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Planning and Design of Intermodal Transit Facilities

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This paper presents an analysis of the present state of the art of transit station planning and design. It discusses the design process in terms of (a) design parameters and standards (e.g., stairways, ramps, and passageways; escalators; platforms; fare and exit control; moving walkways and ramps; bus facilities; and parking facilities); (b) design of the station environment (e.g., lighting, ventilation, acoustics, and fire control; passenger information and graphics; passenger security; commercial activities; and special provision for the handicapped); and (c) design methodology (e.g., deterministic, probabilistic, and impedance models; simulation; and validation problems). A classified bibliography is included.

The planning and design of intermodal transit facilities has become an area of increasing concern because of the major investments now being made in new rapid transit lines and the need to rehabilitate stations in older systems. The function of the transit interface in the overall system operation is to process the flow of passengers between modes. The degree with which the transition is accomplished smoothly and in a safe and pleasant environment will strongly influence system acceptance. Poorly designed transit stations can offset the advantages of the line-haul rapid transit portion of the system if the perceived impedances within the station outweigh the gains in point-to-point travel speed. Since station-to-station travel times cannot easily be decreased because of the relatively short distances involved, the influence of transit station design is critical in the overall system performance and in the share of the urban travel market attracted to new rapid transit systems.

Transit stations have been planned and designed for over a century, and there are many examples of excellent stations in both North America and Europe. Yet, the procedures and methodology for the planning and design of transit facilities have generally been piecemeal, qualitative, and limited in terms of the evaluation of alternative designs. Design data and experiences are scattered so that useful principles and techniques are not easily transferred from one situation to another.

The emphasis in this paper is on the transit facility design process, specifically those planning activities that are concerned with the selection of facility components and their spacial configuration based on parameters such as pedestrian flow and passenger processing needs. Inputs into the process are regional travel demand forecasts, transit station locations, and technology selection.

DESIGN PARAMETERS AND STANDARDS

The planning and design of intermodal transit facilities involve architectural, structural, mechanical, electrical, and transit considerations, and often component selection will involve trade-offs among various factors and constraints. The design parameters described below deal with the provisions necessary to create an environment suitable for processing and transferring passengers within the interface.

Passenger circulation requirements should be assessed prior to the selection, sizing, and location of facility components. Generally, station configurations are based on two primary objectives: to avoid conflicts and to provide adequate capacity. Guidelines for planning a transit station circulation pattern should include avoidance of unnecessary turns and dead-end corridors (i.e., direct paths), provision for unobstructed walking areas (e.g., structural columns and ticket machines in the path) and for duplicate access routes, attainment of smooth and continuous traffic flow, reduction of conflict-producing situations (e.g., avoidance of cross-circulation around fare-collecting areas), and provision of escalators where the vertical height exceeds 3.7 m (12 ft).

The capacity of a transit interface facility will be that of the weakest link, and exceeding the capacity will cause congestion, queues, and general passenger disorientation. The principal components of a station processing facility are its stairways, ramps, escalators, platforms, and fare collection areas. Some common guidelines and standards for these elements are as follows:

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Stairways, Ramps, and Passageways

Standards for stairways and ramps require a minimum width of 138 cm (54 in) between handrails, sufficient for two lanes of moving traffic. Ramp grades should not exceed 6 percent. Stairway tread width should be at least 28 cm (11 in), and riser height should not exceed 18 cm (7 in). The most favorable design (3) is a 15-cm (6-in) riser, 30.5-cm (12-in) tread, and 26.5-deg climb. A stair landing of at least 1.8-m (6-ft) depth should be provided every 16 steps within the station. The capacities of ramps and level passageways that meet the above standards are 50 and 55 persons/lane/min respectively; the stairway capacities are 25 (up) and 35 (down)/min.

Escalators

The provision of escalators in new stations is almost universal, although a ramp or stairway should be available as an alternative. Escalator specifications require a minimum tread depth of 40 cm (16 in), a riser height of 22 cm (8.5 in), and a maximum angle of inclination of 30 deg. The normal widths of escalators are 81 and 122 cm (32 and 48 in), which accommodate one- and two-lane passenger movement respectively. Escalator capacity should be sufficient to handle two-thirds of the peak half-hour traffic, and the combined capacity of all stairways, ramps, and escalators should be adequate to accommodate the peak-period traffic with one escalator out of service. Escalator speeds in U.S. transit systems are usually 0.46 to 0.61 m/s (90 to 120 ft/min) [versus 0.61 to 0.76 m/s (120 to 150 ft/min) in Europe]. At a speed of 0.46 m/s (90 ft/min), the ascending capacity is about 3000 passengers/lane/h, but only 2100 descending passengers/lane/h can be accommodated. The installation of two-speed escalators appears to be justified, as a speed of 0.61 m/s (120 ft/min) increases capacity by about 20 percent (15).

