CHAPTER 12

Mass Transit

While real trolleys in Newark, Philadelphia, Pittsburgh, and Boston languish for lack of patronage and government support, millions of people flock to Disneyland to ride fake trains that don't go anywhere.

—KENNETH T. JACKSON

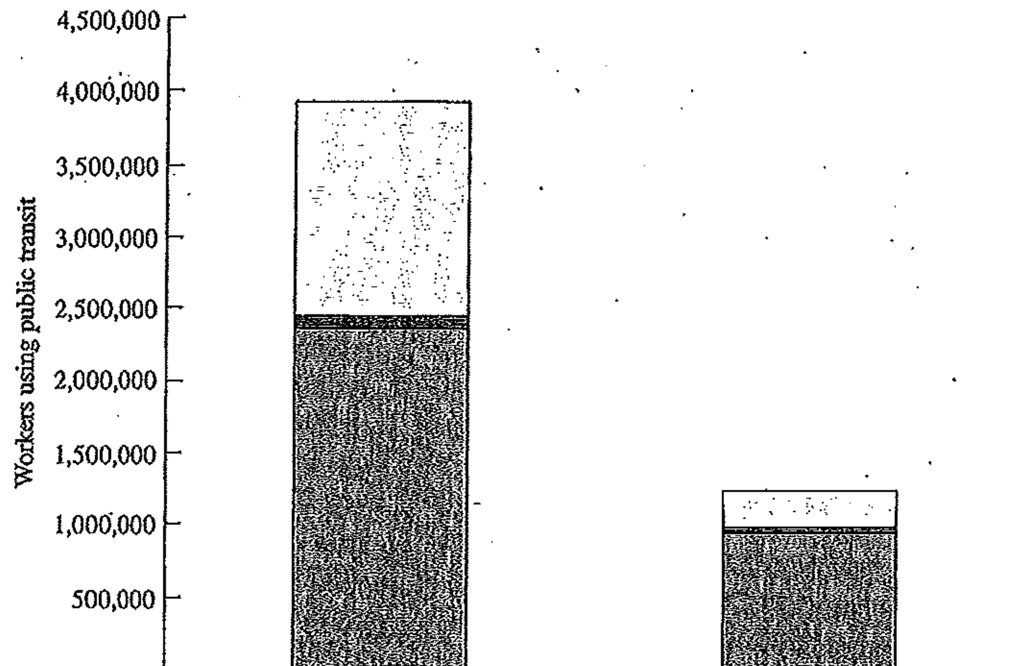
This chapter explores the problems and prospects of urban mass transit. In the last forty years, the percentage of urban travelers using mass transit decreased and the mass-transit sector went from a marginally profitable private-sector enterprise to a deficit-ridden public-sector operation. This chapter explores some of the reasons for this transformation and identifies some changes that could improve the urban mass-transit system. Here are some of the questions we'll consider:

1. How do commuters pick a travel mode, and why do so few choose mass transit?
2. What are the relative costs of different transit systems (heavy rail, light rail, and buses) and how do they compare to the costs of an auto-based system?
3. Is there a dark side to light rail?
4. Are high-occupancy vehicle lanes effective in increasing vehicle occupancy and decreasing congestion?
5. How would the privatization of urban mass transit affect the features of the transit system, ridership, and costs?
6. Do heavy-rail systems like San Francisco's BART have large effects on land-use patterns?

MASS TRANSIT FACTS

As shown in Figure 11–1 (in Chapter 11), a small percentage of metropolitan commuters use mass transit. The share of commuters using transit systems is 6 percent for all metropolitan commuters, 11 percent for central-city residents, and 2 percent for suburban residents. Figure 12–1 shows the distribution of transit ridership among

FIGURE 12–1 Transit Modal Choice for Residents of Central Cities and Suburbs



	Central-city residents	Suburban residents
Heavy rail	1,492,634	260,648
Light rail	52,810	24,197
Bus	2,381,213	950,807

Source: U.S. Bureau of the Census, *1990 Census of Population and Housing, SSTF20, Journey to Work in the United States.* (Washington, DC: U.S. Government Printing Office, 1994).

three transit modes for residents of the central city and suburbs. About 61 percent of central-city transit commuters use the bus, and 38 percent use heavy rail (subways and elevated trains). Suburban transit riders are less numerous; about 77 percent of them use the bus and 21 percent use heavy rail. Although light rail systems have received a lot of attention in the popular press, ridership on these newer systems is relatively low.

