average speed.

As the loaded weight (passengers, driver, vehicle) increases, so does fuel consumption. The values in Table 1 demonstrate the effect of passenger load on vehicle fuel economy. A 15-passenger van, for example, drops from 13.6 miles/gal with the driver only to 13.3 miles/gal with 15 passengers. The energy efficiency per person-mile, however, increases as the load increases.

A simulation of energy efficiency of the transit bus was carried out by Booz-Allen and Hamilton for UMTA (11). The fuel economy shown for the standard transit bus in column four in Table 1 is from a simulation of a route like the Portland, Oregon, "ZOO" route. Other simulations of energy used by a standard 40-ft bus with no passengers, on several different routes, were also done; efficiency varied by route between 2.59 and 5.43 miles/gal of diesel. Characterization of standard transit vehicles done for the TAPCUT project estimates an average of 3.5 miles/gal for all urban buses (5). The newer articulated buses operate at only 2.5 miles/gal. The simulation showed that at 20 passengers (higher than the present average of 11.2), the productivity of the standard bus can vary from 47.8 to 103.8 pax-mi/gal of diesel, depending on the route. Bus routes in Chicago with similarly high average loads also have energy productivity levels in this range (9). System averages are, of course, much lower than the best routes.

The general conclusion from these data is that as urban passenger transportation systems are now operated, buses are 27-90 percent more energy productive than small and large cars, about as energy efficient as carpools, and far less energy efficient than vanpools. Second, at high load factors, transit is far more productive than personal cars, but still loses to a full vanpool vehicle.

Table 1. 1980 urban passenger vehicle energy productivities (pax-mi/gal).

				Bus		
Load	Small Otto Cycle 4-Passenger Car	Large Otto Cycle 6-Passenger Car	15-Passenger Vanpool	Standard Transit[c]	Standard	Articulated
Driver only	18.3	12.2	13.6	3.32	3.5	2.5
Average	30.7[d]	20.6[d]	125[e]	43.1[f]	39.2[f]	
Carpool	47.8[g]	32.2[g]	-	-	-	-
Maximum	69.8	69.6	176	140[h]	175[h]	313[h]
Various						
20 passengers	-	-	-	62.0	70.0	50
50 passengers	-	-	-	140	175	125
75 passengers	-	-	-	189	263	-

[a] The different energy content of diesel and gasoline is not included in these calculations. A unit of diesel fuel contains 1.104 times the energy of the same unit of gasoline. First three columns assume gasoline; second three assume diesel fuel.

[b] City cycle average speed 16.8 mph, except buses (5). Last two columns exclude effect of passenger weight.

[c] See Booz-Allen and Hamilton (11).

[d] 1.7 people.

[e] 10.2 people (12).

[f] 11.2 people (1).

[g] Average carpool of 2.68 people (12).

[h] 50 people for standard buses, 125 people for articulated buses.

Figure 1. Operating energy productivity of urban vehicles at average passenger loads (load factor).

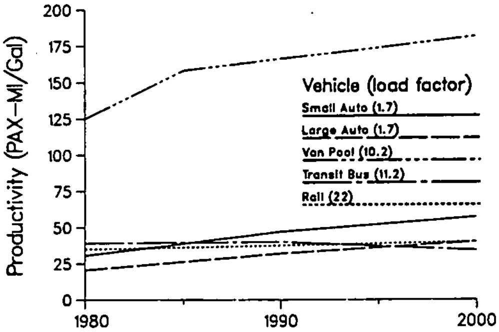
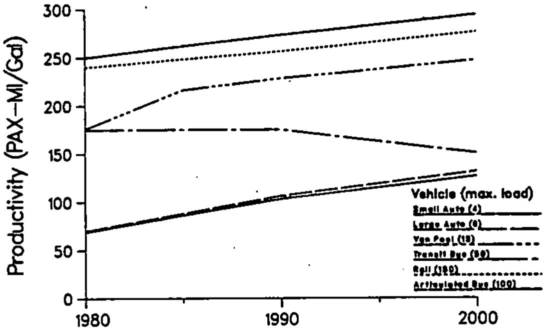


Figure 2. Theoretical energy productivity: urban vehicles at maximum load.



