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U.S. Department
of Transportation
**Federal Transit
Administration**

Operational Assessment of Paralympics Transit System: Low-Floor Buses, Lift-Equipped Buses, and Signage

David Spiller
Lawrence Labell

Research and
Special Programs
Administration
John A. Volpe National
Transportation Systems Center
Cambridge, MA 02142-1093

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From August 15-25, 1996, Atlanta hosted the Paralympics, a world-class athletic competition for athletes with disabilities. To support the Paralympics, a specialized transit service was planned and deployed to service the travel needs of the athletes, trainers and officiating staff using a combination of low-floor buses and lift-equipped buses.

The U.S. Department of Transportation's Volpe Center conducted a limited operational assessment, focusing specifically on bus access technologies that enable boarding and alighting operations. An additional area of focus for this study is Information Signage (on-board the buses, and at wayside boarding/alighting locations) that also either enable or limit full access to the transport services that are rendered.

This study complements several concurrent activities in support of the Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA) to document "lessons learned" in deploying new technologies (including Intelligent Transportation System (ITS) technologies) during the Olympics and Paralympics events.

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PREFACE

From August 15-25, 1996, Atlanta hosted the Paralympics, a world-class athletic competition for athletes with disabilities. To support the Paralympics, a specialized transit service was planned and deployed to service the travel needs of the athletes, trainers and officiating staff using a combination of low-floor buses and lift-equipped buses.

At the request of the Federal Transit Administration (FTA), the US Department of Transportation's Volpe Center conducted a limited operational assessment, focusing specifically on bus access technologies that enable boarding and alighting operations. An additional area of focus for this study is Information Signage (on-board the buses, and at wayside boarding/alighting locations) that also either enable or limit full access to the transport services that are rendered.

The most significant finding is that no major problems were observed with either the low-floor bus ramp or the bus lift. Recommendations have been made to improve both planning and transport operations for future special events that involve large-scale ridership of persons with disabilities, particularly mobility impairments.

This study complements several concurrent activities in support of the Federal Highway Administration (FHWA) and the FTA to document "lessons learned" in deploying new technologies (including Intelligent Transportation System (ITS) technologies) during the Olympics and Paralympics events.

The authors thank a number of individuals for contributing to this study: R. Stout, Director of Planning Operations, FTA; G. Izumi, Office of Program Guidance and Support, FTA; T. McCormack, FTA Region 4; S. Schruth, FTA Regional Administrator, Region 4; T. Weyandt, APOC Director of Transportation; F. Haley, APOC Bus Operations Manager; J. Buckley, APOC Bus Maintenance Manager; D. Smith, G. Hoffman, L. Green, and T. Fix from Lift-U, Division of Hogan Manufacturing, Inc., and A. Graffeo, Senior Technical Editor, EG&G Dynatrend, Inc.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (ha) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

°C=5/9(°F - 32)

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

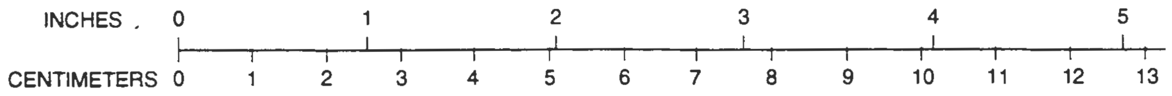
VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

°F=9/5(°C) + 32

QUICK INCH-CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

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EXECUTIVE SUMMARY

From August 15-25, 1996, Atlanta hosted the Paralympics, a world-class athletic competition for athletes with physical disabilities. To support the Paralympics, a specialized transit service was planned and deployed to service the travel needs of the athletes, trainers and officiating staff using a combination of low-floor buses and lift-equipped buses.

At the request of the Federal Transit Administration (FTA), the US Department of Transportation's Volpe Center conducted a limited operational assessment, focusing specifically on bus access technologies that enable boarding and alighting operations. An additional area of focus of this study is Information Signage (on-board the buses, and at wayside boarding/alighting locations) that also either enable or limit full access to the transport services that are rendered.

Key findings of this study are:

- No major problems were observed with either low-floor ramp or lift operations.
- Direct observation confirmed three very distinct advantages to the low-floor bus operation: a. boarding and alighting operations were not disrupted by malfunctioning ramp hydraulics; rather, the ability to deploy and stow the ramp manually precluded the need for a roadcall, or for the insertion of supplemental service via dispatch of a spare bus; b. non-disabled persons could more easily access the bus via the ramp or a single step into the bus; and c. once deployed, the ramp does not have to be recycled for use by other passengers.
- Mean marginal boarding time per mobility-aided passenger for the ramp was measured at 6.3 seconds; mean marginal boarding and alighting times per mobility-aided passenger for the lift were measured at 33.7 and 38.5 seconds, respectively. There were insufficient observations to measure the mean marginal alighting time per mobility-aided passenger for the ramp.
- An availability statistic for the lift, calculated from the logged number of lift-related service problems and the estimated total number of lift cycles during the Paralympics Event, yields a result greater than 99 percent (1 failure in 4600^{+} cycles).
- Direct observation and discussion with drivers indicated that passengers on the buses rarely made use of the securement straps to tie down the mobility aids.
- A limited sample of persons with mobility aids or with mechanical walkers indicated a preference for the lift versus the ramp for access to the bus, primarily due to the reduced human effort and energy expended in boarding and alighting from the bus.

- Analysis of a wayside fixed ramp that was used for alighting operations indicated that the wayside fixed ramp was always faster than the lift for alighting when two or more persons with mobility aids who needed to alight were on the bus.

- For the most part, bus route and destination signs at wayside and on-board the buses were well designed, and well placed. The destination sign characters should have been twice their actual height for a better legibility distance, particularly for visually impaired persons. (The width-to-height ratio, and the stroke-width-to-height ratio of the destination signs were within the limits defined by the Americans with Disabilities Act Accessibility Guidelines (ADAAG), Section 4.30, but the minimum character height of the upper case letters was only half the minimum height set by ADAAG (33 mm (1.32") versus 75 mm (3")).

- Direct observation and discussion with staff indicated problems with bus maneuverability and negotiability with tight route geometrics, including pulling in and out of bus loading and discharge zones; in some cases, these problems resulted in bus accidents.

Several recommendations have been made for planning and operating bus transportation services for future special events involving, in particular, large-scale mobility-impaired ridership. These recommendations should be understood, however, in the context of what the authors observed to be a very well-planned and well-run Paralympics Transportation System:

- In addition to a CADD system to help plan transport facilities and circulation patterns at venues, it is recommended that use be made of additional software such as AutoTURN^{tm} which can interface with CADD systems to test via simulation, for all planned routes, large vehicles such as buses making all required turning movements, and to test other required clearances based on the planned route geometrics. Each planned route that is identified with potential problems with bus maneuverability and negotiability should have a test run using a professional transit driver. Changes should then be made to the planned routes, giving due regard to additional safety margins if the driver roster is to include non-professional bus drivers.

- In planning future special events, time should be scheduled to provide sufficient training of drivers for route and equipment familiarization, including operation of the lifts and ramps, knowledge of the interlocks, turning the buses, and pulling in and out of bus loading and discharge zones.

- In operating future special events, transportation managers should establish a larger pool of standby drivers and buses than would normally be used for a conventional transit service. A larger pool would: service unusual or unplanned crush loading conditions and other contingencies, adjust operations to reduce excessive delays in bus running times, provide additional flexibility to the dispatch control center, and help operations' staff adhere to planned schedules.

- In operating future special events, the use of both low-floor buses with ramps and lift-equipped buses is recommended. Each has distinct advantages, and, based on this study, it appears that the optimal policy is a hybrid fleet.

- In operating future special events (assuming a hybrid fleet of both low-floor and lift-equipped buses, and where physical space permits), it is recommended that wayside fixed ramps be used to expedite alighting operations.

1. INTRODUCTION

From August 15-25, 1996, Atlanta hosted the Paralympics, a world-class athletic competition for athletes with physical disabilities. To support the Paralympics, a specialized transit service was planned and deployed to service the travel needs of the athletes, trainers and officiating staff using a combination of low-floor buses and lift-equipped buses. Although a special event operation (as opposed to a public fixed-route transit service), this is nevertheless a unique opportunity to gain additional insight of bus accessibility technologies, including the comparative operational performance and passengers' preferences for low-floor ramp versus lift technologies. It is also an opportunity to observe and measure performance of both access technologies under peak loading conditions.

At the request of the Federal Transit Administration (FTA), the US Department of Transportation's Volpe Center conducted a limited operational assessment, focusing specifically on bus access technologies that enable boarding and alighting operations. An additional area of focus of this study (see Section 3., Scope of Report) is Information Signage (on-board the buses, and at wayside boarding/alighting locations) that also either enable or limit full access to the transport services that are rendered.

This study complements several concurrent activities in support of the Federal Highway Administration (FHWA) and the FTA to document "lessons learned" in deploying new technologies (including Intelligent Transportations System (ITS) technologies) during the Olympics and Paralympics events.

2. A BRIEF HISTORY OF THE PARALYMPIC GAMES

The Paralympic Games were born of the vision of Sir Ludwig Guttman, an English neurosurgeon at Stoke-Mandeville Hospital in Aylesbury, England, in 1948 when he organized the International Wheelchair Games to coincide with the 1948 London Olympics. This first effort was symbolic; a deliberate attempt to connect the Olympics and the Paralympics was not made again until 1960, when the first Paralympic Games were held in Rome, just a few weeks after the 1960 Rome Olympics. In the first years, only wheelchair athletes competed.

Four hundred athletes from 23 countries joined together on that day in Rome. The Paralympic Movement was created, and Sir Guttman was saluted by Pope Paul XXIII, who declared, "You are the Coubertin of the paralyzed." Since then, the two events have shared cities four times (Tokyo 1968, Seoul 1988, Barcelona 1992, Atlanta 1996) and countries three times (Germany 1972, Canada 1976 and United States 1984). The Xth Paralympiad was celebrated in Atlanta in 1996 with 17 full medal sports, 14 of which were included in the Olympic Games program. Minor modifications are sometimes made to the rules of individual sports in order to accommodate the disabilities of athletes. Athletes are classified according to functional level and compete against athletes with similar abilities.

Most sporting events use the same Olympic venues. Over 3500 of the best disabled athletes from 120 nations participated in the Xth Paralympiad.