Platforms

Both side and island platforms are used in transit station design, the selection being dependent on economic and local factors. Island platforms are easier to maintain and control and can serve both morning and afternoon peaks, but side platforms may be more suitable where track alignment problems exist (e.g., cut-and-cover on street right-of-way or aboveground). Side platforms should be at least 3.7 m (12 ft) wide, with a minimum distance of 1.5 m (5 ft) between the edge of the platform and any obstructions such as railings, escalators, or stairways. Island platforms should be at least 3.7 or 5.5 m (12 or 18 ft) wide, depending on whether the access facilities are located at the ends or at the center of the platform (14). The optimal width for a side platform may be closer to 4 m (13 ft), which provides 1.8 m (6 ft) for the escalator or stairway and a 2.1-m (7-ft) clear area. This allows for two lanes of moving passengers, one standing lane, and a safety lane at the edge of the platform. By these criteria, a center-access island platform should be at least 6 m (20 ft) wide. For volumes in excess of 5000 passengers/d, these dimensions should be revised upward according to expected peaking characteristics.

Fare and Exit Control

Fare control components include change booths and turnstiles. The technology ranges from coin-operated low turnstiles to magnetically stored tickets that compute the fare and control entry and exit. Capacities of turnstiles range from 15 persons/min for coin-operated machines to 30 persons/min for machine-read tickets. Low turnstiles are not recommended where illegal entry is a problem, and exits should have sufficient capacity to permit all debarking passengers to leave the station before the next train arrives. [The Chicago Transit Authority (7) suggests a one-agent booth and a low coin-operated turnstile for each 800 peak-hour passengers. On the other hand, the New York World Trade Center has found one coin-operated machine per 2000 peak-hour passengers to be adequate.]

Moving Walkways

Moving walkways are not widely used in transit stations because the walking distances are relatively short and walkway speeds are low [maximum 0.91 m/s (180 ft/min)]. Generally, the treadway slope should not be greater than 15 deg and the walkway length should not be greater than 305 m (1000 ft). The capacity of a moving walkway depends on its width and speed. With a 64-cm (25-in) width and a speed of 0.64 m/s (125 ft/min), a walkway can accommodate approximately 3600 persons/h.

Bus Facilities

Feeder and line-haul bus service should be integrated within the terminal facility for the comfort and convenience of the passenger. Among the desirable items are (a) separation of buses from other vehicles to avoid conflicts with automobiles and to permit free flow of the buses for better schedule adherence and increased safety, (b) simple connections between buses and trains so that walking is direct and short, (c) provision for expansion to accommodate increased traffic, (d) separation of bus terminal roadways from those for parking or kiss-and-ride access, and (e) a lane for defective or pull-in buses in each turnaround area.

Parking Facilities

The provision for automobile parking at suburban transit stations is essential because park-and-ride is one of the principal access modes. Generally an area of 28 to 42 m^2 (300 to 450 ft^2)/space has been allowed for parking, but newer designs such as used by BART have higher standards that require 42 to 44 m^2 (450 to 475 ft^2)/automobile. The parking policy can influence the design, for example, in the provision of meters, spaces for business parking, or for short-term and long-term commuter parking, security, and lighting and policing functions.

DESIGN OF THE STATION ENVIRONMENT

The quality of the station environment is a design objective equal in importance to those of passenger flow and capacity. The perception of the station in terms of such human attributes as comfort, security, orientation, and scale will be reflected in passenger acceptance and use. Stations should be well-lighted, simple to negotiate, quiet, temperature controlled, and supportive of other passenger needs.

Lighting, Ventilation, Acoustics, and Fire Control

Design standards for lighting, ventilation, temperature-humidity control, and noise have been defined by the transit industry and in professional society handbooks and codes. There is also a considerable amount of research by the U.S. Department of Transportation on noise and ventilation to assist designers in these matters.

The Institute for Rapid Transit (IRT) (10) lists the following important considerations in station lighting: minimum illumination levels, maximum brightness ratios, maximum discomfort glare rating, reflectance, and provisions for emergencies. The IRT design standards can be used to test the adequacy of lighting for each station configuration.

Station ventilation is critical for underground stations and can be accomplished by the piston action of the moving trains and mechanical means. Ventilation by piston action requires coordination of vent shafts, tunnel sections, and stair and passageway areas. Mechanical ventilation involves a system of fans, air intakes, exhaust structures, and distributive duct work.

The goals for station acoustics are to maintain noise levels in vehicles and stations within acceptable limits and to limit the noise impact of stations on the surrounding community. Noise control is achieved by the acoustical designs of the vehicle, station, and roadbed. The IRT has established design criteria and standards for noise and vibration levels that vary with their intensity and the location. The maximum tolerable noise level in a station is in the range of 80 to 85 dBA, although constant exposure to noise at this level could be harmful. Accordingly, the noise levels of the trains should be minimized, and sound-absorbing materials should be used in the stations.

Fire control is accomplished by (a) using materials that are fire resistant and produce only limited amounts of dense or toxic smoke in the station, vehicles, and equipment; (b) furnishing adequate fire alarm and detector systems, standpipes and hoses, and portable fire extinguishers; (c) providing means for passenger escape and entry for fire-fighting equipment; and (d) providing mechanical ventilation equipment that can remove smoke from tunnels in alternate directions and supply fresh air to exits as needed. Fire hazards should be eliminated and provisions made to isolate and confine danger areas.

Passenger Information and Graphics

Information and directions for passengers are essential to the functioning and operation of a transit station. Passenger orientation is the principal criterion for the effectiveness of an information system, and the design should provide a continuous path of graphic directions between the transit vehicle and the street. Messages should be simple to understand and provided at frequent intervals. Principles and guidelines for passenger information systems are (a) to use a single style of lettering, standard signs, and simple words; (b) to avoid confusion by eliminating advertising in the vicinity of information graphics; (c) to locate information at critical decision points; (d) to provide map space near fare collection areas and on platforms; (e) to minimize the number of independent messages at each point; (f) to maintain continuity, consistency, and sight distance; and (g) to furnish direct information that does not require translation into other terms or units.