Forecast Fuel Economy

Several forecasts of urban vehicle energy productivity are shown in Figure 1, using present-day average passenger load factors. The vehicle fuel economy increases if technology developments allow it, but the load factor is unchanged. Vanpools are clearly the most energy-efficient mode now operating. The other vehicles are relatively close to each other in productivity and get closer over time. The standard transit bus falls to the bottom of the heap in 2000. This decrease is due to expected further lowering of vehicle fuel economy as buses are made heavier and continue to use air conditioning. Even the most optimistic expectation for transit buses raises that figure of 34 pax-mi/gal in 2000 to only 45 pax-mi/gal of diesel--still lower than the small car (13). Use of small 20-seat buses would raise it to 80 pax-mi/gal, however. Rail transit does not surpass bus in productivity until 2000. The 17 percent increase in operating efficiency for rail cannot compensate for the low average load factor. Merely doubling the load factor would make rail as efficient as the small bus above. More extensive use of light rail systems in place of the now-dominant heavy rail also provides an opportunity to save energy. These systems are 20 percent more efficient than heavy rail at the same average load.

The small and large automobile and vanpool productivities are based on gasoline. Conversion to equivalent diesel gallons would raise the values by 10 percent. Small cars would still come out as most fuel-efficient. Productivity of large cars would fall below that of an improved transit bus in 2000, using Btu-based, rather than volume-based, computation.

Through 2000, vanpools are far and away the most energy-productive of urban travel modes, but serve only work trips, as they depend on the employer for coordination of the origins, destinations, and time of travel. For non-work travel, the transit bus is most productive in 1980. Increased non-work or off-peak use of transit is currently fuel efficient. As early as 1990, however, a small car is better than a bus at average load. If non-work trips by automobile continue to have higher load factors than work trips, energy benefits will accrue from the use of large cars in 1990 also. Unless transit load factors increase, or currently unlikely technological advances occur in bus design, transit will not be the energy-efficient mode of the future. Of course, inclusion of land consumed by automobiles and the size of the infrastructure to support the automobile may influence final judgment on total energy.

The maximum theoretical energy productivity of each vehicle in Figure 1 is shown in Figure 2. The assumed maximum load factors are indicated in parentheses on the figure's legend. The results are much different from those of Figure 1. A packed articulated bus tops the list; but 31 standing passengers are assumed to calculate the 250 (in 1980) to 293 pax-mi/gal (in 2000) productivities. Similar conditions on a heavy rail car (150 people/car) lead to nearly as high productivity for that transit mode. Light rail could achieve the same productivity with only 120 people/car. Vanpools are in third place, with 15 people in a 15-passenger van. The transit bus assumes only 50 passengers; productivity still falls due to the technology development assumptions. Full passenger cars are at the bottom of this chart, even though their productivity almost doubles in the 20-year-period due to expected advances in automobile design. Again, automobile values assume gallons of gasoline, not diesel.

Comparison of these two figures shows that gains in load factors for transit vehicles would greatly change their energy-saving value. The other sources of increase in energy productivity--vehicle design improvements--is more likely for automobiles than for transit vehicles. This emphasizes the importance of load factor improvements or use of smaller vehicles for transit. (The smaller 20-ft buses have double the vehicle fuel efficiency of the standard bus.) Further, there are many alternate propulsion systems under development for automobiles, which may raise automobile fuel efficiency still further (3,5). Similar advances are unlikely for bus and rail vehicles because of the small, shrinking markets. Only spin-off benefits from truck improvements are likely (3,14).

Forecasts of Fuel Supply and Price

A few sources have forecast the availability of petroleum fuel to the year 2000. Although the price of petroleum is expected to change significantly over the next two decades by most forecasters, petroleum supply to the United States is not expected to diminish in the aggregate until after the turn of this century. More forecasters also see a growth in the U.S. fuel consumption in the aggregate especially up to 1990. The petroleum component is expected to diminish as a fraction but not in absolute amount. Table 2 shows the supply forecasts made by the U.S. Department of Energy as well as two forecasts sketched out for the TAPCUT project.

The difficulty in forecasting fuel supply is that both the amount of resource available and the market competing for that resource worldwide must be specified to determine U.S. supplies. For this reason, most forecasts tend to be based on continuation of present trends. Furthermore, the forecasts presume some stability in the world situation; severe shortfalls in petroleum are not assumed in the long-term forecasts.

Table 2. Projections of domestic fuel supply (quads).

