ADELAIDE, AUSTRALIA

O-BAHN GUIDED BUSWAY

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SUMMARY

Adelaide's 12-kilometer [7.4-mile] O-Bahn Guided Busway opened in 1986 and was completed in 1989. The 6.2-meter-wide [20-foot-wide] busway links downtown Adelaide with the northeastern suburbs. Standard and articulated buses circulate in residential areas before entering the three-station busway. A combination of concrete tracks and buses equipped with special lateral guidewheels allows the vehicles to operate manually, with normal service on roads, and automatically on the guideway by connecting the protruding guidewheels to the concrete track. Speeds of up to 100 km/h [62 mph] are reached, cutting the journey time by more than half. Ridership has increased steadily since 1986 to about 30,000 per day. Construction costs were approximated at $100 million in Australian dollars (A).

CITY CONTEXT

The State of South Australia was founded in 1837 and developed in the first half of the nineteenth century. Its capital is the port city of Adelaide. Metropolitan Adelaide has a population of 1.1 million. The urban area is 80 kilometers [50 miles] long and 15 kilometers [9 miles] wide. The historic city is 1 square mile with a grid pattern of streets. Adelaide's square-mile central business district (CBD) is a major hub. In 1991, 21% of the regional jobs and 13.5% of the regional retail sales were in the CBD. Surrounding the area is a ½-mile greenbelt of parkland. The low-density areas surrounding the city have progressively developed since the early twentieth century with the advent of streetcar corridors. From the late 1940s, as a result of economic growth and motorization, the city further extended to the north, east, and south. In the late 1970s, the Tea Tree Plaza District, northeast of the city center, was the largest remaining underdeveloped, nonindustrial land in the metropolitan area.

Public transport, including guided bus, tram, and suburban rail service, is administered by the Passenger Transport Board and mainly operated by TransAdelaide. There are 100 bus routes, 1 tram line, and 6 suburban rail routes. Annual ridership approximates 40 million, of which more than 80% is on buses. The bus fleet has 790 vehicles. Adelaide's 12-kilometer [7.4-mile] Guided Busway (O-Bahn), opened in 1986 and completed in 1989, provides major bus service to the CBD from the northeastern suburbs.

PLANNING AND IMPLEMENTATION BACKGROUND

During the 1960s, transportation planning in Adelaide mirrored North American perspectives. When the region was rapidly suburbanizing, major freeways were proposed to handle traffic growth, and public officials began preserving rights-of-way. However, by the 1970s, growing concerns over environmental quality and energy consumption led to public backlash, and only one freeway was actually built between the central city's edge and the hills to the east. The O-Bahn corridor was designated as a freeway in 1960 [(2)].

An extensive review of Adelaide's transport options in the 1970s led to abandoning the idea of additional freeways in the city [(3)]. Instead, a decision was reached to develop rapid transit to

service the rapidly growing northeastern suburbs, the only corridor not serviced by a suburban rail line.

After extensive study, officials decided to build a new light rail transit (LRT) line in 1978. They preferred light rail over a conventional busway because it would occupy less right-of-way, would emit less air pollution, and was perceived as being quieter and more comfortable to ride. Surveys revealed an overwhelming public preference for LRT service. As work progressed, the projected costs of placing the LRT underground in the city center proved prohibitive.

The O-Bahn was proposed with a change of governments in 1979. In 1981, after a visit to the O-Bahn test tracks in Stuttgart and the first field application in Essen, a decision was made to build a high-speed busway using the O-Bahn technology. Detailed design commenced in 1980, and construction began in 1982.

Using O-Bahn-style track and vehicles designed by Daimler-Benz and Zublin of Stuttgart, the Adelaide O-Bahn was constructed along a riverbed, which is now a beautiful linear park. The first 6 kilometers were opened in 1986 between the city and Paradise, and the extension was opened in 1989. The commitment to O-Bahn was viewed as a courageous choice considering that no area, not even Germany, had actually built anything comparable to what was planned for Adelaide.