Passenger Security

Transit facility design must include provisions for passenger protection from harassment and violence, the surveillance of potential criminal acts, and the means for apprehension of persons involved in vandalism and other illegal acts. The problem is complex, and the role of station design is to provide an environment in which crime is deterred or discouraged. Among the means are (a) provision of open station and platform areas in direct view of station attendants, (b) direct telephone access to the central transit office and local police, (c) television surveillance of selected station areas, and (d) direct communications for passengers via telephone or alarms.

Commercial Activities

The provision of concessions within transit stations is a matter related to management policy. The benefits of providing commercial outlets for the sale of newspapers, candy, and other short-order items are an added convenience for the transit patron, income for the transit agency, and the vitality of the area due to the life and color brought into the station by advertising and concessions. On the other hand, these facilities consume valuable mezzanine space, interfere with the traffic flow, contribute to the untidiness of stations and vehicles, require additional maintenance and cleanup crews, and promote vandalism and loitering.

Special Provisions for the Handicapped

The needs of handicapped persons are being incorporated into modern transit station design. Common barriers that have excluded handicapped persons from transit riding are steps or curbs that are too high; long flights of stairs; inaccessible elevators; steep or narrow walks; gratings in walkways; narrow doors, revolving doors, or hard-to-open doors; narrow aisles; and lack of accommodation for wheelchairs.

DESIGN METHODOLOGY

The process of transit station design involves the testing and evaluation of alternative configurations and includes the following procedural steps: (a) define the constraints on the station location; (b) develop passenger and vehicle flow data by origin, destination, access mode, line, and headway; (c) establish design objectives, criteria, standards, and requirements; (d) prepare alternative station design layouts; (e) evaluate the performance of each design; (f) select the design alternative that best meets the standards and criteria; and (g) refine and iterate the process until an optimal design is prepared.

Application of the station design process has generally followed accepted practices within the architectural and engineering professions and used design standards, codes, judgment (rules of thumb), and results gained from the experiences of established transit operations. Analytical techniques based on mathematical models and computer simulation have not been widely used in the evaluation of alternative station designs. However, a number of research studies dealing with various elements of transit station behavior (e.g., walking and waiting times and arrival and service distributions) have been incorporated into several recently developed station simulation programs. These analytical models and techniques are intended to assist the station designer to answer questions related to the amount of space required for queuing and circulation areas, the number of service (e.g., fare collection) facilities needed, and the locations and dimensions of passageways, escalators, stairs, and connections between service areas.

Simulation Models

Computer design methodology is based on the application of simulation techniques that can analyze the dynamic and microscopic performance characteristics of alternative terminal designs. The principal efforts in these areas are the works of Fausch and Barton-Aschman

Associates, who have developed computer programs to replicate transit station performance for the Urban Mass Transportation Administration (29, 30, 33, 34, 35). The intent of the project was to develop a transit station design tool that is flexible, in terms of user input, accuracy requirements, and computer time; not limited by the availability of data; and usable, in terms of its ability to evaluate a variety of design proposals in terms of specific objectives. This simulation package is designed to determine three basic types of design data for a given station layout. These are the travel times for individuals within the station, the pedestrian occupancy requirements, and the distribution of these variables for comparison with design standards. Among the unique features of this simulation package are the representation of a two-way flow pattern and passenger interaction and a station description in terms of links or nodes for both vehicles and passengers. Design flexibility is available through the capability to add or combine links and thus control the level of detail required.

Validation of Transit Station Models

Computer models for transit station design are tools with which to evaluate alternative interface facility layouts. The designs are the inputs to the model and require the creative efforts of the station design team. Verification of simulation models is generally difficult because of data acquisition problems and the complexity of the passenger flow process. The use of such models in transit station design is not common practice although there is increasing interest in these techniques. They are expensive to implement, but could pay for themselves if used from the outset on large projects in which numerous variables are introduced as time goes on.

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Improving Pedestrian Access to Train Platforms at Grand Central Terminal

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A technical study of the feasibility of providing northern access for train passengers to the upper and lower level platforms at Grand Central Terminal in Manhattan is reported. At present, access is available at the southern ends of the platforms only. The purposes of the study were to identify (a) the functions of Grand Central Terminal, (b) the best location for northern access pedestrian facilities, (c) the passageway widths required to handle peak volumes, and (d) the impacts of the recommended design on the movement of people and trains. Four types of surveys, an on-board rail passenger survey; a pedestrian interview survey; pedestrian volume counts; and special studies on pedestrian walking speeds, platform and train discharge times, and the number of encumbered persons, were conducted. Grand Central Terminal functions as an intermodal transfer facility, a link in the midtown pedestrian network, a commercial center, and an extension of the subway stations. The recommended improvement concept includes two east-west and two north-south passageways to serve both the upper and lower level platforms. The impacts of 25 and 50 percent increases in passengers on the widths required for the proposed passageways were estimated, based on evaluation criteria related to congestion, walking distances, travel times, railroad operations, handicapped persons, orientation, and capital and operating costs.