	Baseline	TAPCUT[a]				EIA[b]	
		Scenario 1		Scenario 3			
Fuel Category	1980	1990	2000	1990	2000	1985	1995
Liquid Fuels							
Domestic oil[c]	20.6	16.7	22.6	21.5	19.8	19.3	21.2
Imported oil	14.4	10.2	3.7	16.1	14.3	14.7	10.6
Coal liquids	-	1.8	3.0	-	-	-	-
Shale oil	-	3.8	8.0	-	-	-	-
Total	35.0	32.5	37.3	37.6	34.1	34.0	31.8
Non-Liquid Fuels							
Renewables	3.0	6.6	11.7	4.9	7.1	3.3	3.6
Natural gas	20.7	22.2	24.2	20.5	17.9	19.5	19.4
Nuclear	2.7	6.5	12.5	5.0	7.0	5.4	8.6
Direct coal	18.9	24.0	25.3	20.4	28.1	16.5	29.5
Coal gas	-	1.2	3.0	-	-	-	-
Total	45.3	60.6	76.7	50.8	60.1	44.7	61.1
Adjustments[d]	-0.3	-	-	-	-	-	-

[a] See LaBelle and others (3).
[b] See EIA (4).
[c] Crude oil from conventional wells and enhanced oil recovery.
[d] EIA other imports and adjustment categories (20).

Even if the total supply of petroleum in the United States is constant over the next two decades, that does not assure sufficient supplies for the needs of transit vehicles. Examination of forecasts of demand by other sectors is relevant. Because of increases in fuel economy of automobiles, total fuel demand by automobiles is expected to decrease by 2000, as long as the price of automobile travel does not drop significantly relative to today (3). Most of that fuel will be gasoline; diesel vehicles cannot penetrate into the automobile fleet fast enough to be large consumers of diesel fuel. In fact, one very likely scenario regarding diesel automobiles is that they will rise in popularity until 1990, after which time production of new vehicles will fall off sharply. The expected improvements in efficiency of gasoline-powered, spark ignition engines will have surpassed diesel fuel economy by that time (3). Should the opposite be true, that diesel automobiles are never surpassed in fuel economy by Otto-engine vehicles, then it is likely that there will be a large increase in the amount of diesel coming out of refineries, relative to the current production ratios.

The other major competitor for diesel fuel is the trucking industry. Truck fuel consumption is expected to grow sharply before 2000 (16). The effect of their rising consumption of diesel fuel may exhibit itself primarily in the form of price.

Our last area of competition for diesel fuel is interesting to investigate. In the world market, many forecasters expect developing nations to sharply increase their demand for No. 2 diesel fuel (17). If this occurs, there may be much pressure on the world petroleum supplies, making it difficult for the United States to obtain even the level of fuel supply it has now.

These speculations on factors influencing supply, in addition to the basic amount of resource remaining in the ground, are useful primarily for indicating the forces on supply. It is safe to conclude that petroleum will be available as a resource to the end of the century, at least at the level now being consumed in the United States. This is about 35 quads of crude petroleum.

Price

There is a wide range from the lowest to the highest price forecast now available. Table 3 displays some recent price forecasts for retail gasoline and diesel. In 2000, gasoline price ranges from $2.06 up to $3.80 (in 1980$). All these forecasts are in constant dollars, excluding effects of inflation. The range of prices reflects the uncertainty both in mechanisms for determining price in the marketplace and in the major factors that are assumed to affect price, i.e., the number of contenders demanding each fuel and the resource base. A further uncertainty in these prices is the amount of tax on the final price. The increases in automobile fuel economy could provide an impetus to governments to raise taxes, so that automobile and truck operating costs do not fall in real terms. This has not yet occurred, however.

Although most sources do not forecast a separate diesel price, there is an assumption that its price will equalize with that of gasoline as the production of diesel fuel increases in response to increases in demand for it. EIA, for example, sees a doubling in the amount of distillate fuels consumed in transportation between 1980 and 1995 (4).

The rationale behind the equalization of prices is based primarily on the refiner's need to collect a return on investment from the petroleum commodity sold in the greatest amount. Although the rate of increase in the near term is difficult to forecast because of the many political and economic factors that influence the daily price level, long-term price rises are inevitable as the supply tightens. Users who cannot increase their fuel efficiency will have to pay higher total amounts in the future for the same activities carried out today.