The reasons for selecting the O-Bahn Busway over LRT included (1) significantly lower initial cost, (2) reduced need for passenger interchange, and (3) avoidance of street track or subway construction in the CBD.

THE O-BAHN CONCEPT

The O-Bahn concept was developed in the late 1970s in Germany. It contains an automatic track guidance for buses that is cost-effective, especially where elevated construction is required, as in Adelaide. The O-Bahn concept enables a standard service bus to be steered both manually and automatically in track-guided operation. In the latter mode, guide rollers directly connected to the steering knuckle of the bus steer the bus when it moves along the tracks' lateral guide rails.

The O-Bahn system operating in Essen for about 20 years was the "model" for the Adelaide system. The Essen system includes mechanical guidance, co-location with LRT, underground stations, dual power, and a median guideway in highways.

Several advantages have been cited for the O-Bahn in general, and Adelaide in particular. These are the following:

1. ***Adaptability***. The O-Bahn is well suited to suburban settings. It permits same-vehicle services and minimizes transfers. If a vehicle breaks down and blocks the guideway, buses can leave the guideway upstairs and use surface streets to bypass disabled vehicles.
2. ***Right-of-way savings***. Because the O-Bahn's 6.2-meter-wide [20-foot-wide] tracks are only a little (100 millimeters) wider than a bus, considerably less right-of-way is needed than for a busway where vehicles are manually steered. This provided significant savings

in Adelaide, particularly in tunnels, on bridges, on elevated structures, and along areas requiring substantial earthwork and landscaping.

3. ***Cost savings***. The avoidance of new capital expenses for depressing the CBD alignment and for advanced signaling systems resulted in a capital cost that was about half what a light rail system would have cost for the 12-kilometer corridor. At $6 million (U.S. dollars) per kilometer (in 1985 dollars), the guided busway cost only 12% more than a busway would have, in part because it required less right-of-way acquisition.
4. ***Lighter weight***. The O-Bahn placed less deadweight load on the corridor's fragile riverbed than the weight that would have been placed by an LRT line or a wider conventional busway.
5. ***Faster service***. As an exclusive, grade-separated corridor, the guideway cut in half the time needed to get to Adelaide's city center from the northeast terminus. The trip time went from 46 minutes on previous regular-stop bus services to 23 minutes on the O-Bahn.
6. ***Safer service***. Exclusive segregation from other traffic, guided steering, and the guideway's high-quality running surface have increased passenger safety. Relieving drivers of steering duties and freeing them to concentrate on managing speeds and braking, if necessary, have reduced the chance of driver error in high-speed operations. Safety has also been enhanced by a back-up steel-wheel system that allows vehicles to proceed along the busway at up to 50 kilometers per hour in the event that a tire suddenly deflates.
7. ***Greater comfort***: Because guide rollers act as horizontal stabilizers and the precast concrete track was built to such fine tolerances, buses run very smoothly, providing a ride quality well above that of a normal busway.
8. ***Quieter ride***. Owing to the smoother running surface and the absorption of tire noise by the L-shaped guideway surface and surrounding beams, the O-Bahn provides a relatively quiet ride. Nearby residences are also spared from loud noise, there is less noise than what a busway or steel-on-steel railway would have generated.
9. ***Staging flexibility***. As with a busway, the O-Bahn provides staging advantages over rail systems. The guideway does not have to be continuous or built, operated, and opened in one fell swoop; rather, it can be built incrementally.

It should be noted that items 2, 4, 6 and 9 also apply to conventional busway service.