The feasibility of providing northern access for train passengers to and from the upper and lower level platforms at Grand Central Terminal (GCT) has been studied by a group of consultants (1). At present, railroad commuters have access to the platforms at the southern end (Forty-second and Forty-third streets) only, which means that a commuter bound for a destination north of Forty-seventh Street, who arrives on the last car on a 10-car train that stops underneath Forty-seventh Street, must walk an extra 610 m (2000 ft), adding more than 7 min to the overall trip time (Figure 1). The present pattern of local destinations is such that over half of the commuters are northbound from the terminal. This means that they must walk south along the platforms and then backtrack north along the avenues to reach their ultimate destinations.

The conceptual solution to the problem is relatively apparent: Provide northern access to the upper and lower level platforms. However, the major question is how to physically provide northern access in the face of the following severe constraints:

1. Narrow platforms, generally 4.6 m (15 ft) wide, with obstructions created by building columns and baggage elevators;
2. Serious structural engineering problems because of the large office buildings that have been constructed on both sides of Park Avenue on air rights over the train rooms;
3. The need to minimize the impact on the commuter rail operations of the Penn Central Transportation Company;
4. The desire to avoid serious disruptions to private properties; and
5. Financial limitations.

MAJOR STUDY ISSUES

The question of providing northern pedestrian access to the train platforms raises four issues directly related to pedestrian flow characteristics and train operations: How does GCT function (its roles)? Where should northern access facilities for pedestrians be provided (their location)? How wide should the facilities be in order to handle the anticipated peak flow (their design)? What are the impacts of northern access on the movements of people and trains (their costs and benefits)?

To deal with these issues, a data base using the results of four surveys was created.

1. A rail passenger survey was conducted on-board all 70 inbound trains arriving at the terminal during the 8:00 to 9:40 a.m. period; the questionnaire shown in Figure 2 was used. The data were obtained from a sample of the passengers and included the total number of passengers by railroad car and train, and their origins, destinations, trip purposes, and departure (from GCT) modes.
2. Pedestrian surveys were conducted at all of the significant entry points into GCT (sidewalks, subway station connections, Pan American Building escalators, and passageways) during the 8:00 to 9:00 and 10:00 to 11:00 a.m. periods. The data collected here included a count

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of the volume of people, and their origins, destinations, trip purposes, and departure modes. Figure 3 shows the questionnaire used in this survey.

3. Pedestrian volume counts by direction of travel were made at all access connections to and from GCT and between the lower (suburban) level and the upper (express) level during the period from 7:30 to 11:30 a.m. on 1 weekday. At three key locations counts were also taken from 7:00 a.m. to 7:00 p.m. for 5 weekdays to establish daylong and day-of-week volume characteristics.

4. Special studies to describe certain specific characteristics of GCT pedestrian activity were undertaken. These included pedestrian walking speed, delay studies at crowded locations, encumbered persons counts, short-time (2-min) volume surge counts, train platform and car unloading time observations, and external (to GCT) pedestrian volume counts on north-south sidewalks along Madison, Vanderbilt, Park, and Lexington avenues.

ROLES OF GRAND CENTRAL TERMINAL

Grand Central Terminal is an important element in the New York City transportation system. Located along Forty-second Street, its superstructure covers about four blocks (Figure 1). The substructure covers a much larger area, reaching from Forty-second Street to Fiftieth Street between Lexington and Madison avenues. The Commodore, Roosevelt, and Biltmore hotels and the Pan American Building are integrated with the terminal.

The Lexington, Flushing, and Times Square Shuttle subways are located along the Forty-second Street edge, and station access into GCT is provided. Given this

Figure 1. Physical setting of Grand Central Terminal.