SUMMARY

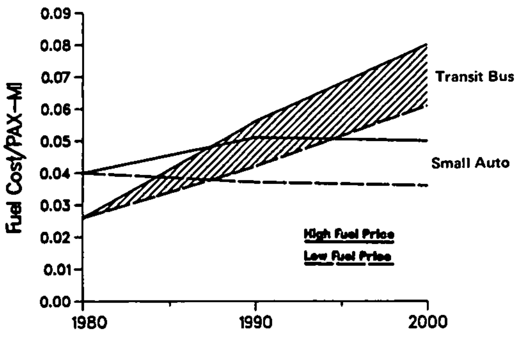
Although availability of appropriate fuel is not likely to be a problem, the price of fuel to operate transit systems is likely to continue to rise to burdensome levels. Both diesel fuel and electricity prices are forecast to rise between now and the year 2000, with diesel rising much more rapidly than

Table 3. Four forecasts of retail fuel price (1980$/gal).

Year	EIA[a] Mid-Price Scenario Gasoline	TAPCUT[b]				National Energy Policy Plan[c]-81 Gasoline
		Strong Economy Scenario		Moderate Economy Scenario		
		Gasoline	Diesel	Gasoline	Diesel	
1979	0.92	-	-	-	-	
1980	-	1.22	1.00	1.22	1.00	
1985	1.37	-	-	-	-	
1990	1.75	2.32	2.25	2.68	2.59	1.67
1995	2.20					-
2000	-	2.86	2.77	3.80	3.60	2.06

[a] SEE EIA (4). [b] See LaBelle and others (3). [c] See U.S. Department of Energy (15).

Figure 3. Change in operating costs due to fuel use for transit bus and small automobile under two price scenarios.



electricity. (Electricity prices may rise more in a few regions, however.) No compensating improvements in vehicle or system fuel efficiency are foreseen that would mitigate the effect of rising fuel price on transit operating cost. Transit's primary competitor, the private automobile, is also subject to the same price increases, but is the beneficiary of substantial improvements in vehicle fuel efficiency. These improvements are large enough to compensate for rising prices, slowing, or perhaps reversing the recent real increase in private automobile operating costs. The fuel portion of these costs are shown in Figure 3, which uses the fuel prices forecast under TAPCUT-Strong Economy Scenario in Table 3 and the average fuel productivities shown in Figure 1.

There are more energy-efficient modes of group travel than the standard transit bus or railcar under average load. The vanpool for work travel is unsurpassed for energy productivity. Transit vehicles can improve on the van's energy productivity only by including standees in addition to the maximum seated load. Use of smaller transit vehicles could raise transit's energy productivity above that of the year-2000 passenger car, at today's average passenger loads, and possibly lower the cost of services used. Of course, increasing the average passenger load would also directly increase the energy productivity of transit.

Although no long-term fuel availability problems are expected in this century, short-duration episodes of unavailability are still likely. These energy contingencies provide an opportunity for transit to serve new markets, but pose the problem of obtaining transit vehicle fuel at affordable prices during the shortfall. As all regulations passed before or during the last contingency have been allowed to expire, we will approach the next shortage only with our experience.

TRANSIT DURING A FUEL SHORTFALL

Impact of Shortfall on Transit Operations

The first fuel shortfall in the decade of the 1970s signaled the beginning of the first rise in transit ridership other than World War II since 1920 (18). Some cities' transit systems experienced ridership increases during both shortfalls, and nearly all systems experienced sharp increases during the second shortfall in 1979. Ridership gains that continued between 1973 and 1979 were due to short periods of rising price of gasoline, but more to the significant increases in transit service and concomitant reductions in fares that occurred in the middle of the decade (1,19).

Of course, most responses to fuel shortfalls come in the form of alterations in driving patterns, as has been documented in many studies (21). However, there are some by-choice riders who do opt for transit. A recent conference on energy contingency planning summarized many of these changes (22).

During a shortfall, several other factors affect transit operations. One is that the price of diesel fuel as well as the price of gasoline will rise somewhat. The extent of the rise will of course depend not only on the market but also on controls imposed by government. In the past two shortfalls, government limited the extent of price increases immediately during the shortfall. This may or may not be the case in future contingency situations. In addition to the immediate price problem, acquisition of diesel fuel for transit operations may also be troublesome. During 1979, it was necessary for transit operators to lobby for special set-asides of diesel fuel in order to assure that their operations could continue. Regulations passed during that time period have all expired, and have not yet been renewed.