ADELAIDE'S O-BAHN

Adelaide's O-Bahn Northeast Busway extends 12 kilometers [7.4 miles] from the central area to the Northeastern suburbs. (See Figure 1.) Buses from 18 different routes wind through the northeast suburbs before entering the guideway at one of two access stations (called "interchanges"): the terminus at Tea Tree Gully (15 kilometers from the CBD) or the Paradise interchange (9 kilometers out). With steering completely controlled by the guideway, buses reach speeds of up to 100 kilometers per hour [62 mph] on the fully grade-separated facility. They stop at a third station, Klemzig (5 kilometers out), if there is customer demand. Unlike the other two stations, Klemzig has no direct bus ingress-egress or park-and-ride facilities; all of its passengers

are either walk-ons or arrive by bike or bus transfers. On reaching the outer edge of the CBD, vehicles leave the guideway and travel the remaining 3 kilometers to the core stations on city streets, just like regular buses. Some 1,000 park-and-ride spaces are provided at the two main stations. A linear park and bicycle way parallel the busway.

DESIGN FEATURES

The O-Bahn Busway is shown in Figure 2. Construction involved using pre-cast concrete and providing concrete crossbeams on piles, L-shaped runway slabs, and railway-type fasteners. (See Figure 3.)

ENGINEERING

Guide rollers are fixed to rigid arms that are in turn connected to the front axle of the bus. The rollers, functioning as horizontal stabilizers, interact with a raised concrete lip to automatically guide the vehicle, freeing the bus driver from steering duties. The track consists of precast concrete elements assembled like a railroad track. Concrete crossbeams are supported on bored piles to provide long-term stability. L-shaped concrete slabs atop the crossbeams form the guidance surfaces. To handle Adelaide's high-speed bus services and to provide a comfortable ride, a continuous and precisely fitted concrete surface was needed. Prefabrication was required to achieve proper accuracy. Adelaide's busway tracks were constructed to tolerances of plus or minus 2 millimeters. To achieve such precision required the introduction of rigid quality-control procedures both at the manufacturing plant and during track assembly [(3)].

Track alignment was designed for speeds up to 100 km/h except at stations and exits, and was developed to minimize the impact on adjoining suburbs. In most sections, the track is depressed below the natural surface and passes below most roads, as opposed to a more visually intrusive overhead structure.

Numerous structures were required because of the O-Bahn Busway's corridor through a river valley and urban areas. The busway was totally grade-separated from all roads and pathways for maximum safety at optimum speeds and to avoid delay to other traffic streams.

Bridges were designed with special consideration to aesthetics, economy, and efficiency. There are 11 bridges over water, 1 over a road, 14 road overbridges, and 8 footpath bridges.

Entry to the track is gained via a tunnel constructed with steel guide rails attached to a reinforced concrete slab that is cast onsite. The driver positions the off-side guidewheel on the prolonged rail and then accesses the track at a maximum speed of 40 km/h [25 mph], the optimal speed for which the tunnel was designed.

Extensive landscaping was also required. For many years, the River Torrens, now one of the features for the Linear Park corridor, was a neglected urban drain in many areas, inaccessible to the public.

STATIONS

The busway was designed as a "bridge" through the inner suburbs, reducing travel times for residents in outlying districts. Three stations were planned to permit the following:

- Passenger transfer between bus routes,
- Climatic shelter for waiting patrons,
- Protected pedestrian areas and walkways,
- Transition entry/exit lanes for buses,
- Ample guideway width to permit bicycle access and storage parking, and
- Landscaping.

Modbury Interchange (Tea Tree Plaza) has a bus entry route onto the O-Bahn and a large parking area. Paradise Interchange Station permits outlying bus routes to enter the southern third of the O-Bahn and offers a large parking area. The Klemzig Station has very limited parking and no bus entry for local services.

BUS OPERATIONS

A wide range of operating strategies were analyzed in developing a service plan. The underlying goals were to

- Maximize passenger accessibility,
- Provide a distance between routes of between 800 and 1,000 meters,
- Minimize deviation or backtracking of routes to gain access to the busway,
- Minimize travel time,
- Make routes long enough to generate economic levels of patronage and frequency of service,
- Minimize the number of passengers transferring to other buses,
- Ensure that as many buses as possible operate from outer route terminals to the city center, and
- Ensure all routes using the busway enter the system as soon as possible to minimize travel time.