As the Paralympic Movement grew, other classes of athletes began to participate, including amputees, the blind, and those with cerebral palsy. In 1982, the International Coordinating Committee (ICC) of World Sports Organizations for the Disabled was established as a counterpart to the International Olympic Committee, with four international federations under its umbrella:

- Cerebral Palsy International Sports and Recreation Association (CP-ISRA).
- International Blind Sports Association (IBSA).
- International Stokes-Mandeville Wheelchair Sports Federation (ISMWSF).
- International Sports Organization for the Disabled (ISOD) - governs amputees as well as athletes with a variety of other disabilities (e.g., dwarf athletes).

In 1992, the ICC was restructured and has become the International Paralympic Committee (IPC).

Cities and countries who have hosted the Paralympic Games include:

1960 Rome, Italy
1964 Tokyo, Japan
1968 Tel Aviv, Israel
1972 Heidelberg, Germany
1976 Toronto, Canada
1980 Arnhem, Holland

1984 Stoke-Mandeville, England and
Nassau County, New York, U.S.A.
1988 Seoul, Korea
1992 Barcelona, Spain

1996 Atlanta, Georgia, U.S.A.

Both the Olympic and Paralympic Games will be held in Sydney, Australia in the year 2000.

3. SCOPE OF REPORT

This study encompasses a field investigation of actual bus operations at several sampled venues, focusing on two critical issues: bus access technologies for boarding and alighting, and Information Signage on-board the buses and at the wayside loading and drop-off points. General observations on other issues, such as bus maneuverability into and out of bus bays, are offered in the interest of highlighting some "lessons learned," but these issues were not the focus of this study. For elaboration on other issues pertaining to the deployment and operation of low-floor buses (e.g., planning and implementation, maintenance costs, driveability), refer to (King, R., 1994). For low-floor bus design and engineering issues, refer to (Prentice, C. and Kershaw, D., 1994).

For lift-equipped buses, the investigation focused on timing measurements based on actual operation, direct observation of lift usage, driver operational problems with activating and stowing the lift, passenger preferences for lift versus ramp, and passenger problems with usage of lift and ramp access technologies. Condition surveys of the lifts on the fleet of lift-equipped buses before, during and after deployment were not undertaken nor were engineering issues addressed such as deflection and rotation of the lift platform, lift component stresses, force loads due to lift overextension, or lift dynamics affecting passenger comfort and safety (i.e., excessive speed, acceleration or jerk rates).

4. PARALYMPICS TRANSPORTATION SYSTEM DESCRIPTION

The concept of operations for the Paralympics Transportation System (PTS) established varying levels of service and priority for classes of tripmakers, defined as any person who makes a trip as a result of the 1996 Paralympics Games. The various classes of tripmakers, estimated volumes (persons, not trips!), and mode and level of service are outlined in Table 1. Of note is that the PTS was designed to provide direct service only to a subset of all tripmakers, namely "user-groups." These are credentialed guests of the Atlanta Paralympic Organizing Committee (APOC) and include athletes and delegation staff, members of the Paralympic Family, competition officials, and media.

PTS direct service to the "user groups" consisted primarily of a shuttle bus service operating from established origin points such as residential areas at the Paralympic Village or from the Paralympic Headquarters Hotel at the Mariott Marquis to identified destinations such as training and competition venues. Many of the competition and training venues, and the associated street system are illustrated in Figure 1. Bus round-trip transit time on the shuttle circuits, operating from the two main hubs at the Paralympic Village/Transportation Mall and the Mariott Marquis, respectively, were generally less than one hour in duration. A few of the peripheral competition venues had longer transit times. Assigned vehicles and motor pool operations augmented the PTS to service individual tripmaking requirements of Paralympic Family and staff to support Game operations.

APOC transportation staff also worked closely with other APOC functions to identify appropriate locations at each venue for the required transportation facilities, in particular loading and drop off spaces. The staff worked closely with a variety of local agencies, including MARTA, to manage traffic access to and around all APOC venues to facilitate safe pedestrian flows while maintaining traffic circulation for both PTS and other vehicles. Parking controls, curbside space and parking management were also implemented at each venue site (see Figures 2 and 3).

MARTA also operated several shuttles, using low-floor buses and paratransit vans, from key rail line stations to the Olympic Stadium and other competition venues. MARTA's Brady Garage served as the PTS bus and vehicle staging area, transportation operations center, and maintenance depot.

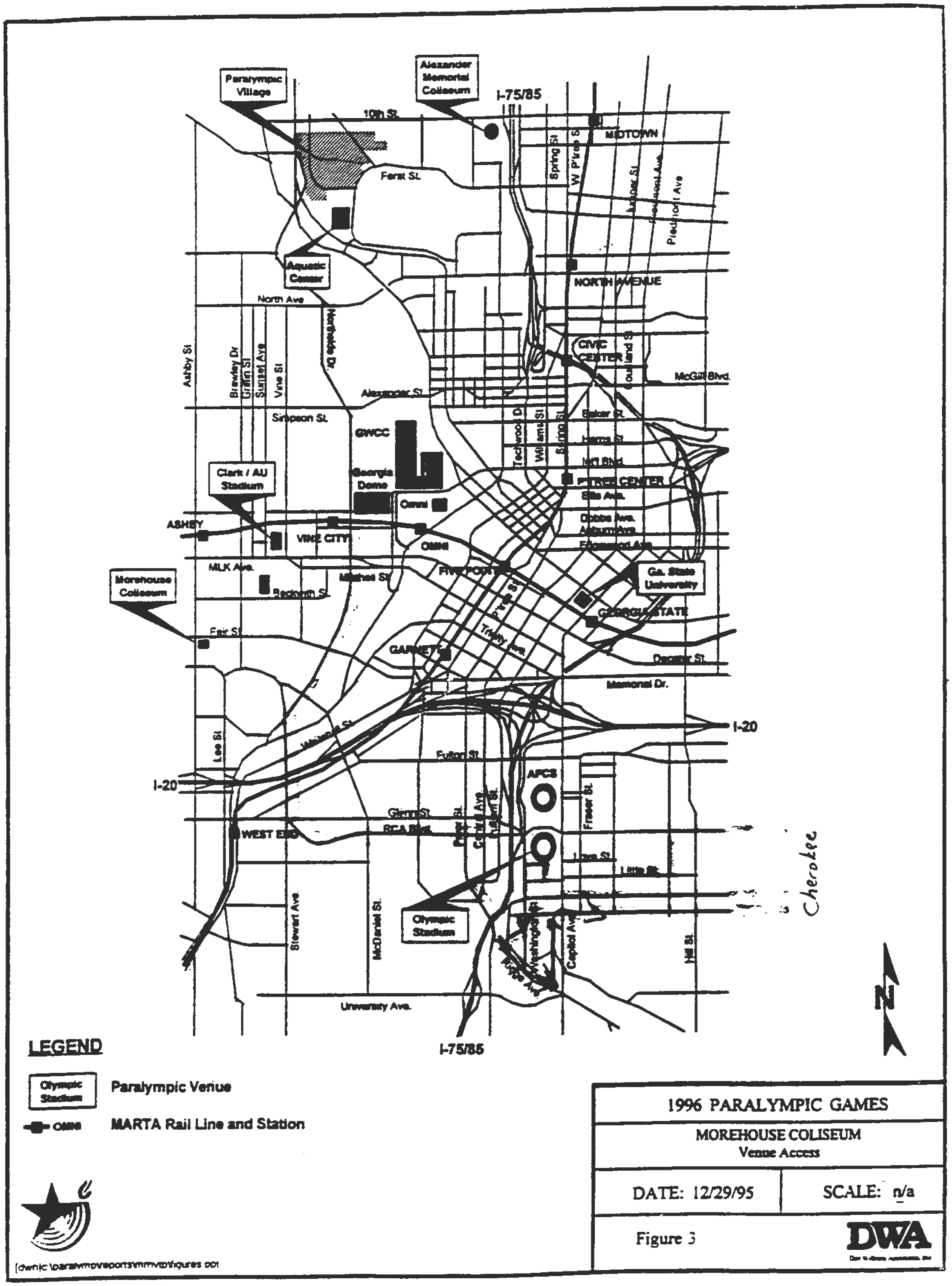
Critical to the success of the PTS, confirmed by direct observation, was that each venue had a Venue Transportation Manager on-site, and a relatively large contingent of volunteers. Bus schedule adherence, management of the movement of passengers to and from the buses, management of bus access and egress to and from the street, and management of any unplanned contingency were handled effectively by the Venue Transportation Manager, his/her staff, and the contingent of volunteers.

The PTS bus fleet consisted of 61 low-floor buses and 151 lift-equipped buses on loan from other transit properties across the nation. Drivers were military personnel. Both the buses and the drivers had been deployed in support of the Olympics. Bus deployment of low-floor buses was limited to routes that would not present any road clearance problems due to

Table 1. Tripmakers Level of Service and Estimated Numbers:
1996 Paralympic Games