Transit Capacity During a Shortfall

Transit ridership is sharply peaked during two periods of the day. Systems are generally sized to meet the demand of those peaks. Excess capacity on transit systems is generally available between these peaks and before and after them in the course of a day. This poses a significant problem for transit operators trying to accommodate the needs of urban travelers during a shortfall. Most of the travelers who are experiencing difficulty obtaining fuel want to travel during those peaks, but the transit operator really cannot accommodate much more than a few percent increase in the peak.

Options for Transit Operators

It is clear that transit systems must plan how to handle a fuel shortage before it occurs. Both the capacity problem during peak periods and the issue of availability of diesel fuel are sufficient reasons to make plans in advance of the highly likely next shortage. UMTA has produced a three-volume work suggesting actions to be taken by transit operators and metropolitan planning organizations during shortfalls (23). Some of the actions within the sphere of influence of the transit operator include making strategic changes to routes and schedules to accommodate the demand; encouraging area employers to allow staggered work hours stretching out the peak period of travel; and encouraging the use of other group travel modes, such as vanpools and carpools to minimize the crush loads on the transit vehicles. Another likely action for transit operators is to lobby the state legislature for enabling legislation that allows mandatory set-asides for transit operators, similar to the rules in 1979.

The rules and regulations that pulled us through the shortfalls of the 1970s have all expired; it is not clear whether such rules will be enforced in the next shortfall. A transit operator must be prepared regardless of whether such regulations are again passed.

One suggestion that has been made is for transit operators to stockpile fuel (24). The idea is to have about three months' worth of fuel on hand at any time. To cash-short transit operators, this may seem a difficult proposition. However, it might be reasonable to ask public funding agencies to advance capital funds for the acquisition of tanks to store fuel. Otherwise, the transit operator could take loans to buy in the fuel futures market. It is, of course, the decision of a specific transit operator as to whether such buying in advance is worth the risk.

One change has occurred since the last shortfall, i.e., the establishment of national, emergency petroleum reserves. It is difficult to determine the impact of the Strategic Petroleum Reserve (SPR), however. It now contains about 275 million bbl; current U.S. petroleum consumption is about 16 million bbl/day of which about 6 million bbl is imported. The amount now stored would have made up the losses experienced under the two shortfalls of the 1970s. Perhaps its use then would have lessened the impact on world oil prices somewhat. How the SPR will be used, given the uncertainty of the depth and length of a shortfall, is difficult to predict. Certainly, the price of petroleum will rise. The method of domestic allocation of the reserve has not been fully specified, and certainly has never tested for its effect on fuel users. Other countries have similar reserves; and the international agreements about the sharing of oil in reserves may prove difficult to honor and may limit domestic allocation in schemes that are finally agreed on.

MARKET FOR TRANSIT IN AN ELECTRONIC AGE

Rapid-fire improvements in electronics have led to the design of many new communication devices. The variety of devices is astounding; data transfer as well as voice transfer of information can be done easily now. As more and more specialized devices, which become very low-priced as the designs improve, come into common use, many raise questions as to the behavioral changes that might arise as a result of these devices. If, for example, items to be purchased at a department store can be viewed over a television screen from the home, will trips in the automobile to the department store be eliminated? Will there be an increase in the use of trucks to bring consumer goods directly to households? In the area of work travel more and more extensive use of data transfer by electronic means allows different workplace organization. Will there be any change in the pattern of travel to work? We will attempt to address these questions, providing a framework for determining some answers to them.

Telecommunications Technology Forecasts

At present, the telephone network is widespread and inexpensive. It is used for voice transmissions, and is being used more and more for transfer of data. The transfer can be between computers directly, or from the user to a central computing facility. Furthermore, specialized hardware for processing of printed reports is now widely available and the equipment can receive data transmissions by phone from remote locations. The devices for data transfer are becoming more lightweight and inexpensive. Optical scanning equipment can read printed pages, transforming information into electronic representation. These devices are also improving in the accuracy and ability to read more kinds of printed information.

Software--the sets of instructions particular to one task to be carried out on a hardware device--is being developed for more and more purposes. Tailoring telecommunications devices to particular uses is the innovation wave of this decade. Manufacturing processes, assembly of parts, as well as tax computations and learning algebra, can be assisted by the use of telecommunications devices and software keyed to that situation.