Accordingly, existing bus routes were restructured, and new services were implemented. During the peak periods, routes operate through suburban neighborhoods and then access the busway for high-speed service. During the off-peak period, some routes provide only feeder service to the main stations. A high level of service is provided on the busway, with headways on the main segment of 1 to 5 minutes (65 buses per hour) during peak periods and 5 minutes during the off-peak times (12 buses per hour).

Some 18 bus routes operate via the O-Bahn, providing service between Northeast Adelaide and the city center. Several routes (S40, S41, S42, S44, and S46) serve all three busway stations. Two routes serve the farthest reaches of the northeast corridor, and, after stopping at the Tea Tree Gully Station, run express to the central business district.

Service is steadily monitored, and operations have gained a significant body of experience. Street modifications had to be made principally at sharp gradient changes to avoid curb alignments and

projections and to avoid damage to the low-slung guidewheels. A major series of tests and trials were conducted to confirm that the bus/track combination met specified criteria for high-speed operation and system safety.

VEHICLES

About 50 articulated and 40 rigid Mercedes-Benz buses initially operated on the guideway, and MAN articulated buses were also available for guideway operation should demand grow. In 2001, there were 118 vehicles assigned to 18 services. To achieve the speed specified on the track, the buses are fitted with uprated diesel engines of 240 hp in rigid buses and 280 hp in articulated vehicles. ABS (antilock) brakes are fitted. The route is designed to allow for future electrification.

Vehicles have rear axle ratios and engine power permitting a maximum speed of 100 km/h. Adelaide temperatures reach over 40 degrees Celsius in summer, requiring the vehicles to be equipped with cooling systems.

To achieve express operation of 100km/h buses needed special adaptations including the following:

- Uprated engines (177 kW for rigid buses and 207 kW for articulated buses),
- Antilock brake system for safety reasons both on and off the track,
- High-intensity driving lights for use on the track at night because apart from station areas the Adelaide O-Bahn is unlit, and
- Guide rollers for guideway operation and tow or push-bar couplings at both the front and rear of the bus to facilitate recovery of broken-down buses on the track.

The guide rollers are fixed to rigid arms that are in turn connected to the front axle of the vehicles. In the event of damage to the front tires, the wheels are equipped with a metal inner tire, which prevents full deflation. This inner ring permits a loaded bus with deflated tires to be driven for 16 kilometers at a speed of 50 km/h [31 mph], a more than sufficient distance to allow a bus to leave the busway for maintenance and repairs.

Since regular services began, expert technical personnel have continued to assess and modify the vehicles and have assembled considerable expertise in devising original solutions to mechanical problems. Engineering staff have calculated the exact breaking strain of the guidewheel attachment to allow it to break off on heavy impact, rather than deflect the bus off course in the event of a collision while operating on normal roads.

BREAKDOWNS AND SAFETY

Operations on a particular track must stop in the event of a bus breakdown. However, on the rare occasions that this has happened, rescue is rapid, and services return to normal with little delay. To avoid collision with following vehicles, the operator of the disabled bus switches on a highly visible hazard light, and the Traffic Control Center is informed. After this, alarms sound on all work channels of the radio network.

Special maintenance and recovery vehicles, equipped with guidewheels and capable of traveling in both directions on the track, are used for bus recovery and track maintenance. In the event of a problem, buses traveling the O-Bahn at 100km/h can stop in less than two bus lengths.

There have been two accidents in which a number of passengers and drivers suffered injuries. One occurred when a driver stopped on a track to remove a bicycle left there by vandals. A following bus collided with the stationary bus about 1 minute afterwards. The accident happened in daylight with no visibility problems and has been attributed to human error. The second accident occurred off track in a station area and was also a rear end collision. Even with these accidents taken into account, per bus mile traveled, a bus on the busway is considerably safer than a bus in mixed traffic.