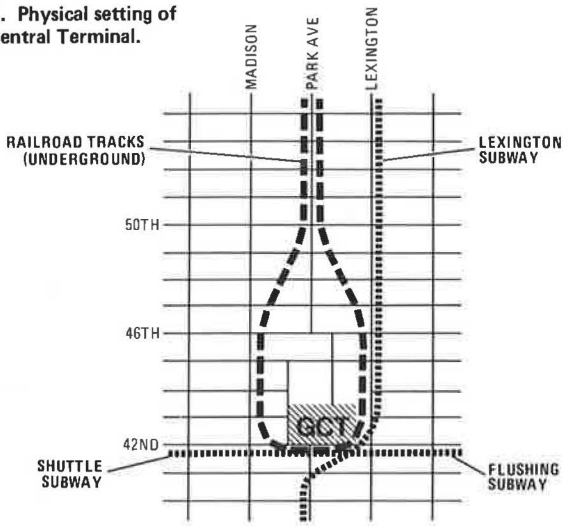
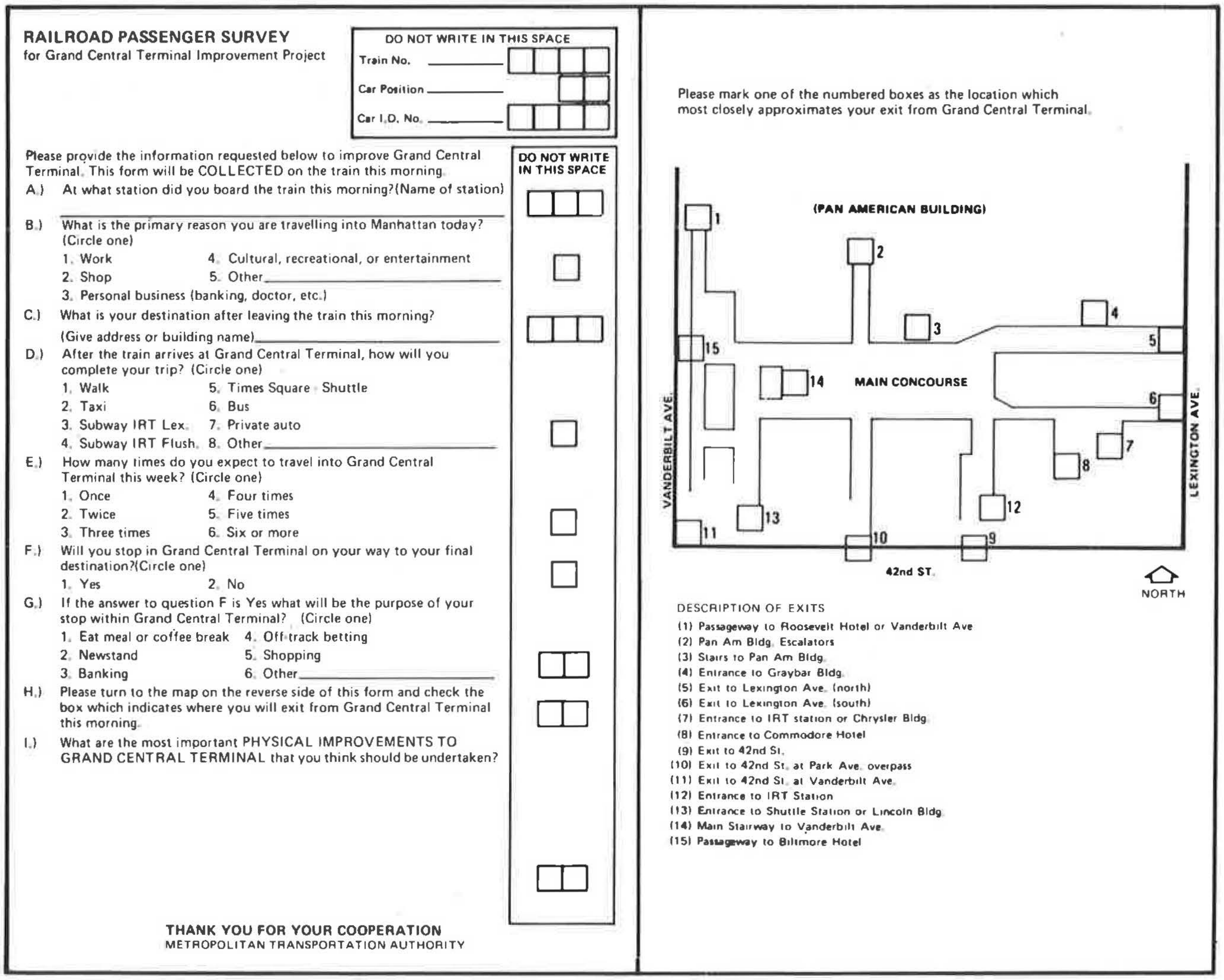


Figure 2. Rail passenger survey questionnaire.



RAILROAD PASSENGER SURVEY
for Grand Central Terminal Improvement Project

DO NOT WRITE IN THIS SPACE
Train No. ______
Car Position ______
Car I.D. No. ______

DO NOT WRITE IN THIS SPACE

Please provide the information requested below to improve Grand Central Terminal. This form will be COLLECTED on the train this morning.

A.) At what station did you board the train this morning?(Name of station)
______

B.) What is the primary reason you are travelling into Manhattan today? (Circle one)
1. Work
2. Shop
3. Personal business (banking, doctor, etc.)
4. Cultural, recreational, or entertainment
5. Other ______

C.) What is your destination after leaving the train this morning?
(Give address or building name) ______

D.) After the train arrives at Grand Central Terminal, how will you complete your trip? (Circle one)
1. Walk
2. Taxi
3. Subway IRT Lex.
4. Subway IRT Flush.
5. Times Square Shuttle
6. Bus
7. Private auto
8. Other ______

E.) How many times do you expect to travel into Grand Central Terminal this week? (Circle one)
1. Once
2. Twice
3. Three times
4. Four times
5. Five times
6. Six or more

F.) Will you stop in Grand Central Terminal on your way to your final destination?(Circle one)
1. Yes
2. No

G.) If the answer to question F is Yes what will be the purpose of your stop within Grand Central Terminal? (Circle one)
1. Eat meal or coffee break
2. Newstand
3. Banking
4. Off-track betting
5. Shopping
6. Other ______

H.) Please turn to the map on the reverse side of this form and check the box which indicates where you will exit from Grand Central Terminal this morning.

I.) What are the most important PHYSICAL IMPROVEMENTS TO GRAND CENTRAL TERMINAL that you think should be undertaken?

THANK YOU FOR YOUR COOPERATION
METROPOLITAN TRANSPORTATION AUTHORITY

Please mark one of the numbered boxes as the location which most closely approximates your exit from Grand Central Terminal.