The main features of change in the communications technology are the lowering of costs with the use of semi-conductor materials, the compactness of new devices, and the flexibility of software specific to a particular task. One example of this change is in banking; credit cards with a microchip embedded in it, called a smart card, can be used in place of checks. Automatic debiting of the account can occur over the phone link from store to bank, saving the high cost of check processing ($1/check now) (25).

Besides telephone line communication, another growing area is television cable communication. Currently, televisions are used as one-way broadcasting devices. The development of two-way communication links along television cable opens up the possibility of a new, large-scale, two-way network. The carrying capacity of television cable is extremely large in comparison to telephone communications equipment.

The means of transmitting voice and data communications is another area of rapid technological advance. A greater and greater share of telephone communications is carried by microwaves. Advances in switching equipment and the use of optical fiber cables promise large increases in the carrying capacity of the network for telecommunications. The use of digital instead of analog transmission is increasing the capacity of existing lines. These increases in capacity are responsible for much of the large reductions in the cost of communication. Without these reductions in transmission costs, the availability of terminals, such as telephone and computer access devices, is relatively unimportant.

Further utilization of computers will also be encouraged by improvements to the input and output devices. Simplified keyboards and cathode-ray tube (i.e., television) terminals are some advances. Breakthroughs in two-way voice communication with machines are expected within a few years.

Possible Changes in Work Travel

It is clear that the advances in electronics and communications allow many significant changes in the way in which work is carried out. Office work, such as report preparation and filing, can be streamlined by the use of automated word-processing machines and magnetic information storage and retrieval systems. Once information is stored magnetically, it can be accessed through remote devices. It is not necessary to be physically located in the office where the reports are stored to examine and modify those reports. If report modification or preparation is the main focus of one person's job, then it is not necessary for that person to be located at the workplace to complete all of the tasks.

In the area of voice communication, more extensive use of teleconferencing could theoretically substitute for business travel. Both voice and data communication devices will change many jobs so radically as to eliminate them. Electronically controlled mechanical devices could carry out many tasks now carried out by people. Assembly of automobiles is one current example. Programmable communication devices that control robots eliminate the need for the assembly-line worker. However, personnel will be required who are skilled in programming and maintaining the device that now performs the task.

These changes that are allowed by the existence of new communications devices are not foreordained to occur, however. There are many constraining factors. One factor has to do with the quality of the data transmission. If many errors creep into longer-distance transmission of data, for example, then there will still be an incentive to come to the office daily. In the case of manufacturing, the change in jobs from assembly to programming and electronics repair may shrink the work force, but does not eliminate the need for the work force to be present. There will certainly be a change in the basic skills required for production of manufactured goods.

Many have argued that the opportunity to have an office at home, yet still communicate easily with coworkers via electronic devices, would greatly reduce work trips for white-collar employees. For significant changes in the amount of travel by white-collar workers to occur, concomitant changes in organizational structure are required. It is now critical for workers to be present in the same location a majority of the time in order to develop the hierarchy of staff that maintains the workplace. Much of the identity with a particular employer derives from their physical location of employment. Control over employee productivity is maintained through direct observation of the employee. Changes in the way in which businesses are organized are not impossible, but appear at this point to be very difficult. Even the recently begun practice of flextime, where employees are not required to arrive and depart at a fixed hour, has come into question recently (26). Not all companies have experienced that practice as resulting in improved employee productivity and reliability. If the need for physical proximity dominates the organization of office, then telecommunications devices will be used strictly as ways of improving productivity within the office. Under that situation there will be no change in trips to the workplace.

The existence of the telecommunications equipment might facilitate dispersed office set-ups, however. Although daily presence at an office site would be required, many smaller office structures might be fostered in the future. This is a trend already in place; large corporations frequently make use of small offices in several locations in a metropolitan area to increase contact with clients. Banks and savings and loans are certainly at the forefront of this trend, with the widespread use of neighborhood branch bank offices. Several scenarios of office dispersal are described in a report by SRI International (27) and in a recent report on the mechanization of work (37).

Another area of possible change is business-related travel rather than travel to and from the workplace. The area of intercity trips, possible candidates for substitution by teleconferencing, is beyond the scope of this paper, however. Intercity travel has very little connection with transit use.