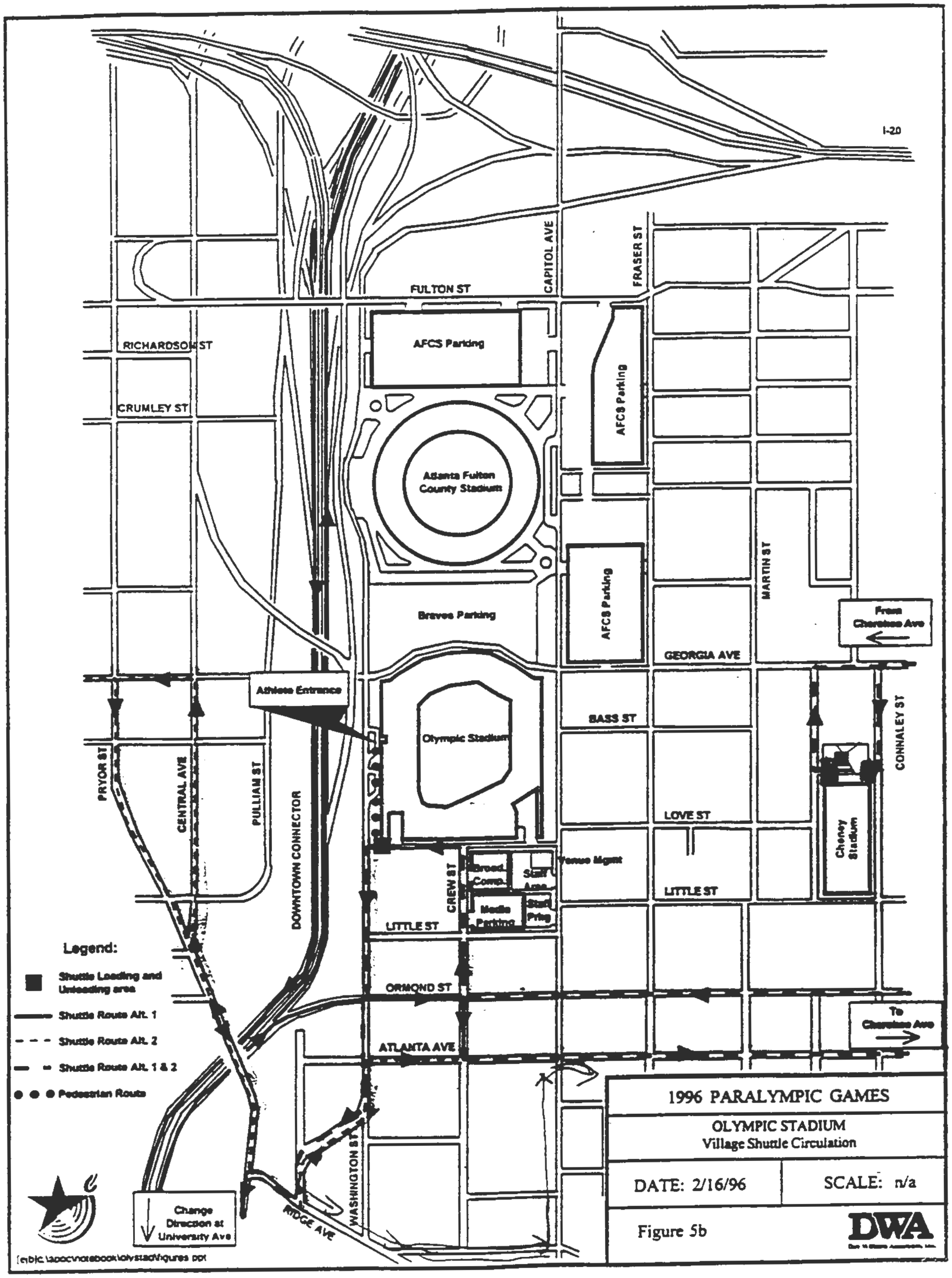
Tripmaker	Estimated Volumes	Mode and Level of Service
Athletes, Delegation Staff & Technical Officials	4500	PTS Shuttle System - from the Village to the competition venues and training sites.
Competing & Spectating	3300	
Athletes Delegation Staff & Technical Delegates	1200	Motorpool
Competition Officials & Classifiers	700	PTS Shuttle System - will use same shuttle as athletes except for team sport officials, who will be transported on vehicles separate from team.
Paralympic Families	2081	Paralympic Family Shuttle - from select hotels to venues.
1. International Paralympic Committee	115	
2. National Paralympic Committee	544	
3. VVIPs	488	Assigned Cars
4. VIPs	800	
5. Observers	134	Motor Pool
6. Sponsors		
Staff	700	Staff/Technician Motor Pool
APOC Staff	200	Staff/Technician Shuttle
Sponsors - Technicians	500	
Volunteers	15,000	Will work with MARTA to ensure availability of Public Transportation and may provide supplementary shuttle system.
Media	1000	Media Shuttle - from the Main Press Center and/or media hotel headquarters to the venues via PTS Shuttle System.
Spectators	1.5 million	None - will work with MARTA to ensure availability of Public Transportation or will use private vehicles.
Individual Spectators/Small Groups		
Charter Groups		
Paralympic Experience		
Sponsor Guests		

Source: APOC Transportation Staff



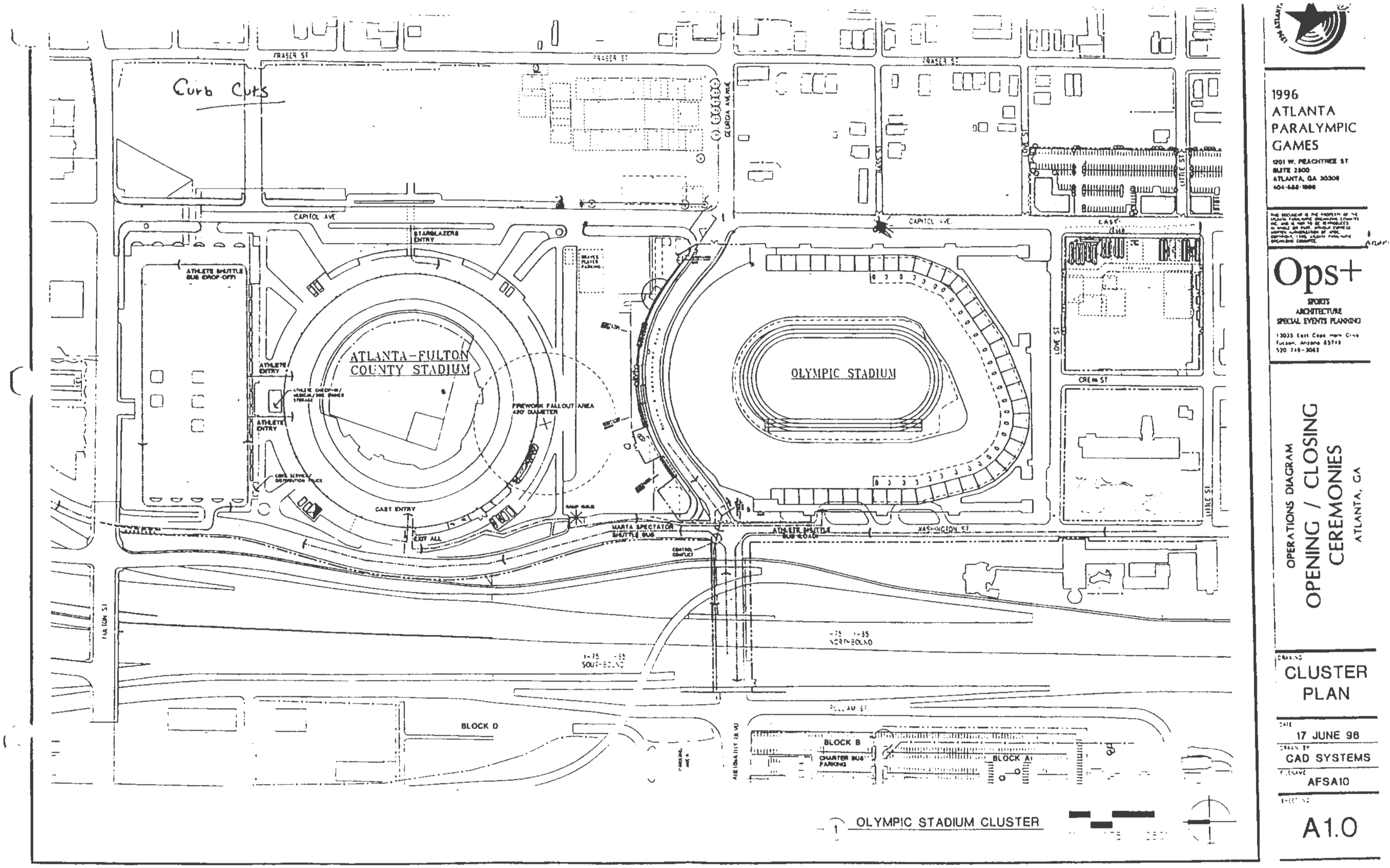
Source: APOC Transportation Staff

Figure 1. Orientation of Paralympic Venues in Relationship to Street Network



Source: APOC Transportation Staff

Figure 2. Illustration of Paralympic Shuttle Bus Routes, Pedestrian and Parking Facilities near the Olympic Stadium



Source: APOC Transportation Staff

Figure 3. Paralympic Shuttle Bus Circulation Patterns: Olympic Stadium

operation on a street with a large gradient vertical profile. APOC staff found, however, that the low-floor bus could operate over more routes than originally anticipated. Bus routing and scheduling were closely coordinated with Game Operations and worked out to ensure that all user-groups arrived at the appropriate location at the proper time (approximately 1 to 1-1/2 hours before game time). Equipment and supply vehicles were operated in convoy fashion with the buses carrying the athletes to ensure that both equipment and athletes arrived concurrently at the competition and training venues.

5. FIELD DATA COLLECTION METHODS AND LIMITATIONS

A site visit, including a meeting with APOC Transportation staff, was made prior to the Paralympics' Events to gain a general understanding of the Paralympics Transportation System operations, including information relevant to bus type deployments, and bus circulation patterns at major boarding/alighting locations. Bus measurements for the low-floor buses were made at the Brady Garage while the buses were not yet in service. A conventional millimeter-graded ruler and tape measure were used for the measurements, with a measurement error of ±1 millimeter.

Direct observations and timing measurements were made at three locations by two analysts from August 19-22, 1996: the Paralympic Village/Transportation Mall; the Headquarters Hotel at the Mariott Marquis; and the Olympics Stadium. Timing measurements were made by a conventional stop watch, with a measurement error of approximately 0.2 second. Observations of the low-floor buses operated by MARTA at the West End Station on the North/South Line were stopped after discussion with a street supervisor indicated that almost all mobility-aided passengers were transported by the paratransit vans that were also servicing this station as part of a shuttle service to the Olympics stadium. Only on rare occasions were the ramps on the low-floor buses at the West End station being used.

In order not to interfere with the operation to any great extent, only short, informal discussions were made with passengers and drivers during bus layovers. This limited the amount of information collected, as well as the sample size. Language barriers also reduced the sample size and may have biased the results reported in this study.

The original plan called for most of the data to be collected while riding on-board the buses. As a result, more focus had been placed on internal circulation within the bus, as well as access to and egress from the securement bays (see Appendix, Sample Data Collection Forms). Direct observation, confirmed by discussions with a sample of drivers, indicated that the securement straps for the mobility aids and occupant restraints for the mobility aid occupants were not being used (except, perhaps, on rare occasions). Further, many of the athletes in mobility aids had sufficient upper body strength to transfer to a seat. Limited space on-board the buses and logistical considerations forced a rethinking of this plan. Observations and measurements were made curbside at the three boarding/alighting locations. The rapid pace of the actual operations at times complicated the ability to observe and measure it accurately.

Finally, actual field conditions always force a degree of necessary 'real-time' flexibility and adaptation with respect to what part of the operation can feasibly be observed and measured while still providing information utility.