Transit ridership varies with the path of the commuter trip. As shown earlier in the book, about 40 percent of metropolitan workers commute from one suburb to another. Less than 2 percent of these commuters use mass transit. Transit usage is highest among workers who commute within the central city; about one in six of these commuters use mass transit.

Table 12–1 shows trends in transit ridership. Total ridership in 1995 was about 45 percent of ridership in 1950. After steady increases in ridership between 1970 and 1990, the number of transit rides has decreased recently, with the largest reductions in bus ridership. The trolley coach (a bus powered by overhead electric wires) reached its peak in 1950 and has declined since then. The use of light-rail systems (streetcars) decreased steadily between 1940 and 1980, but has recently staged a recovery; systems have recently been built or restored in Portland, San Jose, Sacramento,

TABLE 12–1 Public Transit Ridership, 1940–1995 (numbers in millions)

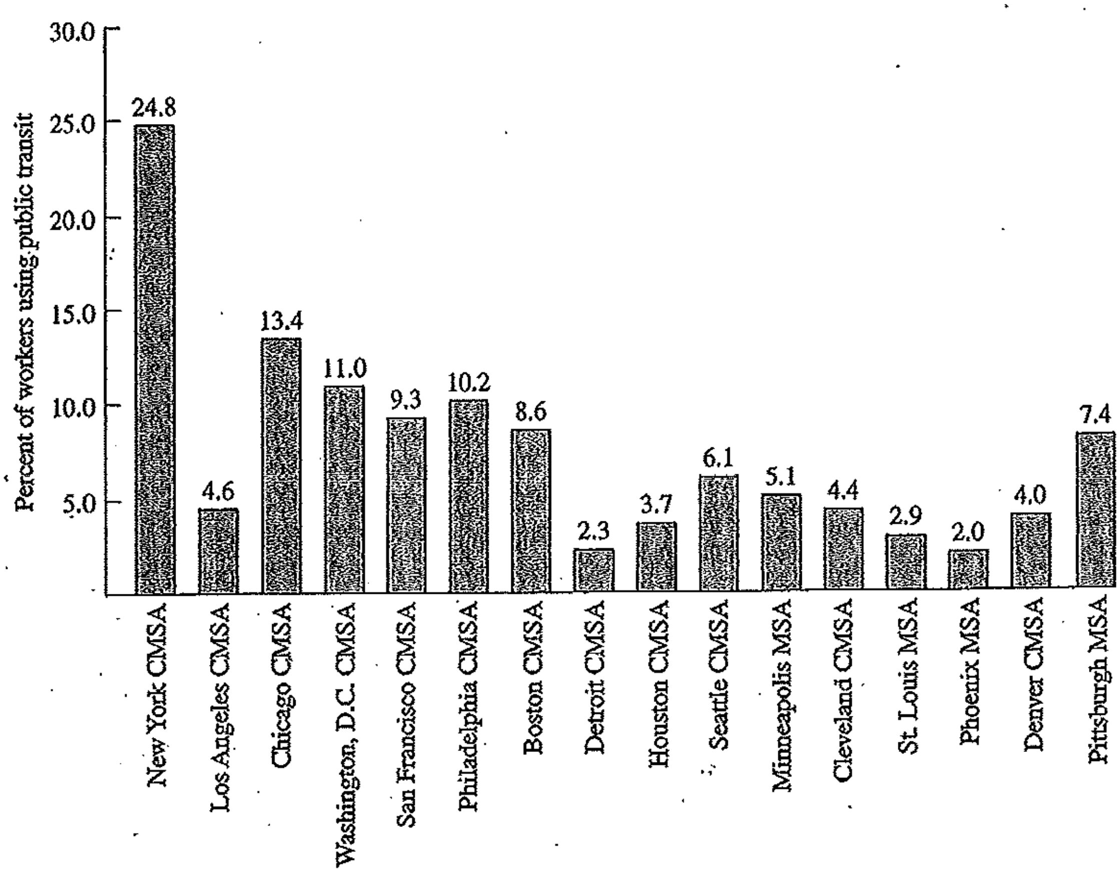
Year	Total Rides	Heavy Rail	Light Rail	Trolley Coach	Motor Bus
1940	13,098	2,382	5,943	534	4,239
1950	17,246	2,264	3,904	1,658	9,420
1960	9,395	1,850	463	657	6,425
1970	7,332	1,881	235	182	5,034
1980	8,567	2,388	133	142	5,837
1990	8,873	2,346	176	126	5,784
1995	7,763	2,033	251	119	4,848

Source: American Public Transit Association, *Transit Fact Book* (Washington, DC, 1991).