COSTS

Developmental costs for the busway are shown in Table 1. Costs totaled $97.8 million (A) for the busway and another $86.4 million (A) for river landscaping, about $8.2 million and $0.7 million (A) per kilometer, respectively.

The first 6-kilometer stage of the Adelaide O-Bahn accounted for 75% of the total expenditure because it included both of the intermediate busway stations, all of the river bridges, all land acquisition, 92 buses, some earthwork, and two bridges in the Section Stage.

TRAVEL TIME

The exclusive right-of-way and wide station spacing substantially reduced travel times. Travel times for trips between downtown Adelaide and the suburbs were reduced from approximately 40 minutes to 25 minutes.

RIDERSHIP

O-Bahn Ridership approximates 2.5 million passengers annually and 30,000 per day. Ridership on the O-Bahn has grown steadily, unlike ridership on the region's system. (See Figure 4.) Between 1986 and 1987 and between 1995 and 1996, annual patronage on the region's bus, rail, and tram system fell from 82 million to 62.9 million boardings, about 23% [(2)]. During the same period, annual ridership on the 18 bus routes using the guideway increased by 75%, from 4.2 million to 7.4 million, an increase well in excess of the 18% growth rate in the busway's primary catchment area.

Although the region's transit modal split was just 7% of all trips in 1991, for radial journeys along the northeast corridor to the city center, transit captured a 42% market share [(2)]. In real dollar terms, operating costs per boarding fell by 27% during the first 7 years of O-Bahn operations, while rising 5% for all bus transit services operating within the region [(2)].

Cross-system comparisons are also revealing. Between 1986 and 1996, ridership on the O-Bahn increased three times faster than ridership on the region's commuter railways serving the northwest, southwest, and southeast corridors. The O-Bahn's "guideway effectiveness" is also nearly 10 times higher than that of the railways, handling about 670,000 versus 69,000 passengers per route, per kilometer, per year. Between 1984 and 1985 and between 1991 and

1992, boardings per vehicle kilometer rose 36% along the northeast corridor while falling 14% along railway lines.

The busway was reported to generate a 24% increase in patronage from new riders. During peak hours, riders are mainly workers and students heading to the city center. This produces a directionally biased, tidal pattern of patronage. Surveys show that some 40% of new passengers during commute hours previously drove their automobiles to work [(3)].

During the O-Bahn's first 5 years of service, the greatest ridership growth actually occurred in discretionary trips headed to the CBD during the mid-day, mainly for shopping purposes. Surveys reveal that in addition to being attracted by receiving transfer-free services, mid-day discretionary trip makers like the pleasant views of the corridor's riverscape and the safety of the guided, segregated track. The most frequently cited benefit of the O-Bahn is its convenience [(4)].

On an average weekday, more the 4,000 riders enter the downtown area in the morning peak hour. About 80% board at street stops, and 20% board at the three busway stations.

Parking at stations is limited to several hundred spaces. Space has not been expanded because of concerns of nearby residents. With additional parking, O-Bahn ridership would probably increase.

IMPACTS ON DEVELOPMENT

Some clustered, station-area development has occurred, the joint product of regional planning and market forces. For several decades, the busway's terminus, Tea Tree Gully, has been designated as one of five regional town centers. The region's latest "Planning Strategy" continues the commitment to directing future suburban growth along high-capacity transit axes, including the northeast O-Bahn corridor. To date, the O-Bahn appears to have helped to convert Tea Tree Gully from a somewhat sterile new town, designed around a regional shopping mall, to an emerging urban village featuring a wide range of land uses. In the early 1990s, the site of a new regional college campus was relocated adjacent to the terminal station to take advantage of the parcel's superb access to the CBD. A medical complex has also sprung up nearby. Tea Tree Gully's shopping mall is presently being expanded atop existing surface parking in the direction of the busway terminus.

Around the two other O-Bahn interchanges, local residents want nothing to do with transit-oriented development and have kept the areas from increasing their densities.