DESCRIPTION OF EXITS
(1) Passageway to Roosevelt Hotel or Vanderbilt Ave
(2) Pan Am Bldg. Escalators
(3) Stairs to Pan Am Bldg.
(4) Entrance to Graybar Bldg.
(5) Exit to Lexington Ave. (north)
(6) Exit to Lexington Ave. (south)
(7) Entrance to IRT station or Chrysler Bldg.
(8) Entrance to Commodore Hotel
(9) Exit to 42nd St.
(10) Exit to 42nd St. at Park Ave. overpass
(11) Exit to 42nd St. at Vanderbilt Ave.
(12) Entrance to IRT Station
(13) Entrance to Shuttle Station or Lincoln Bldg.
(14) Main Stairway to Vanderbilt Ave.
(15) Passageway to Biltmore Hotel

physical setting, GCT serves four basic functions.

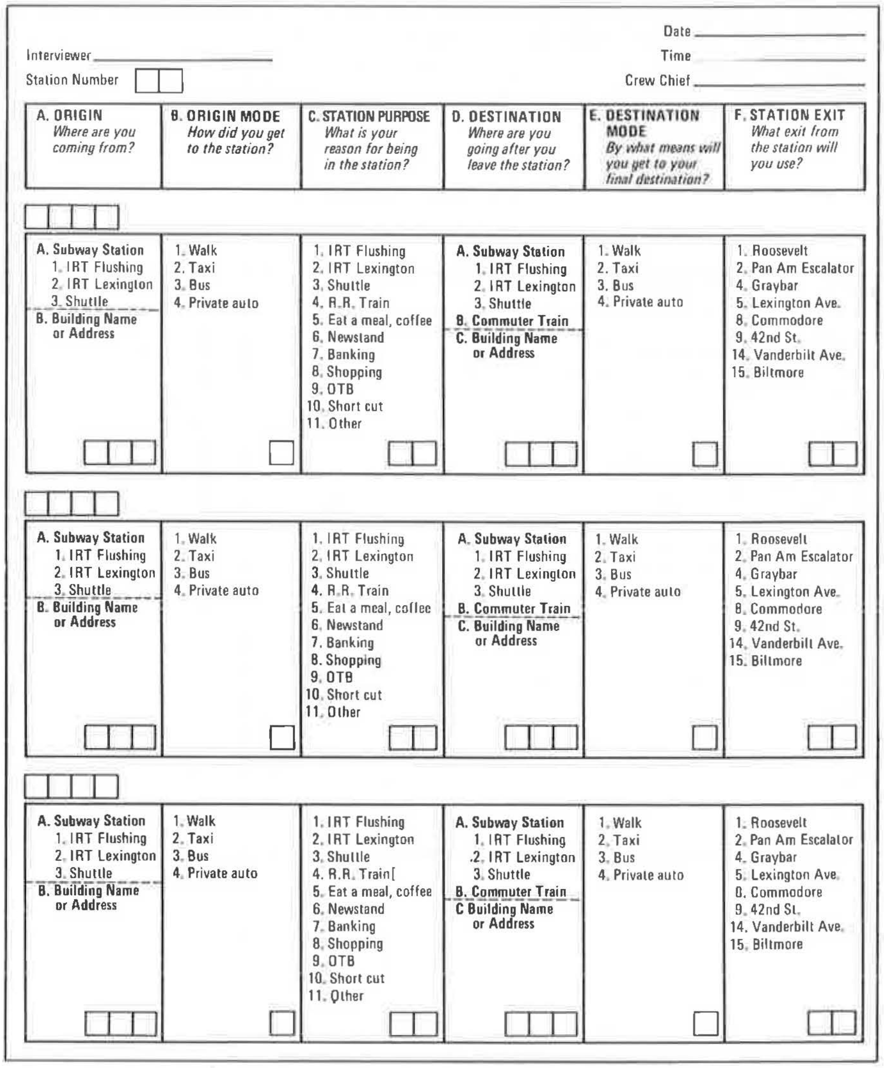
1. It is an intermodal transfer facility. The majority of the people entering GCT are changing their modes of travel among walking, subway, railroad, and bus/automobile/taxi. It is the major Manhattan terminal for three Penn Central commuter lines and Amtrak and is contiguous with three subway lines. About 250 000 people use the terminal during an average weekday. As illustrated in Figure 4, the most significant interchanges are rail-to-walk, subway-to-walk, and rail-to-subway.
2. Because of its location in the mid-Manhattan major activity area and its direct pedestrianway connections to other buildings, GCT is a link in the midtown pedestrian circulation system, especially in inclement weather.
3. GCT also contains nontransportation land uses and is a commercial activity center. This function includes branch banks, off-track betting, various commercial service enterprises, and restaurants. The retail activities in the terminal are secondary trip destinations and people going to work may stop for a newspaper, coffee, or another purpose as part of their primary commuting trips.
4. GCT is an extension of the subway stations. It functions as a distribution system for the Lexington Avenue, Flushing, and Times Square Shuttle subway patrons.

LOCATION OF PROPOSED NORTHERN ACCESS FACILITIES

Sixteen alternative concepts were developed by using combinations of three kinds of components: (a) east-west passageways, perpendicular to the train platforms, to collect people from the platforms in the morning and distribute them in the evening; (b) north-south spines (passageways), parallel to the platforms, to connect the upper level concourse, the east-west passageways, and the street access points; and (c) vertical movement facilities (stairs and escalators) for access from the passageways to the street, necessary for network continuity. The recommended concept (Figure 5) includes

1. Two east-west passageways between the upper and lower tracks: one under Forty-seventh Street that would serve as a collector and distributor for upper level platform passengers and one under Forty-fifth Street that would do the same for lower level platform passengers;
2. Two north-south spines that would connect the two east-west passageways, the upper level concourse, and the street, and would require discontinuing tracks 22 and 31 on the upper level (the trash collection stub tracks); and
3. Access from the east-west passageways to Park Avenue at Forty-seventh and Forty-ninth streets and to

Figure 3. Pedestrian survey questionnaire.