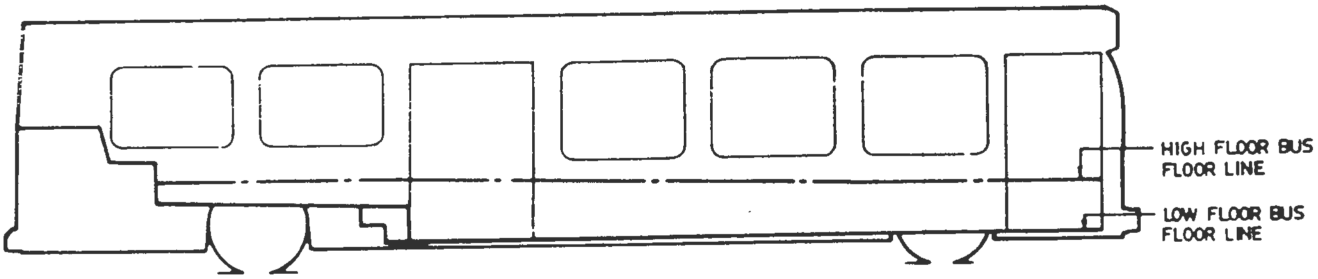
6. LOW-FLOOR BUS OPERATIONS

The type of low-floor bus deployed for the Paralympics was a New Flyer Industries D40LF model, a heavy-duty standard size (40') bus, and its 35' equivalent (D35LF). The sketch in Figure 4 shows basic differences between a conventional bus and a low-floor bus from a passenger access perspective (TCRP Synthesis 2, 1994). The floor of a conventional bus is flat and continuous, and is approximately 890 mm (35") above the street. Access to the floor level is provided by steps at both the front and rear door. For persons with disabilities, only lift or high platform (level loading) is possible; the height above street or curb precludes use of an extendable ramp with a ramp slope less than 1:4, the maximum slope that a mobility-impaired person can negotiate over a short distance unassisted (although with difficulty) based upon human factor tests (Booz-Allen & Hamilton Inc., 1980).

The floor level of a low-floor bus is approximately 380 mm (15") off the street between the front and rear doors. The floor area over the rear axle is elevated and access to this area is either by steps (in the case of the D40LF and D35LF) or a ramp in the floor (certain European models, none of which was used at the Paralympic Games). There are no steps to negotiate in the front or rear doors, and for mobility-impaired persons, a ramp is feasible within acceptable slope limits, particularly when the kneeling capability of the bus is utilized. The kneeling of the bus effectively lowers the front of the bus by approximately another 100 mm (4").

Certain measurements taken on a low-floor bus parked at the Brady garage are presented in Table 2. The vertical discontinuities measured at the ramp/bus floor interface and the ramp/street and street curb interfaces were less than 6 mm (1/4"), posing no negotiability problems and well within the Americans with Disabilities Act Accessibility Guidelines (ADAAG) specification (ref. Section 4.5.2).

From the ramp area to the center aisle, however, a vertical discontinuity of 19 mm (3/4") was measured. This could potentially pose an obstruction hazard to persons using canes, crutches and other mechanical walking aids based on evidence from human factor tests conducted under the Transbus program where a discontinuity of this magnitude under controlled laboratory conditions did create a barrier to movement. Side edges on the ramp were 50.8 mm (2"); this is sufficient height, based on prior crash tests (Booz-Allen & Hamilton, 1980), to prevent mobility aid rollovers. There are no handrails on the ramp, but handrails are located on the door to assist in boarding and alighting, although the length of the ramp (1117.6 mm (44")) may require a person in a mobility aid to partially ascend the ramp befor he/she can grab the handrail to assist in completing the boarding. The surface treatment of the ramp consisted of a non-skid longitudinal ribbed rubber mat. The drainage grooves appeared to be sufficiently narrow not to pose an obstruction hazard for ambulatory persons with canes, crutches or walkers. With the bus kneeled, ramp slope was 1:4.5, within the envelope for ramp slopes that permit unassisted entry (but possibly with some difficulty) (see Figure 5). One bus operational advantage of the relatively steep ramp slope, however, is that the steep angle (12.5° for a 1:4.5 slope) reduces the maneuvering time for mobility aids because the momentum associated with faster speed is necessary to overcome the steeper angle.



LOW FLOOR BUS

Source: TCRP Synthesis 2, 1994

Figure 4. Floor Level Differences between Conventional and Low-Floor Buses

Table 2. Low-Floor Bus Dimensions

Low-Floor Bus Manufacturer: New Flyer
Low-Floor Bus Model: D40LF

Ramp Location: Front Door
Ramp Width: 762 mm (30")
Ramp Length: 1130 mm (44 1/2")

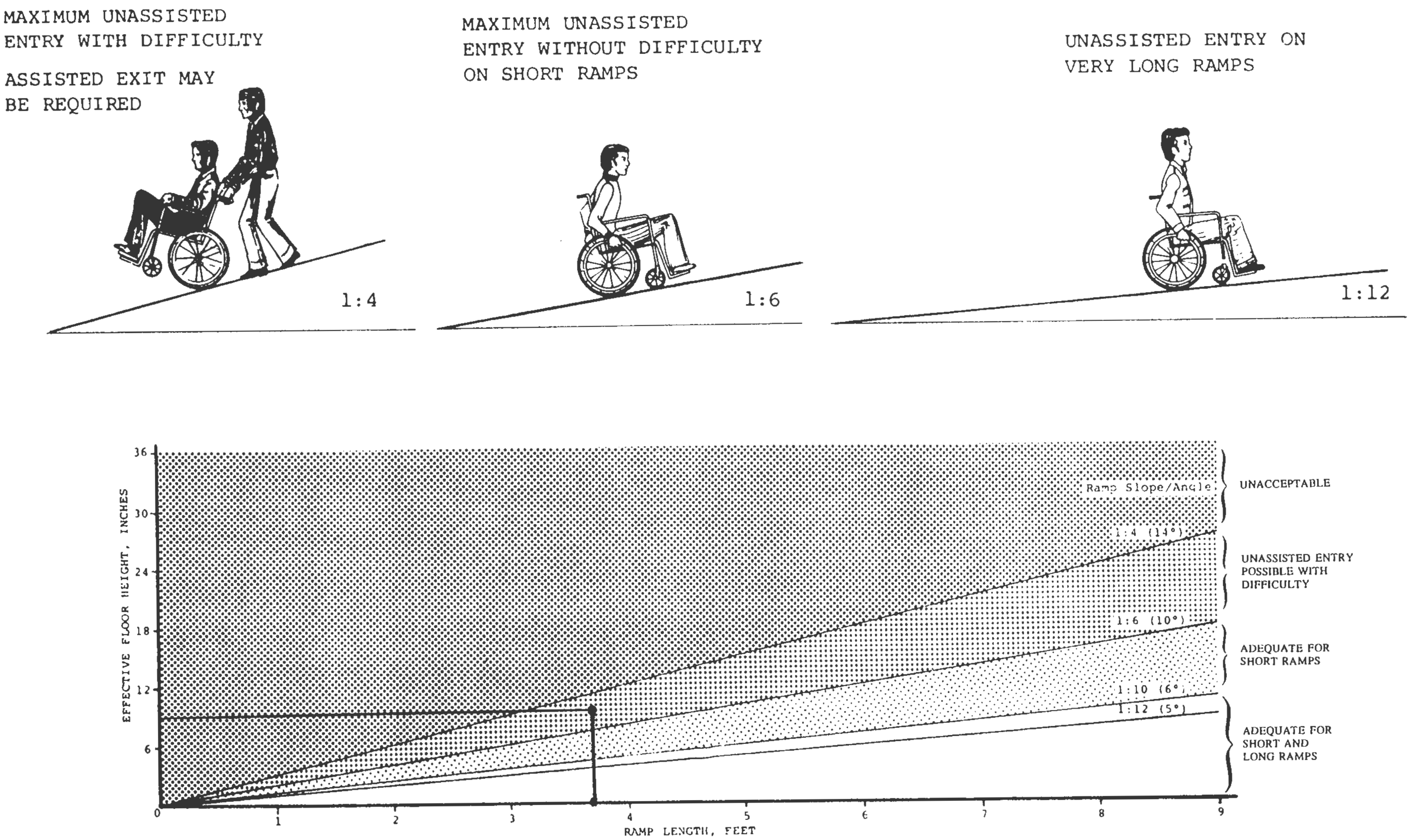
Vertical Discontinuity at Ramp/Bus Floor Interface: 6 mm (1/4")
Vertical Discontinuity at Ramp /Street Curb Interface: 3 mm (1/8")
Vertical Discontinuity at Ramp Envelope/Center Aisle: 18 mm (3/4")

Ramp Side Edge Height: 51 mm (2")

Location of Hand Rail: On Door

Height from Street to Bus Floor with Kneeling: 248 mm (9 3/4")
Height from Street to Bus Floor without Kneeling: 330 mm (13")

Ramp Slope (Bus Kneeling): 1:4.5



Source: Booz, Allen & Hamilton Inc., 1977

Figure 5. Human Factor Research Results for Acceptable Ramp/Slope Angle:
Data Point Corresponds to Paralympics Low-Floor Bus Ramp

The clear turning radius of the vestibule arc (the subtended circular arc, measured from the edge of the right wheelwell, that just clears the farebox and driver's platform terminating at the edge of the left wheelwell) was measured at 896 mm (35-1/4"). Prior human factor tests at this radius have indicated that 42 percent of the test participants reported that this turning radius was either close or difficult to negotiate (Booz-Allen & Hamilton, 1980). Aisle width, measured from edge of right wheelwell to edge of left wheelwell, was measured at 914 mm (36"). This width equals the required minimum clear width for an accessible path (ADAAG, Section 4.3.3) and exceeds the minimum clear width for doors (ADAAG, Section 4.13.5). However, the most constricted point that persons in mobility aids would have to pass is the width of the front door of the low-floor bus, measured between the handrails. This length was 813 mm (32"), the minimum clear width for doors established by ADAAG (ADAAG, Section 4.13.5).

6.1 BOARDING OPERATIONS

The ramps associated with the low-floor bus are of the "flip-out" design, and can be operated manually. Boarding operations for persons with mobility aids are initiated by first having the bus operator kneel the bus, after the bus has been positioned parallel to the loading zone, then activate the ramp. An audio signal warns persons waiting at curbside or passing near the loading zone of the ramp activation. One distinct advantage of the ramp is that only one deployment-stowage cycle is necessary, irrespective of the number of boarding persons with mobility aids. Also, once the ramp is deployed, all persons - ambulatory or not - may board. The mean time to deploy and stow the ramp for non-manual and manual operations, respectively, were measured and are presented in Tables 3 and 4. Manual operation of the ramp is approximately 2 seconds faster (8 seconds versus 10.5 seconds).