Buffalo, San Diego, and Pittsburgh. In Canada, there are new light-rail systems in Edmonton and Calgary.

There is substantial variation in transit ridership across metropolitan areas. Figure 12–2 shows the percent of workers who use public transportation for metropolitan areas (CMSAs or MSAs) with at least 1 million workers. The cities are arranged, left to right, in descending order of total employment. In the New York CMSA, about 25 percent of metropolitan workers uses public transit. No other metropolitan

FIGURE 12–2 Percentage of Workers Using Public Transportation, Selected Cities



Source: U.S. Bureau of the Census, *1990 Census of Population and Housing, Labor Force Characteristics and Journey to Work.* (Washington, DC: U.S. Government Printing Office, 1994).

area has a transit share greater than 14 percent. In fact, there are only three other metropolitan areas where transit ridership is at least 10 percent: Chicago, Washington D.C., and Philadelphia. Transit ridership is much higher among central-city residents: 47 percent of workers who live in New York City use transit, as do 26 percent of workers in Chicago and 25 percent of workers in Philadelphia.

What are the elasticities of demand for mass transit? By how much would transit ridership increase when transit fares decrease or transit service improves? There are four general conclusions from empirical studies of transit ridership:

1. **Price elasticity.** The demand for transit is price-inelastic, with a price elasticity between −0.20 and −0.50 (Beesley and Kemp, 1987). A common rule of thumb is that a 10 percent increase in fares decreases ridership by about 3.3 percent, meaning that the price elasticity is −0.33. According to Small (1992), the price elasticity is relatively large for off-peak trips and trips by high-income commuters.
2. **Time elasticities.** The demand for transit is more responsive to changes in travel time. For the **line-haul** portion of the trip (time spent in the vehicle), Domencich, Kraft, and Valette (1972) estimate an elasticity of −0.39: a 10 percent increase in line-haul time decreases ridership by about 3.9 percent. For access time (time spent getting to the bus stop or transit station), they estimate an elasticity of −0.71.
3. **Value of travel time.** According to Small (1992), the average commuter values the time spent in transit vehicles at about half the wage: the typical commuter would be willing to pay half of his hourly wage to avoid an hour on the bus or train. The value of time spent walking and waiting is two to three times larger: the typical commuter would be willing to pay between 1.0 and 1.5 times his hourly wage to avoid an hour of walking or waiting time. The value of travel time increases less than proportionately with income; a 50 percent difference in income generates less than a 50 percent difference in the value of travel time.
4. **Noncommuting trips.** The elasticities of demand for noncommuting travel are higher than the elasticities for commuting trips.

There are three principal implications from these empirical results. First, an increase in transit fares increases total fare revenue. A fare increase decreases ridership by a relatively small amount, so total revenue (fare times ridership) increases. Kraft and Domencich (1972) suggest that dropping the price of mass transit to zero—making transit free—would increase ridership by only about a third. Second, a simultaneous improvement in service and fares may increase ridership. Suppose that a transit authority increases the frequency and speed of buses and finances the improved service with increased fares. Because people are more sensitive to changes in time cost than changes in fares, ridership may increase. Third, service improvements that decrease walking and waiting time (more frequent service, shorter distances between stops) generate larger increases in ridership than improvements that decrease line-haul time.

CHOOSING A TRAVEL MODE: THE COMMUTER

This section discusses modal choice from the perspective of the commuter. The commuter chooses the mode that minimizes the total cost of travel (the sum of time and monetary costs). Suppose that a commuter has three travel options: the automobile, the bus, and a fixed-rail transit system such as San Francisco's Bay Area Rapid Transit (BART) or Washington, D.C.'s, Metro.

The commuting trip can be divided into three parts. The **collection phase** involves travel from the home to the main travel vehicle. The auto mode has no collection cost because the driver uses his own vehicle. The bus mode has a moderate collection cost because the rider must walk from his home to the bus stop. The fixed-rail system has the highest collection cost because there is a relatively long average distance between transit stations, so riders must either walk a long distance or take another mode (e.g., auto or bus) from the home to the transit station. The **line-haul phase** is the part of the trip spent on the main travel vehicle. The heavy-rail mode has the shortest line-haul time because it has an exclusive right-of-way, so it avoids rush-hour congestion. Although the bus and the auto both travel on congested streets and highways, the auto is faster because the bus must stop to pick up passengers along the way. The **distribution phase** involves travel from the end of the vehicular trip (at the downtown transit station, parking garage, bus stop) to the workplace. If parking is available near the workplace, the auto has the shortest distribution time, followed by the bus and the fixed-rail system.