Date ____________

Interviewer ____________

Time ____________

Station Number ☐☐

Crew Chief ____________

A. ORIGIN *Where are you coming from?*	**B. ORIGIN MODE** *How did you get to the station?*	**C. STATION PURPOSE** *What is your reason for being in the station?*	**D. DESTINATION** *Where are you going after you leave the station?*	**E. DESTINATION MODE** *By what means will you get to your final destination?*	**F. STATION EXIT** *What exit from the station will you use?*
☐☐☐☐					
A. Subway Station 1. IRT Flushing 2. IRT Lexington 3. Shuttle **B. Building Name or Address** ☐☐☐	1. Walk 2. Taxi 3. Bus 4. Private auto ☐	1. IRT Flushing 2. IRT Lexington 3. Shuttle 4. R.R. Train 5. Eat a meal, coffee 6. Newstand 7. Banking 8. Shopping 9. OTB 10. Short cut 11. Other ☐☐	**A. Subway Station** 1. IRT Flushing 2. IRT Lexington 3. Shuttle **B. Commuter Train** **C. Building Name or Address** ☐☐☐	1. Walk 2. Taxi 3. Bus 4. Private auto ☐	1. Roosevelt 2. Pan Am Escalator 4. Graybar 5. Lexington Ave. 8. Commodore 9. 42nd St. 14. Vanderbilt Ave. 15. Biltmore ☐☐
☐☐☐☐					
A. Subway Station 1. IRT Flushing 2. IRT Lexington 3. Shuttle **B. Building Name or Address** ☐☐☐	1. Walk 2. Taxi 3. Bus 4. Private auto ☐	1. IRT Flushing 2. IRT Lexington 3. Shuttle 4. R.R. Train 5. Eat a meal, coffee 6. Newstand 7. Banking 8. Shopping 9. OTB 10. Short cut 11. Other ☐☐	**A. Subway Station** 1. IRT Flushing 2. IRT Lexington 3. Shuttle **B. Commuter Train** **C. Building Name or Address** ☐☐☐	1. Walk 2. Taxi 3. Bus 4. Private auto ☐	1. Roosevelt 2. Pan Am Escalator 4. Graybar 5. Lexington Ave. 8. Commodore 9. 42nd St. 14. Vanderbilt Ave. 15. Biltmore ☐☐
☐☐☐☐					
A. Subway Station 1. IRT Flushing 2. IRT Lexington 3. Shuttle **B. Building Name or Address** ☐☐☐	1. Walk 2. Taxi 3. Bus 4. Private auto ☐	1. IRT Flushing 2. IRT Lexington 3. Shuttle 4. R.R. Train 5. Eat a meal, coffee 6. Newstand 7. Banking 8. Shopping 9. OTB 10. Short cut 11. Other ☐☐	**A. Subway Station** 1. IRT Flushing 2. IRT Lexington 3. Shuttle **B. Commuter Train** **C Building Name or Address** ☐☐☐	1. Walk 2. Taxi 3. Bus 4. Private auto ☐	1. Roosevelt 2. Pan Am Escalator 4. Graybar 5. Lexington Ave. 8. Commodore 9. 42nd St. 14. Vanderbilt Ave. 15. Biltmore ☐☐

Vanderbilt Avenue at Forty-seventh Street.

The placement of the cross passageways under Forty-fifth and Forty-seventh streets will provide access to the lower and upper level platforms at the most northern points common to both levels. It also will permit construction of the passageways in an area free of building columns. Similarly, the recommended north-south spines are located under the sidewalks of Park Avenue, giving balance and choice to northbound pedestrians and providing the most direct access to the building plaza areas above. The track 22 spine can be extended underground as far north as Forty-ninth Street and the track 31 spine to Forty-seventh Street without serious effects on railroad operations. (The trash collection activities can be relocated to tracks 11 and 13 immediately adjacent to the upper level yard area and the passenger trains now using these two tracks accommodated in schedule gaps on other passenger tracks.)

Figure 4. Intermodal transfers (morning peak hour).

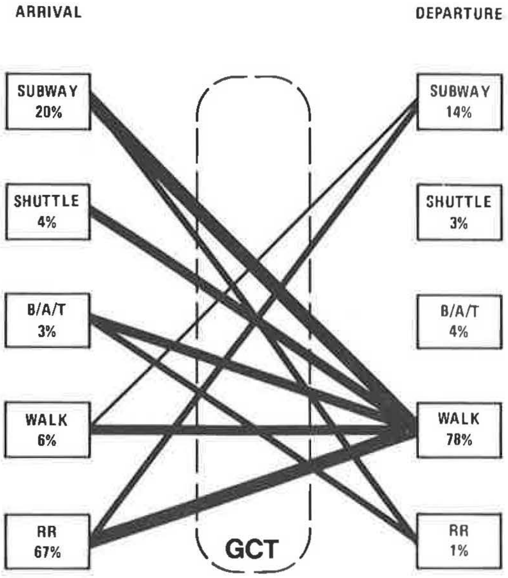


Figure 5. Concept 1.