One component of bus dwell time is the marginal boarding time for a person with a mobility aid. Using two alternative methods of measurement, the mean marginal boarding time for a passenger in a mobility aid approximates 6 seconds (see Table 5), an order of magnitude of four to five times shorter than for a lift operation (24 - 35 seconds, see Table 6). It should be pointed out, however, that bus dwell time, for normal transit operations, also depends on the time to maneuver to the securement bays, secure the mobility aid, and prepare the bus for departure. Previous studies, based on controlled wheelchair trials, have yielded results which confirm our findings of an advantage to the low-floor design regarding the time to raise the mobility aid from sidewalk level to bus level, but a disadvantage in time penalty due to maneuvering to a more distant securement bay, and securing the mobility aid with a more complex securement system (Levine, J. and Torng, G., 1994).

6.2 ALIGHTING OPERATIONS

One potential concern of the low-floor ramp design is excessive speed of the mobility aid during alighting (or conversely, the required strength on the part of the mobility aid occupant to control excessive speed) due to the rather steep ramp angle. Fear of falling or instability during alighting for ambulatory persons using mechanical walking aids is also a concern. Less than adequate traction during wet weather conditions exacerbates these concerns. Free

Table 3. Mean Time to Deploy Low-Floor Bus Ramp
(Number of Observations in Sample)

Venue	Non-Manual Operation (seconds)	Manual Operation (seconds)
1. Paralympic Village	-	-
2. Marriott Marquis	10.3 (3)	7.3 (2)
3. Olympic Stadium	10.6 (3)	-
4. Pooled Sample (All Three Venues)	10.5 (6)	7.3 (2)

Table 4. Mean Time to Stow Low-Floor Bus Ramp
(Number of Observations in Sample)

Venue	Non-Manual Operation (seconds)	Manual Operation (seconds)
1. Paralympic Village	-	-
2. Marriott Marquis	11.0 (4)	8.8 (2)
3. Olympic Stadium	10.2 (4)	-
4. Pooled Sample (All Three Venues)	10.6 (8)	8.8 (2)

Table 5. Mean Marginal Boarding Time per Mobility-Aided Passenger:
Low-Floor Bus Using Ramp (seconds)
(Number of Observations in Sample)

Venue	Method 1*	Method 2**
1. Paralympic Village	-	-
2. Marriott Marquis	7.8 (3)	8.4 (1)
3. Olympic Stadium	5.2 (4)	5.3 (3)
4. Pooled Sample (All Three Venues)	6.3 (7)	6.0 (4)

* Method 1 - Direct timing measurement, based on observing the front wheels of each mobility-aid crossing the ramp/street threshold, and the back wheels clearing the 'ramp footprint closing envelope' on the bus.

** Method 2 - Calculated for only boarding events by taking the timing measurement of the total time to board all mobility-aided passengers, and dividing by the number of such passengers who boarded the bus.

Table 6. Mean Marginal Boarding Time per Mobility-Aided Passenger:
Lift-Equipped Bus Using Lift* (seconds)
(Number of Observations in Sample)

Venue	Method 1**	Method 2***
1. Paralympic Village	-	-
2. Marriott Marquis	-	32.7 (1)
3. Olympic Stadium	24.4 (16)	33.9 (7)
4. Pooled Sample (All Three Venues)	24.4 (16)	33.7 (8)

* All lifts observed are Lift-U™.

** Method 1 - Direct timing measurement, based on a complete lift cycle between consecutive boardings of mobility-aided passengers.

*** Method 2 - Calculated for only boarding events by measuring the total time from initial deployment of the lift to final stowage of the lift, and dividing this time by the number of mobility-aided passengers who boarded.

space or a recovery zone at the terminus of the ramp at street or curbside becomes important. While the authors did observe some rather rapid descents on the ramps, it did not seem to be a problem. Unfortunately, insufficient observations were made to measure the mean marginal alighting time for persons with mobility aids.

6.3 GENERAL OBSERVATIONS

No major problems were observed with the low-floor ramp operations. On several occasions, a person with a mobility aid had to remove a wheel or ride on the siderail in order to negotiate the relatively narrow ramp. However, the authors also observed the same phenomenon on the wider lift platform. Because of the greater frequency of non-standard sized mobility aids, especially the long tri-wheeled competition wheelchairs, the narrower low-floor ramp design could be a potential problem for a special event such as the Paralympics, inhibiting smooth loading and unloading operations. APOC transportation staff recognized this potential problem by deploying "chase" trucks to carry equipment as much as possible. The relatively narrow ramp and door width of the low-floor bus, however, is the result of a design constraint to maintain a minimum approach angle for the bus of 9 degrees to prevent the front of the bus from scraping the road when accelerating on a steep grade (the front overhang can strike the road before the front wheels reach the grade), and also from striking high curbs when pulling into bus stops (Black, T. and Mateyka, J., 1976).

None of the persons with mobility aids was observed to use the securement straps on board the buses. Making a right angle turn into the bus aisle did not seem to pose any problems, except for the long tri-wheeled competition wheelchairs.

On several occasions, the authors observed manual operation of the ramp. The drivers operating the ramp manually had no problems. This appears to be a great benefit of the ramp design; because of the manual operation, there was no need for a road-call, or dispatch for supplemental service at the loading points in question. There was also no disruption to the boarding and alighting operations.

Because the rear door can not stay open on the low-floor buses (the doors are spring-loaded to return to a shut position for safety reasons), on several occasions the authors observed the doors shutting on passengers. The inability of the rear doors to stay in an open status also disrupted smooth boarding and alighting operations using the rear door as a supplemental, parallel 'server' to the front door.

For ambulatory persons, the authors observed that stepping onto the low-floor bus from the street or the curb was substantially easier than negotiating three steps.

7. LIFT-EQUIPPED BUS OPERATIONS

Certain physical dimensions were also measured for a sample bus of the lift-equipped bus fleet. The vertical rise to the first step was 737 mm (14-1/2"). As a frame of reference, this is substantially greater than recommended design criteria for maximum rise for exterior steps (330 mm; 6-1/2") (Gelick, M., et. al., 1974), and the large rise to the first step for transit buses has been rated as a primary impediment to accessibility by passenger focus groups (Barkow, B., 1991). The rise to the second step was measured at 470 mm (9-1/4").

The tread depth for the first step was 737 mm (14-1/2"); the tread depth for the second step was 584 mm (11-1/2"). The non-uniform tread depth is a safety hazard because it violates a fundamental human factor requirement of anticipatory consistency; as a result, a person could easily misjudge position on the second step and lose his/her balance. For exterior steps in buildings and facilities, ADAAG requires uniform rise and tread depth (Section 4.9.2), but ADAAG has not specified design requirements for interior steps in buses because of the extensive structural redesign such requirements would impose, and concern that minimum tread and maximum rise dimensions would interfer with maneuvering space within the vestibule area (36 CFR Part 1192, Final Guidelines, 1991).

Several width dimensions were measured for the vestibule and aisle areas. The distance between the top of the steps and the drivers platform was 1994 mm (39-1/4"). Between the two front seats in the bus across which a person in a mobility aid would make a right angled turn, the width was 1689 mm (33-1/4"). However, the most constricted point with respect to access to the interior of the bus, and to the securement bays was measured at 1410 mm (27-3/4").

The lift-equipped buses on loan from the transit systems all had front door lifts. All lifts were Lift-U^{tm} models. Most of the seats were removed and additional securement bays were installed.

The internal reconfiguration permitted 11 mobility aids to be secured. Limited observations, confirmed by discussion with a sample of drivers, indicated that the securement straps were generally not being used. The reconfiguration did allow for better internal circulation within the bus, including moving mobility aids to and from the lift at the front door.

7.1 BOARDING OPERATIONS

Measurements were taken of the mean time to deploy the lift for a boarding, and the mean time for a single lift cycle. The mean time for a single lift cycle was measured between consecutive boardings and between consecutive alightings, and the results reported are an average of the mix between consecutive boardings and consecutive alightings. These results are reported in Tables 7 and 8, respectively. The mean time to deploy a lift for the initial boarding is approximately the same (~10 seconds) as the mean time to activate the ramp (compare Tables 3 and 7).

Table 7. Mean Time to Deploy Lift[*] for Boarding a Mobility-Aided Passenger (seconds)
(Out-Down Operation)
(Number of Observations in Sample)

Venue	Mean Time
1. Paralympic Village	10.6 (31)
2. Marriott Marquis	-
3. Olympic Stadium	10.7 (32)
4. Pooled Sample (All Three Venues)	10.6 (63)

[*] All lifts observed are Lift-U™.

Table 8. Mean Time for a Single Lift[*] Cycle: Boarding or Alighting (seconds)
(Out-Down-Up-In-Operation)
(Number of Observations in Sample)

Venue	Mean Time
1. Paralympic Village	-
2. Marriott Marquis	-
3. Olympic Stadium	24.4 (16)
4. Pooled Sample (All Three Venues)	24.4 (16)

[*] All lifts observed are Lift-U™.

Notes:

Timing measurements made between consecutive boardings of mobility-aided passengers, and between consecutive alightings of mobility-aided passengers; samples combine both types of measurements.

Again, using the same two alternate methods (see footnotes on Tables 5 and 6), the mean marginal boarding time per mobility-aided passenger using a lift is approximately 24 to 34 seconds. The larger estimate is probably the more accurate or meaningful number since it accounts for actual normal operational delays by the driver and/or passenger or both.

7.2 ALIGHTING OPERATIONS

Similar to boarding operations, measurements were taken of the mean time to deploy the lift for alighting a mobility-aided passenger, and the mean marginal alighting time per mobility-aided passenger. Also, the mean time to stow the lift was measured. These results are reported in Tables 9, 10 and 11, respectively. All of the measured times are roughly comparable to boarding times, although it was noted that the mean marginal alighting time is approximately 4.5 seconds longer in duration (38.1 seconds versus 33.7 seconds). This probably is due to the additional operation of bringing the lift platform up to the bus floor level.

7.3 GENERAL OBSERVATIONS

No major problems were observed for the lift-equipped bus operations. None of the drivers that the authors observed had any operational problems with deploying the lift. At times, the authors observed as many as 12 persons with mobility aids being loaded via the lift onto the bus without any delays or operational problems. The following statistical data confirms their limited direct observations: annotated logs of service problems for the lifts from August 12 through August 23 show that only 52 service problems were noted, 18 of which could properly be attributed to lift-related causes (annotated logs, Lift-U Division of Hogan Manufacturing, Inc., 1996). The majority of the service problems were either bus or bus maintenance related, or due to insufficient driver training.