An Example of Modal Choice

Table 12–2 lists the monetary and time costs of the three travel modes for Carla, a commuter who travels 10 miles from her suburban home to a job in the central city. The computations are based on the assumption that Carla values the time spent on the transit vehicle at half her wage rate and values time spent walking and waiting

TABLE 12–2 Costs of Travel Modes and Modal Choice

	Auto	Bus	BART
Collection time cost			
Collection time (minutes)	0	10	15
Cost per minute ($)	0.30	0.30	0.30
Collection time cost ($)	0.00	3.00	4.50
Line-haul time cost			
Line-haul time (minutes)	40	50	30
Cost per minute ($)	0.10	0.10	0.10
Line-haul time cost ($)	4.00	5.00	3.00
Distribution time cost			
Distribution time (minutes)	0	5	9
Cost per minute ($)	0.30	0.30	0.30
Distribution time cost ($)	0.00	1.50	2.70
Monetary cost			
Operating cost or fare ($)	2.00	1.00	1.50
Parking cost ($)	3.00	0.00	0.00
Total monetary cost ($)	5.00	1.00	1.50
Total time cost ($)	4.00	9.50	10.20
Total Cost ($)	9.00	10.50	11.70

at one and one-half times her wage rate. If her wage is $12 per hour, she is willing to pay $6 to avoid one hour of in-vehicle time and $18 to avoid one hour of walking and waiting time. Therefore, the cost of walking and waiting time is 30 cents per minute, and the cost of in-vehicle time is 10 cents per minute.

1. **Collection time cost.** Carla walks to the bus stop or the BART station. Since the bus stop is closer to her home, the bus has a lower collection cost.
2. **Line-haul time cost.** BART is the fastest mode (it operates on an exclusive right-of-way), followed by autos (which travel on congested streets) and buses (which travel on congested streets and stop to pick up passengers).
3. **Distribution cost.** Carla parks her auto in a company parking lot under her office building, so the distribution cost of the auto trip is zero. The bus stop is relatively close to the office, so the bus has a lower distribution cost than BART.
4. **Monetary cost.** The monetary cost of the auto trip is $0.20 per mile, or $2.00. The bus fare is $1, and the BART fare is $1.50. Half of the $6.00 parking cost is allocated to the morning commute.

The cost of driving is less than the cost of the bus and BART. Although the monetary cost of driving exceeds the monetary cost of the bus by $4, the lower time cost of the auto more than offsets its higher monetary cost. Similarly, the auto is more expensive but faster than BART. The largest difference in time cost is for collection and distribution costs, where the auto has a cost advantage of $4.50 over the bus ($3.00 for collection + $1.50 for distribution), and $7.20 over BART ($4.50 + $2.70). Since the auto has a lower total cost than both the bus and BART, Carla drives to work.

What would it take to persuade Carla to switch from her auto to mass transit? There are several possibilities:

1. **Subsidized transit.** If the bus and BART were free, Carla would still drive. To get her to switch to the bus, she would have to be paid a bribe of 51 cents per bus ride. A bribe of $1.21 would cause her to switch to BART. Transit fares must decrease by relatively large amounts to offset the time-cost advantages of the automobile.
2. **Line-haul time.** If the line-haul time of the bus decreased from 50 minutes to less than 35 minutes, Carla would ride the bus. She would take BART if its line-haul time decreased to less than three minutes.
3. **Collection and distribution time.** Carla would ride the bus if its collection and distribution time decreased from 15 minutes to less than 10 minutes and would switch to BART if its collection and distribution time decreased from 24 minutes to less than 15 minutes.
4. **Auto monetary cost.** Carla would ride the bus if the car's unit cost increased from 20 cents to 36 cents per mile. The imposition of a congestion tax of at least 16 cents per mile would cause her to switch to the bus. Similarly, if the city imposed a pollution tax of at least 16 cents per mile, Carla would stop driving.
5. **Parking cost.** Carla would ride the bus if the parking cost rose to at least $4.50 ($9 per day).