ASSESSMENT

The Adelaide O-Bahn provides a cost-effective solution to improving bus transit in an environmentally sensitive corridor. It is perceived as incorporating the best features of LRT (safety, comfort, and speedy mainline [trunk] services) with the best features of a busway (the flexibility to leave the guideway and provide transfer-free connections and to do so at lower investment costs).

LESSONS LEARNED

Perhaps the most significant lesson learned is the ability of the O-Bahn to provide rapid bus service, convey a distinct identity, and attract riders, including discretional travelers. And the plan to convert the bus fleet from diesel to CNG has won public praise. Adequate park-and-ride space is essential, and space continues to be added.

Although long range planning controls help guarantee that Adelaide's CBD will continue to be the main commercial center, the emergence of new outgoing centers has resulted in a possible cross-town O-Bahn corridor along the Tea Tree Gully station to Port Adelaide on the east. However, there has been no decision to build another urban line. A possible 12-kilometer [7.4-mile] southern corridor is being investigated.

APPLICABILITY TO THE UNITED STATES

The BRT concept, linking outlying suburbs with a fast link to the city center, is found in BRT plans or operations in several U.S. and Canadian cities. However, in most corridors, there is ample space to use conventional buses rather than O-Bahn. Moreover, from a public perspective, when fixed guideways with train-like operation are discussed, the focus normally shifts to LRT. Possible applications may be appropriate in bus tunnels as in Seattle and Boston.

ACKNOWLEDGEMENT

This case study draws heavily on the Chapter 14 "Guided Busways: Adelaide, Australia" in Robert Cervero's book, The Transit Metropolis: A Global Inquiry. Island Press, Washington, D.C. 1998.

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Table 1: Costs of Adelaide O-Bahn

Item	Total Cost (A$m)
Structures	17.0
Civil Works	10.5
Guided Track	18.9
Stations	6.3
Land Acquisition	5.8
Busway Landscaping	4.6
Vehicle Fleet	22.0
Utility Service Alteration	2.5
Preliminary Design	1.3
Administration and Supervision	8.9
Total (see Note 1 below)	97.8
River Landscaping (see Note 2 below)	6.4

NOTE 1:
The above figures are in actual dollars spent over the life of the project between 1980/81 and 1989/90.

NOTE 2:
In addition to the expenditure above on works directly associated with the Busway system and corridor, the extensive renovation and landscaping of 3 kilometers of river valley as part of the Torrens Linear Park was included in the scope of the project.

Source: Adelaide O-Bahn—The Innovative Solution. Passenger Transport Board, South Australia (not dated).