The number of lift-related road calls was reported at 22, representing 20 percent of all road calls (Haley, F., 1996). Availability of the lift, based on the number of failed cycles as noted in the lift-related service problems and the reported number of lift cycles operated in service during the Paralympics (240,000) (Haley, F., 1996), has been calculated at greater than 99.9999 percent. To put this in perspective, this is equivalent to the air traffic control system, which operates 24 hours per day and 365 days per year, having outages over the year which total only 39 minutes.

As with the ramp, persons with non-standard sized wheelchairs had problems in loading onto the lift, and in negotiating the farebox. On several occasions, the authors observed removal of a wheel in order to use the lift. On one occasion the authors observed a person with a mobility aid hitting a vertical stanchion in attempting to negotiate a right angle turn into the bus. Congestion in the bus aisle sometimes delayed operation of the lift.

Table 9. Mean Time to Deploy Lift* for Alighting a Mobility-Aided Passenger (seconds)
(Out-Down-Up Operation)
(Number of Observations in Sample)

Venue	Mean Time
1. Paralympic Village	9.9 (20)
2. Marriott Marquis	-
3. Olympic Stadium	11.6 (7)
4. Pooled Sample (All Three Venues)	10.4 (27)

* All lifts observed are Lift-U™.

Table 10. Mean Marginal Alighting Time per Mobility-Aided Passenger:
Lift-Equipped Bus Using Lift* (seconds)
(Number of Observations in Sample)

Venue	Method 1**	Method 2***
1. Paralympic Village	-	-
2. Marriott Marquis	-	52.0 (1)
3. Olympic Stadium	24.4 (16)	31.1 (2)
4. Pooled Sample (All Three Venues)	24.4 (16)	38.1 (3)

* All lifts observed are Lift-U™.

** Method 1 - Direct timing measurement, based on a complete lift cycle between consecutive alightings of mobility-aided passengers.

*** Method 2 - Calculated for only alighting events by measuring the total time from initial deployment of the lift to final stowage of the lift, and dividing this time by the number of mobility-aided passengers who alighted.

Table 11. Mean Time to Stow Lift* (seconds)
(Number of Observations in Sample)

Venue	Mean Time
1. Paralympic Village	12.6 (1)
2. Marriott Marquis	-
3. Olympic Stadium	11.3 (6)
4. Pooled Sample (All Three Venues)	11.5 (7)

* All lifts observed are Lift-U™.

Note:

Sample combines time measurements made to stow lift after all boardings, and after all alightings.

Unlike the ramp, it was observed that persons using the lift did not have to exert their own energy during boarding and alighting operations. The great majority of persons with mobility aids made either continuous or intermittent use of the handrails on the door to assist in boarding or alighting.

An informal survey of a small sample of drivers (sample size of seven) generally confirmed that there were few problems with operating the lift. One driver did note that when the number of persons with mobility aids exceeded 12 for a single loading event, both the latency time and the total duration to deploy the lift increased. The latency time is the duration of the time lag, measured from the time the driver activated the lift to the time the lift responded. Technical representatives from Lift-U have confirmed that the lift should not be operated more than five minutes consecutively, and that the specification of the lift posits a 10 percent duty cycle, which implies a maximum of 6 minutes in every bus hour. This correlates with the reported experience of the driver(s). In normal transit operations, however, it is extremely rare to have more than two persons with mobility aids boarding or alighting at a single bus stop.

8. MOBILITY-AIDED PASSENGER SURVEY ON BUS ACCESS TECHNOLOGIES

A very limited sample of persons who use mobility aids or mechanical walkers were queried concerning ramp versus lift access technologies. Of the 18 persons who responded, 12 prefered the lift. Those who prefered the lift believed the lift to be easier to use, and almost all also perceived use of the lift as faster as well. Conversely, those who prefered the ramp held that it was faster and easier to use.

Of those who prefered the ramp, opinion was divided as to whether ramps and low-floor buses, if deployed more extensively, would induce a more frequent transit trip rate.

Most respondents reported no problems with using either the ramp or lift. Several respondents, however, did directly experience malfunctioning ramps and lifts. Several respondents commented that use of the ramp did require assistance by a third party. Also, the handling of packages was more difficult when negotiating the ramp. One respondent commented on the need for upper body and arm strength to use the ramp. Another respondent commented on the better (presumably, higher) safety edges on the lift.

Although not related to the method of access to the bus, one respondent also commented on the inability of the shoulder harness on public transit buses to protect against neck whiplash. Note that none of the buses in the Paralympics Transit System (PTS) fleet, as configured for the Paralympic Games, had occupant restraint shoulder harnesses. Straps were to be used to secure only the mobility-aid frame.

9. WAYSIDE FIXED RAMP ALIGHTING OPERATIONS

In addition to the bus ramp and bus lift, a wayside fixed ramp was constructed at the Olympics Stadium to facilitate rapid alighting of mobility-aided passengers. There was sufficient physical space for the ramp to be a straight tangent, with no need for intermediate level landings. Slope was measured at 1:12, conforming with the ADAAG specification (Section 4.8.2). The upper landing had sufficent dimensions to make the turn down the ramp. The ramp was only used for alightings. Two plywood constructed "plugs" were built for two types of buses to fill in the space created by the front steps. The two were not properly identified, and the authors did observe some confusion in selecting the proper plug for specific bus types that pulled into the bus bay.

Operationally, a bus would pull into the bus bay, maneuvering the bus parallel to and approximately 2 feet from the fixed ramp opening. The bus driver or a Paralympics volunteer riding the bus would hand signal to transportation control staff in the bus bay the number of on-board mobility aids. If the number were less than four, the bus would move past the fixed ramp, and discharge all persons in mobility aids using its lift. If the number were four or more, the bus would pull opposite the fixed ramp opening. Two Paralympics volunteers with work gloves would then grab the proper step "plug", and place it in the bus once the front doors were opened. A metal bridge plate (a commercially available product) was then placed by the two staff persons on the top of the plug in the bus, bridging the gap to the top landing of the fixed ramp. With the staff holding the bridge plate down, persons with mobility aids would then move across the bridge plate and down the ramp. After all persons, including ambulatory persons, alighted using the ramp, staff reversed the process by removing the bridge plate and "plug" and allowing the bus to move out.

Based on the above described operations, the mean set-up time, the mean marginal alighting time per mobility-aided passenger, and the mean break-down time were measured. These results are reported in Table 12.

Critically important is that the mean alighting time per mobility-aided passenger is a factor of three less than the time needed for a single lift cycle (12.7 seconds versus 38.1 seconds). Accounting for the set-up and break-down time for the fixed ramp, analysis indicates that the threshold number of persons with mobility aids for which the fixed ramp is preferable to the bus lift for alighting operations is two. Once there are two or more persons with mobility aids on-board the bus who need to alight, the fixed ramp is faster.

Table 12. Wayside Fixed Ramp Alighting Operations
(Number of Observations in Sample)

Mean Set-Up Time* for Using Fixed Ramp at Olympic Stadium for Alighting Operations (seconds): Placement of Bus Step Plug; Positioning of Bridge Plate	Mean Marginal Alighting Time** per Mobility-Aided Passenger Using Fixed Ramp at Olympic Stadium (seconds)	Mean Break-Down Time* for Using Fixed Ramp at Olympic Stadium for Alighting Operations (seconds): Removal of Bridge Plate; Removal of Bus Step Plug
12.2 (7)	12.7 (6)	10.5 (7)

* Calculated by direct timing measurement.

** Calculated by measuring the total time from 'set-up' to 'break-down', and dividing this time by the number of alighting mobility-aided passengers.

10. SIGNAGE

The ultimate factor limiting the visibility of a display is the capacity of the visual system to resolve detail. The normal human visual system is able to to distinguish detail subtending an angle at the eye of between 0.29 mrad (1 angular minute) and 0.15 mrad (0.5 angular minute) (Riggs, 1965 as cited by Jacobs, R., Johnston, A., and Cole, B., 1975). The relationship of visibility distance to the minimum angle of resolution (MAR), letter stroke width, and letter height is illustrated in Figure 6. A person with normal vision would be able to view a display at 0.687 m/mm (57.3 ft/in) of letter height.

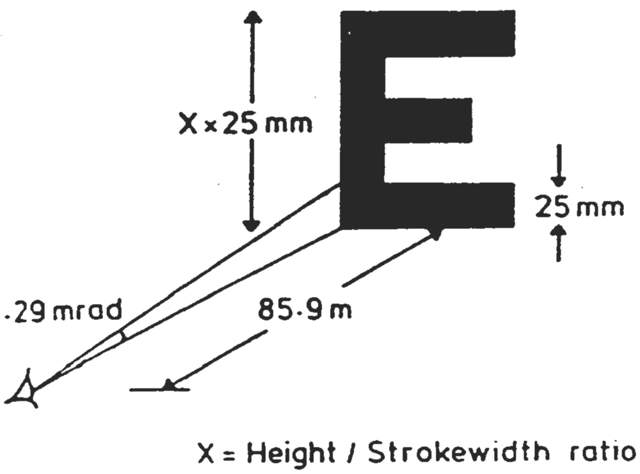
Experiments conducted under controlled conditions with both normal and visually impaired subjects have found (Jacobs, R., Johnston, A., and Cole, B., 1975):

- The average 50 percent threshold legibility distance for symbolic signs is about twice that of alphabetic signs regardless of visual acuity.
- The character size required for 0.95 probability of correct identification is approximately 1.7 times larger than the size giving 0.50 probability of correct identification.
- Reduced visual acuity has a predictable (linearly proportional) effect on legibility distance. A decrease in visual acuity by a factor of two (2) (e.g., from 6/6 or 20/20 to 6/12 or 20/40) also halves the legibility distance.

Other factors affecting the legibility distance of information displays include: the pace or relative motion of the observer; the character font; color contrasts between character and background; illumination levels; and secondary cues such as sign shape, or word length or layout. Many persons with disabilities have limitations in movement of their heads and reduced peripheral vision, additional to problems with visual acuity. These factors affect the optimal placement of information displays.