6. **Wage.** If Carla's wage dropped to $8, the bus would be less costly than the auto, and if her wage dropped to $6, BART would be less costly than the auto. As the wage decreases, the opportunity cost of travel time decreases, increasing the relative attractiveness of the modes with relatively low monetary cost and high time cost.

To summarize, to get Carla to switch to transit, the changes in either the monetary cost or the line-haul time cost would have to be relatively large. On the other hand, she would switch to transit with relatively small changes in collection and distribution time costs. These conclusions are consistent with the transit elasticities discussed earlier in the chapter.

What type of commuters take mass transit instead of driving? There are five possibilities:

1. **Proximity to stops and stations.** A person who lives near a bus stop or a rail station has a relatively low collection cost for transit and is more likely to take the bus or BART.
2. **Low opportunity cost.** For a person who has a low opportunity cost of travel time (e.g., a worker with a low wage, a student, a retired person), the time cost of travel is relatively low. As a result, the advantages of transit (lower monetary cost) dominate the disadvantages (longer commuting time). Such a person is more likely to choose transit.
3. **Low walking cost.** A person who enjoys walking has relatively low collection and distribution costs and is more likely to choose transit.
4. **Disutility of driving.** A person who dislikes the hassle and anxiety of driving is more likely to choose transit. In terms of the numerical example, such a person has a relatively high cost for in-vehicle auto time and is more likely to take the bus or BART. In contrast, a person who considers driving a challenging form of athletics will buy a pair of gloves and drive to work.
5. **No automobile.** Many of the poor do not have access to an auto, so their only option is to use public transit.

Transit Service and Modal Choice

How do changes in transit design and scheduling affect ridership? Transit ridership increases as a result of service improvements that decrease the time cost of transit. As explained earlier, commuters are most responsive to changes in collection and distribution time (walking and waiting time).

Consider first the bus system. The bus company affects time cost in two ways. First, it chooses the bus headway, the period of time between buses on the bus route. As the headway decreases, riders spend less time waiting at the bus stop, so their time cost decreases. Second, the bus company chooses the frequency of stops in the residential collection area. An increase in the frequency of stops decreases walking distances and collection cost. Similarly, the more frequent the stops in the downtown distribution area, the lower the distribution cost. An increase in the frequency of stops also increases line-haul (in-vehicle) time: more time is spent picking up and dropping off passengers, so the trip takes longer.

Consider next the design of a fixed-rail system. San Francisco's BART provides a nice illustration of the trade-offs associated with the design of a rail transit system. There are two basic design trade-offs:

1. **Mainline versus integrated system.** BART is considered a mainline system because it relies on other transit systems to collect its riders from residential neighborhoods. Riders must either walk, drive, or ride a bus to the BART station. The alternative to the mainline system is an integrated system, under which commuters make the entire commute trip on a single transit mode.
2. **Spacing between stations.** BART has widely spaced stations (about 2.5 miles apart), so there are few stops on the way to the city center. As a result, travel time from the suburban station to the downtown station (line-haul time) is relatively short, and in-vehicle time cost is relatively low. On the other hand, the average commuter must travel a relatively long distance from home to one of the widely spaced transit stations, so collection cost (by foot, bus, or car) is relatively high.

BART was designed to compete with the line-haul portion of the automobile trip. It achieves this objective, providing comfortable, speedy service from the suburban stations to the city center. There is a trade-off, however: Collection cost is relatively high because BART is a mainline system with widely spaced stations. Because walking and waiting time is more costly than in-vehicle time, the negative attribute (high collection cost) dominates the positive one (comfortable, speedy line-haul travel), so the full cost of a BART trip is relatively high and BART has diverted a relatively small number of auto commuters.