Possible Changes in Non-Work Travel

Increased use of telecommunication devices has almost unlimited possibilities for shopping and recreational activities. The most obvious is the use of television screens to review items for purchase and use of the telephone or a two-way television communication link to order goods. Then local delivery trucks could be used for many of the shopping trips now done in personal cars. Games, computer dating, travel and tour information, and hobby classes are among the items for entertainment uses of telecommunications. Interactive television opens up opportunities for instantaneous public opinion polls, question and answer sessions with politicians, and gambling on horse races and bingo. Sophisticated monitoring devices might even allow remote control of cooking facilities. Also, some interaction regarding house services could be carried out over communication devices.

As in the case of work travel, the existence of the device does not mandate the change in behavior to use the device. Some of the means of communicating may be inadequate to people's needs. The postulated change in methods of shopping, for example, may occur for only certain types of goods. Clothing, perhaps, will always require a personal visit for fitting.

Net Effect on Transit Use

Estimates have been made by many sources of the maximum possible diversion of trips to telecommunications for both work and non-work purposes. In a survey of the literature done by the National Transportation Policy Study Commission in November 1978 the highest estimate of vehicle miles of travel (VMT) that could be substituted by telecommunications was 16 percent (28). Virtually all of that travel was for work purposes. There is probably no way to validate that estimate, or the estimates of substitution on a trip basis that range up to 22 percent. Even if these estimates were valid, they are for all urban trips. Some further analysis must be done to determine the impact on transit travel in the urban area.

If, as most authors suggest, telecommunications allows further decentralization of population in urban areas, then it will contribute to the ever-decreasing ridership of transit systems nationwide. The recent increases in national transit ridership are due primarily to relative costs of travel by automobile and transit. The cost of automobile travel in urban areas rose sharply in the same five-year period that saw the first increase in transit ridership since World War II (18). As automobile energy efficiency catches up with fuel prices, these increases in operating costs will disappear, as illustrated earlier in this paper. Furthermore, only extremely large increases in the cost of automobile travel result in substantial increases in transit ridership (29).

Telecommunications improvements are not likely to address this difference in costs of transit versus automobile. If telecommunications does foster decentralized work locations, then its effects on transit will be negative. However, the reasons for this negative effect stem from transit's inability to serve well any of the present dispersed (that is, non-CBD) work locations. Thus, it could not be said that telecommunications was causing the mode shift away from transit; rather the many forces (including telecommunications) that disperse employment locations into the suburbs require changes in the provision of transit service that have not yet occurred.

The review of telecommunications impacts on urban transit done by SRI International highlights the extent to which rail transit depends on strong CBDs (27). This relationship depends both on the activity density of the CBD and the high level of capital investment already made by the transit system to serve the CBD. It is instructive to examine the activity density at some of the non-CBD locations, however. Work done for DOT shows that many of these suburban locations are as densely populated in the daytime as are healthy CBDs (30). The difficulties of transit may stem from commitment to rights-of-way and routes rather than from lower activity levels in the new workplace locations. Of course, residential density in the neighborhoods surrounding a suburban center will affect the probability of successful transit service to that center. Also, if parking costs are not levied directly on automobile drivers, transit service would not be price competitive (31).

It is not likely that overall travel will decrease with the introduction of improved telecommunications methods. It can be postulated that telecommunications devices are an improvement in lifestyle, corresponding to an increase in the wealth of the nation. The introduction of the tele-

Table 4. Growth in personal travel before 1940.

Year	Travel by All Motor Vehicles (10^9 VMT)			Private Passenger Cars Registered (10^6 automobiles)	U.S. Population (10^6 persons)
	Reported	Urban	Rural		
1900				0.008	75.99
1905				0.077	
1910				0.458	91.97
1915				2.332	
1920				8.131	105.71
1921	55.0				
1922	67.7				
1923	85.0				
1924	104.8				
1925	122.3			17.439	
1926	140.7				
1927	158.4				
1928	172.9				
1929[a]		107.4	90.3		
1930		111.2	95.1	22.972	122.775
1931		115.6	110.6		
1932		106.4	94.2		
1933		105.6	95.1		
1934		112.5	103.0		
1935		118.3	110.2	22.494	
1936		129.4	122.7		
1937		138.1	132.0		
1938		136.3	134.9		
1939		142.3	143.1		
1940		150.0	142.2	27.372	131.669
1980[b]		847.1	672.7	122.595	225.159

[a] First year of data on urban/rural split. [b] See Highway Statistics 1980 (34).

phone to the United States might be viewed in this way. The telephone is the major communication device introduced before 1910. Even before 1910, rapid growth in telephone use occurred, as the number of conversations grew from 5 billion in 1902 to 11 billion in 1907. Between 1910 and 1920 the number of phones per capita in cities rose 64 percent and in the following decade another 50 percent (32). (Population grew about 15 percent each decade.) In fact, the introduction of the telephone came about at very nearly the same time as the introduction of the automobile. Its introduction provides the main empirical base for observations of trade-offs between transportation and telecommunications. Table 4 (33,35) shows the growth in VMT from 1920 to 1940 and the increase in vehicle ownership from 1900 to 1940, when telephone service was expanding rapidly.