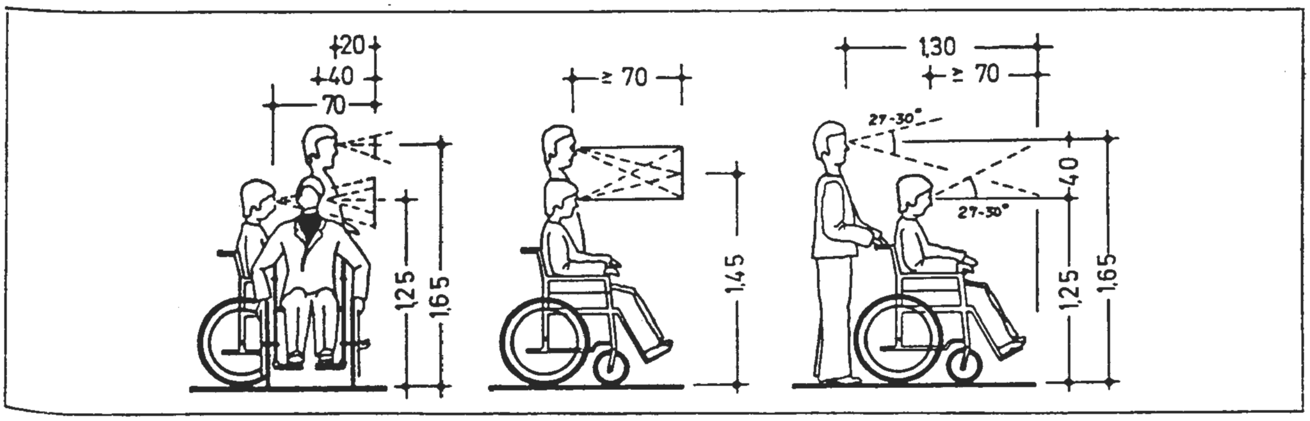
With these fundamentals of information display design in mind, certain measurements were made of information displays at the wayside, and on-board the buses. At the wayside loading points, bus route and destination identification signs were placed on fixed stands. The information signs were white characters on a green background, providing good color contrast. The material was a durable corrugated plastic.

Placement was at a height of 1372 mm (4-1/2 ft), within the cone of vision for both a standing observer and a person in a mobility aid (see Figure 7). The fixed stands were properly positioned perpendicular to the accessible path along the curbside loading zones. Thus, the signs could be seen as the person was maneuvering along the accessible path. No extraneous head motion was necessary. When a bus was ready to depart, the information display was removed from the stand and placed in the windshield, curbside near the front door. The process was reversed when a bus pulled into a loading zone. Bus route and destination identification signs were 406 mm by 305 mm (16" x 12").



Source: Jacobs, R., Johnston, A., and Cole B., 1975

Figure 6. Calculation of Maximum Observation Distances Possible for Observers with Visual Acuity of 6/6 and Minimum Angle of Resolution (MAR) of 0.29 MRAD



Source: Pajonk, E., 1978

Figure 7. The Fields of Vision of Wheelchair Users

The character dimensions for the bus route and destination identification displays are presented in Table 13. The 50 percent threshold legibility distance for the bus route signs for a person with normal vision is more than 46 meters (150'); even for a person with poor vision, the distance would exceed 15 meters (50'). The smaller size of the characters for the destination signage, which is more critical than an abstract route number from the perspective of the passenger, is more problematic. A visually impaired person would not be able to resolve the characters that identify the destination of the bus at a particular loading zone until that person was within 4-1/2 meters (15') of the loading zone. This could contribute to unnecessary congestion at the loading zone; persons in mobility aids who are at the wrong loading zone would then have to scramble to the correct loading zone. Additional communications with wayside staff to identify the proper loading zone would also ensue.

The wayside bus route and destination identification panels at the Paralympic Village/Transportation Mall that were placed at a critical decision point to direct passenger flow to the proper loading bays (12 bays) were better dimensioned. These panels had letter width of 102 mm (4"), letter height of 127 mm (5"), stroke width of 22 mm (7/8"), and height to stroke width (H/SW) ratio of 5.7. Even a person with poor vision would be able to discern the information on the display at a threshold legibility distance of well over 31 meters (100').

Table 13. Information Display Measurements

	Letter Width (w)	Letter Height (h)	Stroke Width (sw)	h/sw
Route Sign	57 mm (2-1/4")	76 mm (3")	16 mm (5/8")	4.8
Destination Sign	22 mm (7/8")[1] 22 mm (7/8")[2]	33 mm (1-5/16")* 25 mm (1")**	6 mm (1/4") 6 mm (1/4")	5.3 4.2

*Capital Letter
**Small Letter

11. GENERAL OBSERVATIONS

Additional and varied comments are made below. These observations should be viewed, however, in the context of a well-planned and well-run transportation systems' operation, a judgement based on our limited direct observation and the review of planning documents.

Persons with mobility aids that had wheels with a large camber (slope), or mobility aids with a long wheelbase such as the tri-wheeled competition wheelchairs, generally had substantially more difficulty in using both the ramp and the lift to access the bus. Because of the narrower width, the problems were probably greater with the ramp.

At the Olympic Stadium, the authors observed that there was no good accessible path, other than the street, between the Paralympic Transit System bus bays at the Olympic Stadium and the MARTA Shuttle bus bays at the Olympic Stadium, due to sidewalk construction.

Both on-board observation, and curbside observation confirmed a number of circumstances in which a driver had difficulty negotiating tight radii curves on the routes, or passing other vehicles on narrow streets. On several routes, the authors observed parked cars too close to the intersection, obstructing corner visibility and making a turning movement by a large standard 40' bus difficult. Note that the New Flyer D40LF low-floor buses that were used require an 11.7 meter (38') turning radius (TCRP Synthesis 2, 1994). A comparable turning radius is required also for the lift-equipped buses. One driver indicated to the authors that there were substantial bus clearance problems on one of the access roads to the Paralympic Village/Transportation Mall due to two-way traffic on the narrow street; the road was eventually made one-way for bus flow, and the problems dissipated.

At the Olympic Stadium interior (northern) bus bay near the fixed wayside ramp, the authors observed evidence of several bus/bollard collisions, and witnessed a bus/bollard collision. Discussions with drivers and transportation control staff at several venues confirmed a number of bus scrapes and accidents. The authors also saw physical evidence on the buses of sideswipes. These were probably due to a combination of tight or difficult route geometrics, and the inexperience with and/or lack of knowledge on the part of the driver roster of the swept path and vehicle blind spots that are associated with a standard 40' bus. The interior southern bus bay at the Olympic stadium could not be used by buses due to the vertical curvature at its entrance.

At least one driver was unaware of the axle load of a standard 40' bus, drove on the sidewalk, and crushed both the sidewalk and the drainage inlet.

On several occasions, the authors observed either problems with the back door of the bus, or problems of the driver opening the back door of the bus. When buses were crowded, it was generally the rear of the bus that was the most crowded, and not being able to open and use the rear door for alighting complicated and slowed the operation.

On several occasions, the authors observed groups of passengers stranded for a substantial duration, waiting for an extra bus to be dispatched to pick them up. Not all buses had route and destination identification signs, and some had non-standard signs.

The authors were told that Opening Ceremonies had a number of buses operating with malfunctioning lifts, and other problems with the control of vehicular and pedestrian flows. The authors attended a meeting of Paralympic staff that was called to plan for and address some of these problems for the Closing Ceremonies.

12. SUMMARY OF FINDINGS

This section provides a summary of key findings of this study. These findings are listed in their order of presentation.

1. No major problems were observed with the low-floor ramp operations.

2. Manual deployment and stowage of the ramp was approximately 2 seconds faster than the controlled hydraulic deployment and stowage of the ramp; mean marginal boarding time per mobility-aided passenger was approximately 6 seconds, a factor of four less than a single lift cycle (6.3 seconds versus 24.4-33.7 seconds). Other studies have shown, however, that the effect on actual operational dwell time, in a public transit service environment, is not likely to be significant between a ramp and a lift due to a countervailing increase in time on low-floor buses to maneuver to a securement bay, secure the mobility aid, and prepare the bus for departure.

3. Direct observation confirmed three very distinct advantages to the low-floor bus operation: a. boarding and alighting operations were not disrupted by malfunctioning ramp hydraulics; rather, the ability to deploy and stow the ramp manually precluded the need for a roadcall, or for the insertion of supplemental service via dispatch of a spare bus; b. non-disabled persons could more easily access the bus via the ramp or a single step into the bus; and c. once deployed, the ramp does not have to be recycled for use by other passengers.

4. No major problems were observed with the lift-equiped bus operations.

5. The mean time to deploy a lift for the initial boarding is approximately the same (~ 10 seconds) as the mean time to activate the ramp.

6. Accounting for normal operational delays, the mean marginal boarding time per mobility-aided passenger for the lift is approximately 34 seconds. The mean marginal alighting time per mobility-aided passenger is approximately 4.5 seconds longer in duration (38.5 seconds).

7. An availability statistic for the lift, calculated from the logged number of lift-related service problems and the estimated total number of lift cycles during the Paralympics Event, yields a result greater than 99 percent (1 failure in every 4600+ cycles).

8. When the number of persons with mobility aids exceeded 12 for a single boarding event, it was reported by the drivers that both the latency and the time to deploy the lift increased, i.e., the lift responded slugishly. This result is consistent with the technical specifications for the lift, which posits a 10 percent duty cycle or 6 minutes of continuous operation in every hour of bus

operation. In normal transit operations, however, it is extremely rare to have more than two persons with mobility aids boarding or alighting at a single bus stop.

9. Direct observation and discussion with drivers indicate that passengers on the buses rarely made use of the securement straps to tie down the mobility aids.

10. A limited sample of persons with mobility aids or with mechanical walkers indicates a preference for the lift versus ramp for access to the bus, primarily due to the reduced human effort and energy expended in boarding and alighting from the bus.

11. Accounting for both set-up and break down time, analysis indicates that the wayside fixed ramp at the Olympic Stadium that was used for alighting operations is always faster than use of the bus lift when the number of persons with mobility aids on-board the bus equals two or more.

12. For the most part, bus route and destination identification signs at wayside and on-board the buses were well designed, and well placed. The destination sign characters should have been twice their actual height for a better legibility distance, particularly for visually impaired persons. (The width-to height ratio, and the stroke-width-to-height ratio of the destination signs were within the limits defined by ADAAG, Section 4.30, but the minimum character height of the upper case letters was only one half the minimum height set by ADAAG (33 mm versus 75 mm, see Table 13)).

13. Direct observation and discussion with staff indicated problems with bus maneuverability and negotiability with tight route geometrics, including pulling in and out of bus loading and discharge zones; in some cases, these problems resulted in bus accidents.