High-Occupancy Vehicle (HOV) Facilities

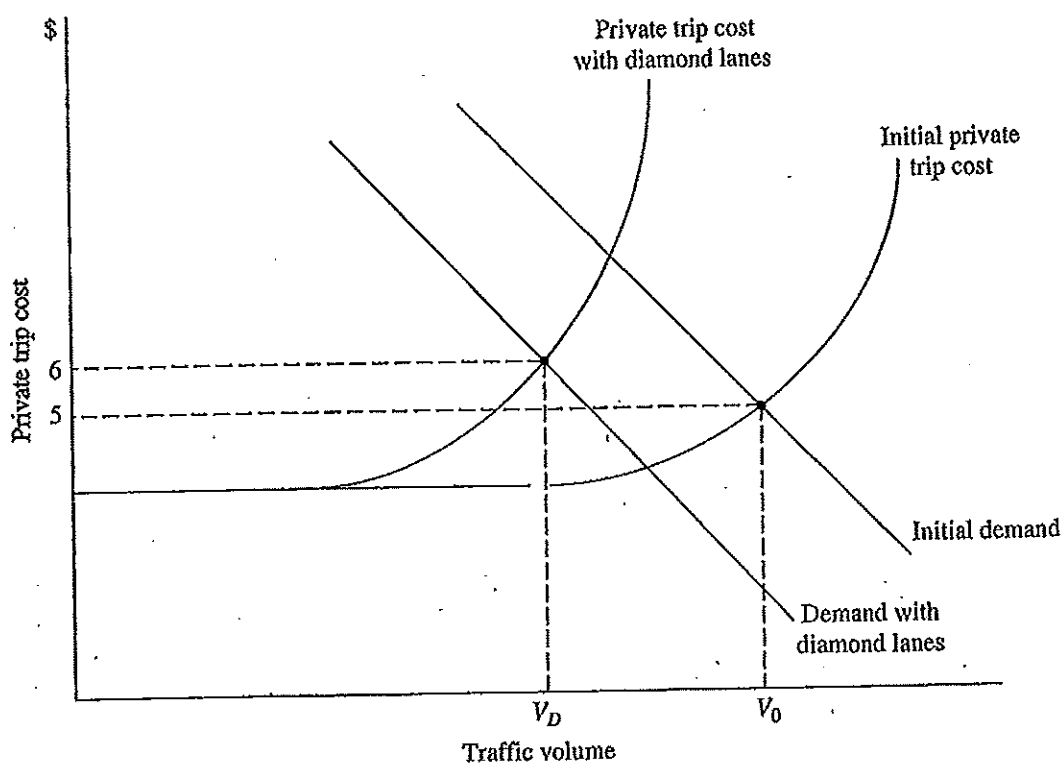
Many cities have established exclusive rights of way for buses, vans, and carpools, allowing these high-occupancy vehicles (HOV) to bypass congested roadways. At one extreme of the range of possible HOV facilities is a separate roadway, sometimes called a "busway"; at the other extreme is simply designating a single lane on an existing highway for use by HOVs (diamond lanes). There are HOV facilities in at least 17 cities, and several cities are using HOV facilities as a core element in their transportation plans (Giuliano and Small, 1994).

As explained by Giuliano and Small (1994), there is evidence that HOV facilities generate large benefits to commuters. HOV facilities improve bus service in two ways. First, line-haul times decrease because buses are able to bypass congestion. Second, any increases in bus ridership allow the bus authority to run buses more frequently, and more frequent service means lower collection and distribution costs. Mohring (1979) shows that the combined effect of these two service improvements leads to significant increases in bus patronage. Richmond (1998) describes recent experiences with HOV facilities that use exclusive right-of-way for buses, van pools, and car pools:

- Pittsburgh's East Busway has higher travel speeds than similar light-rail facilities, and it has increased bus ridership.
- Miami's South Dade Busway has increased bus ridership by 50 percent, in large part because it offers more frequent service and thus has economized on riders' collection and distribution costs.
- Ottawa's bus transitway system allows fast and frequent express service, which has helped the transit system achieve the highest market share of North American metropolitan areas of its size.
- Houston's HOV system is extensive, with almost 70 miles of HOV lanes (generally in freeway medians) in five transportation corridors. The ridership figures for the HOV system include bus riders, vanpoolers, and carpoolers, reflecting Houston's emphasis on mobility rather than transit ridership.

What are the effects of diamond lanes on commuters who continue to drive? There is good news and bad news. The good news is that some auto drivers switch to buses and car pools, so there is less auto traffic. In Figure 12–3, the diamond

FIGURE 12–3 Diamond Lanes and Auto Trip Costs



The addition of diamond lanes (reserved for buses and carpools) affects travel in nondiamond lanes in two ways: there are fewer vehicles in nondiamond lanes, so the demand curve shifts to the left; there are fewer lanes, so the trip-cost curve shifts to the left. If a relatively small number of vehicles are diverted to the diamond lanes, the net cost of travel in nondiamond lanes increases from $5 to $6.

lanes shift the demand curve to the left, decreasing trip cost for the original trip-cost curve.