The use of both technologies grew much more rapidly than did the population from 1900 to 1940. Only the Great Depression dampened the growth in vehicle travel, decreasing travel between 1931 and 1932. As the use of both grew rapidly in basically the same time period prior to World War II, no basis exists to presume a corresponding reduction in travel with increased telecommunications. Shifting in destinations is likely to occur, but in a way that does not lower travel.

The introduction of the television, a one-way communication device, provides one other historical base for determining trade-offs. It may have lowered movie attendance initially, but it had no long-lasting effect on the amount of non-work travel by any mode in urban areas (34). Forecasts for the next 20 years show that personal travel increases by urban households are for non-work purposes rather than for work purposes (29).

Observations

One of the effects of telecommunications on transit then is that there will be no effect at all. The overriding historical momentum toward the use of automobiles over transit far outweighs any perturbation that might be introduced by telecommunications technology alone. Only insofar as telecommunications fosters dispersed land uses that transit now serves poorly can there be said to be any link at all. (The use of telecommunications devices to improve the management and operation of transit systems is reserved for another paper.)

The challenges for transit in determining new markets in the future derive from the land use patterns already established. There are perhaps many opportunities as yet untapped however. Research funded by DOT has demonstrated the existence of many dense daytime activity centers in the suburban areas. Many are as dense or more dense than present major-city CBDs. Many of the suburban centers are not served at all by transit. Provision of service to these centers is a major departure in the present orientation of urban transit systems. Most mass transit systems now have one center, its traditional CBD. Provision of service to multiple centers would be a new way of viewing the service areas.

SUMMARY AND CONCLUSIONS

It is highly likely that energy costs will rise in absolute terms for transit operators. If past trends continue, other costs will rise with inflation, as they are dominated by the labor portion. Energy costs will rise faster than inflation and grow rapidly as a share of total costs. By 1990, fuels and lubricants could grow to 17 percent of costs in contrast to the present level of about 8 percent. Unfortunately, there is no expectation for technology improvements in transit vehicles to counteract the rising costs of fuel. Automobiles by contrast are now in the midst of rapid improvement in fuel economy, which is expected to continue to the end of the century. These improvements in the personal automobile have the effect of keeping the price of automobile travel constant or possibly decreasing.

Even the most optimistic of transit technologies, if there were a market to purchase them, would not improve transit fuel economy very much. Improvements in the load factor, i.e., the use of the system, are really the only way to improve energy productivity of transit systems. At reasonably high load levels, transit is fuel efficient. However, present load levels make transit much less fuel efficient than automobiles by 1990.

The inertia of present trends in transit ridership implies even lower passenger load levels in the year 2000. Ridership is expected to decline in absolute terms in all but a few growing cities. Such forecasts presume that future transit systems are not much changed from present systems in terms of the technologies used and the location of the services. Population growth is forecast for urban areas to occur in the suburban rings, where transit now provides very little service. Further, as household size declines, the center city area will be less densely settled, providing fewer travelers along each transit route-mile. Insofar as telecommunications devices assist the continuation of growth in the suburban rings of metropolitan areas, that is the only connection between telecommunications activity and transit ridership. For significant links between transit and telecommunications, one must look on the hardware side. Improvements in operations or in administration are easy to envision with new telecommunications devices.

In summary, the picture for transit regarding energy is not as bright as it was in the early 1970s. Changes in automobile technology coupled with the low use level of most transit systems set the stage for the automobile's overtaking of transit as the most energy-efficient urban passenger mode. The lower indirect use of energy to build transit systems and their low consumption of land may not be sufficient to compensate for the higher operating energy use expected in the decade of the 1980s.

Energy shortfalls can be viewed as opportunities for transit systems to become visible as efficient transportation providers in urban areas. However, the riders attracted during shortfall situations are not likely to stay unless the price of automobile travel rises relative to the price of transit travel.

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