14. Direct observation at several venues has confirmed that an extremely large pool of on-site volunteers and on-site professional transportation control staff is critical to ensuring a well-run and smooth transport operation for special events such as the Paralympics.

13. RECOMMENDATIONS FOR FUTURE SPECIAL-EVENT TRANSPORT OPERATIONS INVOLVING LARGE-SCALE MOBILITY-IMPAIRED RIDERSHIP

This section offers several recommendations for future special-event transport operations involving, in particular, large-scale mobility-impaired ridership. These recommendations should be understood, however, in the context of what we observed to be a very well-planned and well-run Paralympics Transportation System.

- Based on the review of planning documents, and confirmed by limited observation of actual operations, it was clear that APOC transportation staff and their consultants had accomplished an enormous amount of detailed and well thought planning and conceptualization of the Paralympics Transportation System, as well as other critical vehicular and pedestrian traffic management and control issues. This included the use of a sophisticated CADD system to help plan transport facilities and circulation patterns at venues (see Figure 3). The general success of the on-the-street service, and the success with control and management of non-Paralympics vehicles, parking, and pedestrian flows confirmed the validity of the planning.

  In planning future special events, the authors recommend that this be augmented with the use of software such as AutoTURN™ which can interface with CADD systems to test via simulation, for all planned routes, large vehicles such as buses making all required turning movements, and to test other required clearances based on the planned route geometrics. Each planned route that is identified with potential problems with bus maneuverability and negotiability should have a test run using a professional transit driver. Changes should then be made to the planned routes, giving due regard to additional safety margins if the driver roster is to include non-professional bus drivers.

- In planning future special events, we recommend that time be scheduled to provide sufficient training of drivers for route and equipment familiarization, including operation of the lifts and ramps, knowledge of the interlocks, turning the buses, and pulling in and out of bus loading and discharge zones.

- For special event transport operations, the authors recommend a larger pool of standby drivers and buses than would normally be used for a conventional transit service. A larger pool would: service unusual or unplanned crush loading conditions and other contingencies, adjust operations to excessive delays in bus running times, provide additional flexibility to the dispatch control center, and help operations' staff adhere to planned schedules.

- For special event transport operations, the authors recommend the use of both low-floor buses with ramps and lift-equipped buses. Each has distinct advantages and, based on this study, it appears that the optimal policy is a hybrid fleet.

- For special event transport operations (assuming a hybrid fleet of both low-floor and lift-equipped buses, and where physical space permits), the authors recommend that wayside fixed ramps for alighting operations are preferable to the use of lifts.

APPENDIX

SAMPLE DATA COLLECTION FORMS

US Department of Transportation/Volpe Center
Federal Transit Administration

On-Board Bus Survey II
Measurements and Observations

(Underline: Low-Floor Buses; Lift-Equipped, with Ramp)

Route: ________ **(Complete Separate Form for as Many Boardings**
Page 1 of 2 **and Alightings as Possible)**

Boarding or Alighting?	**B**	**A**
Boarding or Alighting Assisted?	**Y**	**N**

Measurement of Time to Deploy Ramp: __________

Problems with Negotiating Threshold at Bus/Ramp Interface?	**Y**	**N**

Comments:

Problems with Negotiating Threshold at Ramp/Street Interface?	**Y**	**N**

Comments:

Problems with Free Clear Space at Terminus of Ramp at Streetside?	**Y**	**N**
Wheelchair Hit Side-edge and Redirected During Boarding/Alighting?	**Y**	**N**
Any Skidding/Slipping or Difficulty with Traction Observed During Wet Weather?	**Y**	**N**
During Dry Weather?	**Y**	**N**

Use of Handrails during Boarding/Alighting? Y N Continuous Intermittant

Difficulty of Wheelchair Turning into Bus Aisle(Pass Farebox and Driver Platform)?	**Y**	**N**

Comments:

Difficulty of Wheelchair Positioning to Access Securement Bay?	**Y**	**N**

Comments:

Any Problems Passengers Encounter in Storing Canes, Walkers, Seeing-eye Dogs so as not to obstruct Aisle?

US Department of Transportation/Volpe Center
Federal Transit Administration

On-Board Bus Survey II
Measurements and Observations

Route: ______ (Complete Separate Form for as Many Boardings and Alightings as Possible)
Page 2 of 2

Problem Encountered in Deploying Ramp?	Y	N
Appear to be Equipment-Related?	Y	N
Appear to be Due to Bus Positioning?	Y	N

Comments:

Method of Accessing Rear of Bus: ____ Internal Floor Ramp ____ Internal Steps
Any Difficulties Noted:

Measurement of Time to Stow Ramp: _______

Problems with Stowing Ramp? Y N
Comments:

Passenger Standees Repositioning as Result of Door Opening and Closing? Y N

Location of Passenger Standee Concentrations?
Front Third of Bus ____
Middle Third of Bus ___
Rear Third of Bus ____

Difficulties of Passengers Moving To/From Doorways to Alight/Board When Bus Is Relatively Crowded? Y N
Comments:

US Department of Transportation/Volpe Center
Federal Transit Administration

On-Board Bus Survey II (Lift-Equipped Buses)
Measurements and Observations

Route: ______ (Complete Separate Form for as Many Boardings
Page 1 of 2 and Alightings as Possible)

Boarding or Alighting? B A

Boarding or Alighting Assisted? Y N

Measurement of Time to Deploy Lift: ________

Problems with Free Clear Space at Terminus of Lift at Streetside? Y N

Wheelchair Hit Side-edge and Redirected During Boarding/Alighting? Y N

Any Skidding/Slipping or Difficulty with Traction Observed During Wet Weather? Y N
During Dry Weather? Y N

Use of Handrails during Boarding/Alighting? Y N Continuous Intermittant

Difficulty of Wheelchair Turning into Bus Aisle(Pass Farebox and Driver Platform)? Y N
Comments:

Difficulty of Wheelchair Positioning to Access Securement Bay? Y N
Comments:

Any Problems Passengers Encounter in Storing Canes, Walkers, Seeing-eye Dogs so as not to obstruct Aisle?

Problem Encountered in Deploying Lift? Y N
Appear to be Equipment-Related? Y N
Appear to be Due to Bus Positioning? Y N
Comments:

Measurement of Time to Stow Lift: _____

Problems with Stowing Lift? Y N
Comments:

US Department of Transportation/Volpe Center
Federal Transit Administration

On-Board Survey II (Lift-Equipped Buses)
Measurements and Observations

Route: ______ (Complete Separate Form for as Many Boardings and Alightings as Possible)
Page 2 of 2

Multiple Cycling of Lift at Boarding/Alighting Point? Y N
Number of Cycles: ________

Passenger Standees Repositioning as Result of Door Opening and Closing? Y N

Location of Passenger Standee Concentrations?
Front Third of Bus ____
Middle Third of Bus ____
Rear Third of Bus ____

Difficulties of Passengers Moving To/From Doorways to Alight/Board When Bus Is Relatively Crowded? Y N
Comments:

US Department of Transportation/Volpe Center
Federal Transit Administration

Lift-Equipped Bus __
Low-Floor Bus __

On-Board Passenger Survey

Have you ever used a bus ramp prior to the Paralympics' Games? Y N

Have you ever used a bus lift prior to the Paralympics' Games? Y N

Do you prefer the bus ramp or the bus lift in getting on and off the bus? ___ Ramp
___ Lift

Which do you feel is faster? ____ Ramp ____ Lift

Which do you feel is easier to use? ____ Ramp ____ Lift

If your local transit system used only buses with ramps, would you use the service:
____ More Frequently ____ No Change in Frequency ____ Less Frequently

Have you had any problems in using the bus ramp?

Have you had any problems in using the bus lift?

Are there any other comments that you wish to make about this bus?

(e.g., ride quality; views from the bus; interior noise; movement to/from seats; movement to/from securement bays; access to the rear of the bus; sufficiency of aisle width; fare payment; perceptions of safety and security; etc)

US Department of Transportation/Volpe Center
Federal Transit Administration
On-Board Communications Survey

Route and destination sign on front of bus? Y N

Route and destination sign on curbside exterior of bus? Y N

Route line map on interior side of bus? Y N ___Left Side ___ Right Side

Automated real-time system on-board bus? Y N

Automated real-time communication system:

Check for clear sight line to information display at following seat and standing positions:	Clear Sight Line	
a. first seat, left side of bus	Y	N
b. first seat, right side of bus	Y	N
c. midsection seat (aft of rear door), left side of bus	Y	N
d. midsection seat (aft of rear door), right side of bus	Y	N
e. last seat, left side of bus	Y	N
f. last seat, right side of bus	Y	N
g. standing height position in aisle, at first seat position	Y	N
h. standing height position in aisle, at interior step position	Y	N

Check for visibility of the information (ability to read the message) under existing ambient illumination and glare conditions at the following seat and standing positions	Visibility of Information	
a. first seat, left side of bus	Y	N
b. first seat, right side of bus	Y	N
c. midsection seat (aft of rear door), left side of bus	Y	N
d. midsection seat (aft of rear door), right side of bus	Y	N
e. last seat, left side of bus	Y	N
f. last seat, right side of bus	Y	N
g. standing height position in aisle, at first seat position	Y	N
h. standing height position in aisle, at interior step position	Y	N

Audio annunciation clear and audible over ambient background noise? Y N

Total number of stops observed that visual display and audio annunciation are inoperable _____

Total number of stops observed_____

US Department of Transportation/Volpe Center
Federal Transit Administration

On-Board Communications Survey

Information Display Measurements

	Letter Width	Letter Height	Letter Color	Background Color
On Bus				
a. Route sign				
b. Destination sign				
c. Route line map				

US Department of Transportation/Volpe Center
Federal Transit Administration

Bus Stop/Wayside Point Communications Survey

Information Display Measurements

	Letter Width	Letter Height	Letter Color	Background Color
At Bus Stops/Wayside Points				
a. Route sign (including routes served list)				
b. Stop Identification (Destination) sign				
c. Network map				
d. Schedule/Timetable				

Mounting height of displays (measured to bottom edge of display) at bus stops/wayside points ________

Use of pictograms for information displays?	Y	N
Are all routes served by bus stop identified?	Y	N
Information displays standardized across systems' bus stops/wayside points?	Y	N
Tactile displays at bus stops/wayside points for visually impaired?	Y	N
Information displays illuminated for nighttime visibility?	Y	N
Loading point for wheelchairs at bus stops identified?	Y	N
Route maps and schedules available in alternative formats (e.g., large print, braille, audio tape)?	Y	N

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