The bad news is that there are fewer lanes for the remaining autos; the diamond lanes decrease the amount of road space, so the congestion threshold decreases and the trip-cost curve shifts to the left. In this example, the shift of the demand curve is small relative to the shift of the cost curve, so the trip cost increases from $5 to $6. This was the result of the ill-fated diamond lane on the Santa Monica Freeway in Los Angeles. The diamond lane shifted a relatively small number of commuters to car pools, so 25 percent of the freeway's capacity was used by only 6 percent of the vehicles (Dahlgren, 1995). After the resulting public outcry, the lane was returned to general use.

Some HOV lanes are more favorable for commuters who continue to use general-purpose lanes. If the shift of the demand curve in Figure 12–3 were large enough, the demand shift would more than offset the cost-curve shift, leading to less congestion and a lower private trip cost. Houston's HOV system is an example of a system that is favorable to nonusers. The system caused large increases in carpooling and bus ridership, so the HOV lanes diverted large volumes of traffic from general-purpose lanes. The average vehicle occupancy increased by 20 percent and congestion dropped by 4 percent (Richmond, 1998).

CHOOSING A SYSTEM: THE PLANNER'S PROBLEM

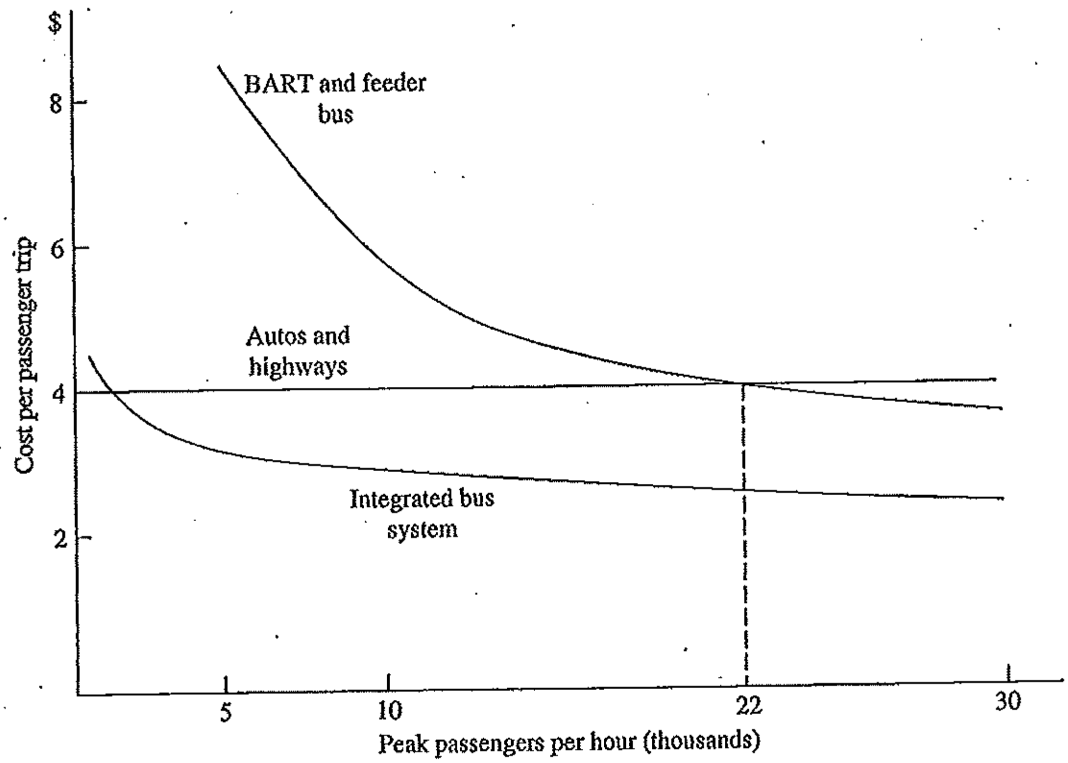
This section discusses modal choice from the perspective of a transportation planner. The planner must decide what type of transportation system to build. There are three options: an auto-based highway system, an integrated bus system, and a fixed-rail system like BART or Metro. Estimates of the cost of these alternative systems are provided by a study of transportation options in the San Francisco Bay area (Keeler, Merewitz, Fisher, and Small, 1975).