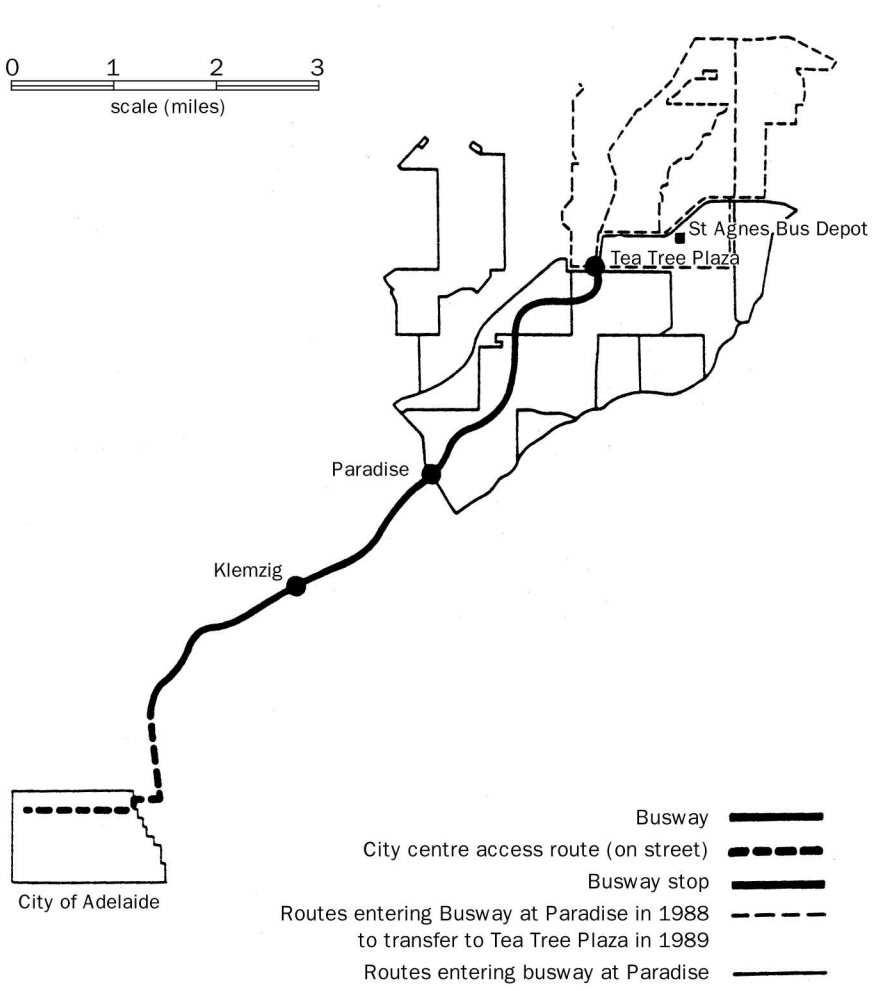

Figure 1: O-Bahn Route Map

Figure 2: O-Bahn Busway

Figure 3: O-Bahn Guideway Section

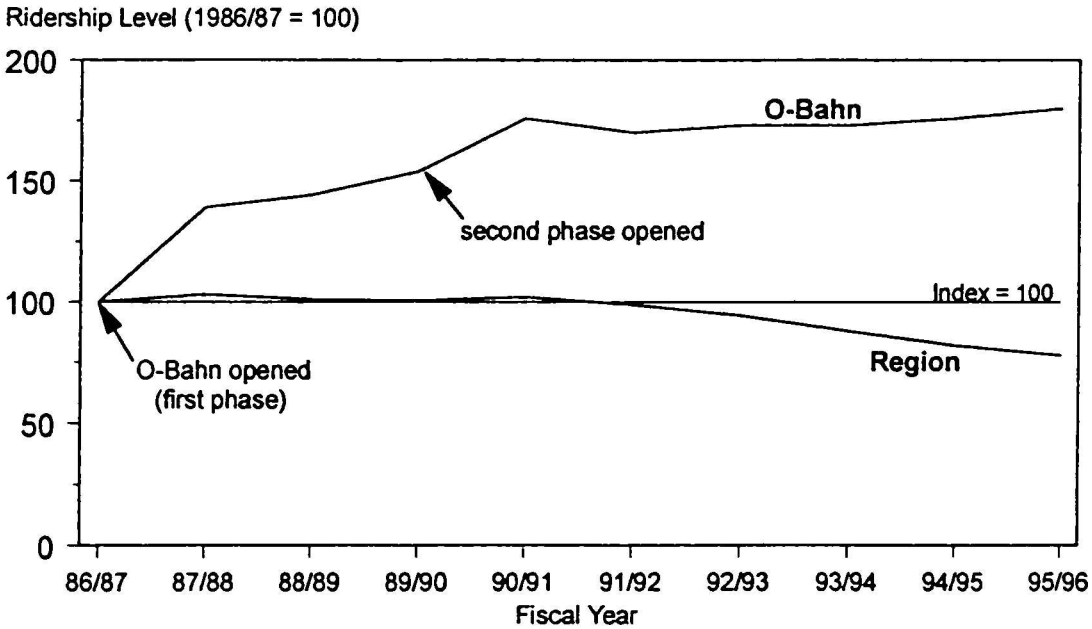

Figure 4: Comparison of Transit Ridership