Keeler et al. estimated the cost of three different commuting systems: an auto-based system, an integrated bus system, and BART. The principal conclusions of their study are shown in Figure 12–4. The horizontal axis measures the number of commuters traveling through a transportation corridor during the one-hour peak period. The vertical axis measures the long-run average cost of a "typical" commuting trip (a six-mile line haul and additional time spent in residential collection and downtown distribution). The cost curves show that the bus system is more efficient than the auto system for volumes above 1,100 passengers per hour and is more efficient than BART for all traffic volumes. The auto system is more efficient than BART for volumes up to about 22,000 passengers per hour.

Cost of the Auto System

The cost of the auto system is the sum of the driver's time and operating cost and the public cost of auto traffic. The public cost includes the cost of building the optimum road system. As explained in the previous chapter, the revenue from the optimum

FIGURE 12–4 Costs of Alternative Transit Systems



The average cost of auto traffic is independent of auto volume, but the average costs of an integrated bus system and BART decrease as volume increases. The bus system is more efficient than BART for all volumes studied and more efficient than an auto-based system for volumes exceeding 1,100 passengers per hour.

congestion tax equals the cost of building the optimum road, so congestion taxes can be used to both internalize congestion externalities and pay for the roads. The public cost also includes the cost of air and noise pollution.

The average cost curve is horizontal for two reasons. First, Keeler et al. assume that the average operating cost and the average pollution cost (cost per mile) do not depend on traffic volume. Second, the trip time (and private trip cost) does not depend on traffic volume: as volume increases, the road is widened to accommodate the increased traffic without any reduction of travel speeds. Given constant returns to scale in highways, a doubling of highway capacity doubles traffic volume without changing the trip time. Using data for 1972, Keeler et al. estimate that the full cost of an auto trip with a six-mile line haul is $4.15.

Cost of the Bus System

The cost of the integrated bus system is the sum of time cost, agency cost, and the public cost of the bus system. The agency cost includes both the operating cost and the capital cost. Included in the public cost are (1) the cost of modifying the roadway to accommodate buses and (2) pollution cost.

The average cost curve is negatively sloped for two reasons. First, as ridership increases, the fixed cost of administering the bus system is spread over more riders. Second, as ridership increases, collection and distribution times decrease. An increase in ridership decreases headways (the time between buses) and decreases the space between bus stops, so riders spend less time walking to and waiting for a bus. In addition, an increase in ridership allows a bus to fill up with a shorter collection route. Less time is spent picking up passengers, so in-vehicle time decreases. According to Keeler et al., if the traffic volume along the corridor exceeds 1,100 passengers, the integrated bus system is less costly than the auto system.

Cost of BART

The BART option involves the mainline heavy-rail system and feeder buses to bring commuters to the BART stations. The time cost of the BART option is the sum of walking and waiting time costs and in-vehicle time cost. The agency cost is the sum of the operating and capital costs of the feeder buses and BART. Given the substantial investment in tracks and rights-of-way, the capital cost of the BART option is large.

The cost curve is negatively sloped for three reasons. First, the system has a substantial fixed cost, which is spread over more riders as ridership increases. Second, as ridership increases, BART headways decrease, decreasing waiting time. Third, an increase in bus ridership decreases the time and monetary cost of feeder-bus service.

BART is more costly than the bus system for three reasons. First, given its design as a mainline system with widely spaced stations, the collection and distribution costs are relatively high. Second, its capital cost is very large; the fixed cost of the system was $1.6 billion. According to Webber (1976), BART could buy enough buses to carry its passengers for only $40 million (2.5 percent of BART's capital cost). Third, BART has a surprisingly high operating cost: in 1975, the operating cost was 15.7 cents per passenger mile, compared to 13.6 cents for a bus. Most planners were surprised to discover that the large investment in capital equipment did not generate large savings in operating cost.

System Choice

The Keeler et al. study provides important information for transit planners. For all corridor volumes studied (up to 30,000 passengers per hour), BART was more costly than an integrated bus system. At a peak volume of 30,000 passengers per hour, BART is 50 percent more costly than the bus system. BART's peak ridership through the transbay tube is about half this amount. The lesson for planners is clear: With the possible exceptions of New York City and Chicago, which have corridor volumes exceeding 30,000 passengers per hour, an integrated bus system is likely to be more efficient than a modern fixed-rail system like BART.

Experiences with new heavy-rail systems in other metropolitan areas are similar to the BART experience. The Metro system in Washington, D.C., would have to