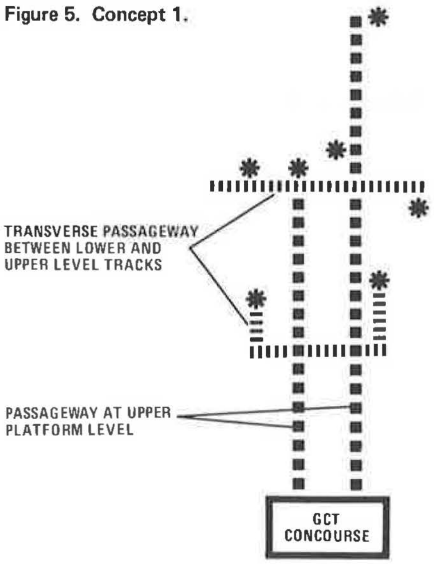
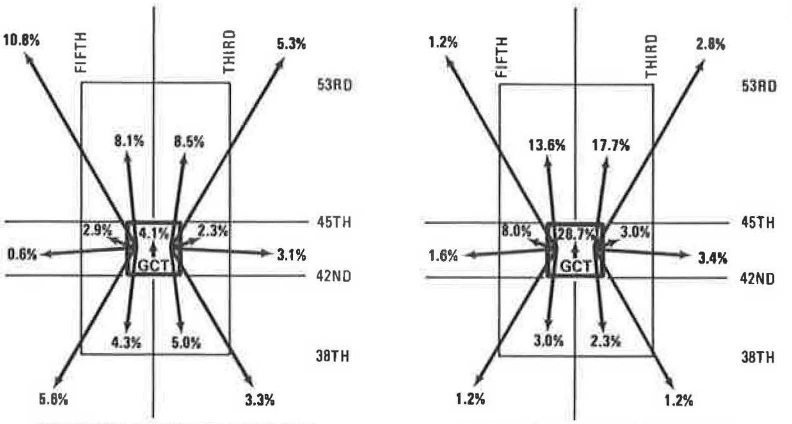


Table 1. Peak-hour volume and capacity.

Access Mode	Capacity	Persons/ Peak-h	Volume to Capacity Ratio (V/C)	Surge Volumes (Equivalent Persons/h)			
				15-min	V/C	2-min	V/C
Pan Am escalators	11 900	13 005	1.1	15 600	1.3	17 900	1.5
Graybar passageway	32 800	7 093	0.2	8 500	0.3	11 300	0.3
Commodore passageway	32 800	4 030	0.1	4 800	0.2	6 500	0.2
Commodore subway stairs	9 900	6 525	0.7	7 800	0.8	11 800	1.2
Forty-second Street subway stairs	6 000	5 894	1.0	7 100	1.2	10 600	1.8
Forty-second Street and Park Avenue passageway	14 200	3 448	0.2	4 100	0.3	4 800	0.3
Forty-second Street and Vanderbilt Avenue ramp	7 200	3 826	0.5	4 600	0.6	5 300	0.7
Lower/upper concourse stairs	3 700	2 646	0.7	3 200	0.9	3 700	1.0
Roosevelt passageway	7 600	3 509	0.5	4 200	0.6	4 800	0.6

Figure 6. Pedestrian travel patterns from GCT.



DIRECTION OF EGRESS FROM GCT (RAIL PASSENGERS)

DIRECTION OF EGRESS FROM GCT (NON-RAIL PASSENGERS)

DESIGN OF PROPOSED NORTHERN ACCESS FACILITIES

The width necessary for each proposed pedestrian facility was estimated by using the survey data to determine the existing pedestrian volume on each link and a multipath assignment algorithm to estimate the number of existing passengers who would use the proposed links if they were built and then converting these volumes into the effective widths required at different levels of service, using standards described by Fruin (2). The implications of 25 and 50 percent increases in pedestrian volume were tested by means of a sensitivity analysis procedure. Both the methodology and the conclusions reached are described below.

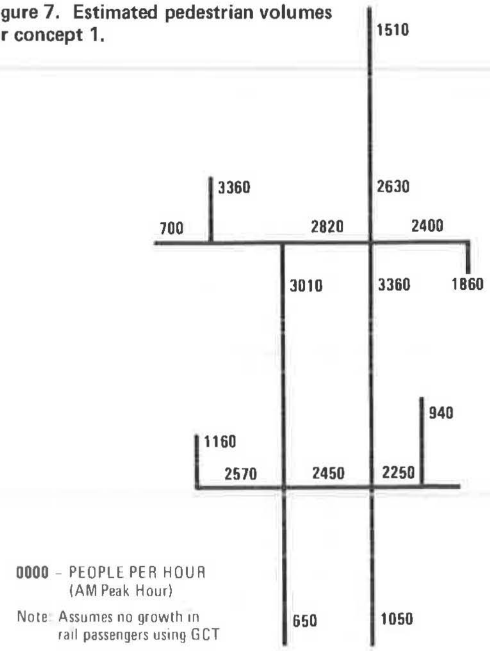


Figure 7. Estimated pedestrian volumes for concept 1.

0000 – PEOPLE PER HOUR (AM Peak Hour)

Note: Assumes no growth in rail passengers using GCT

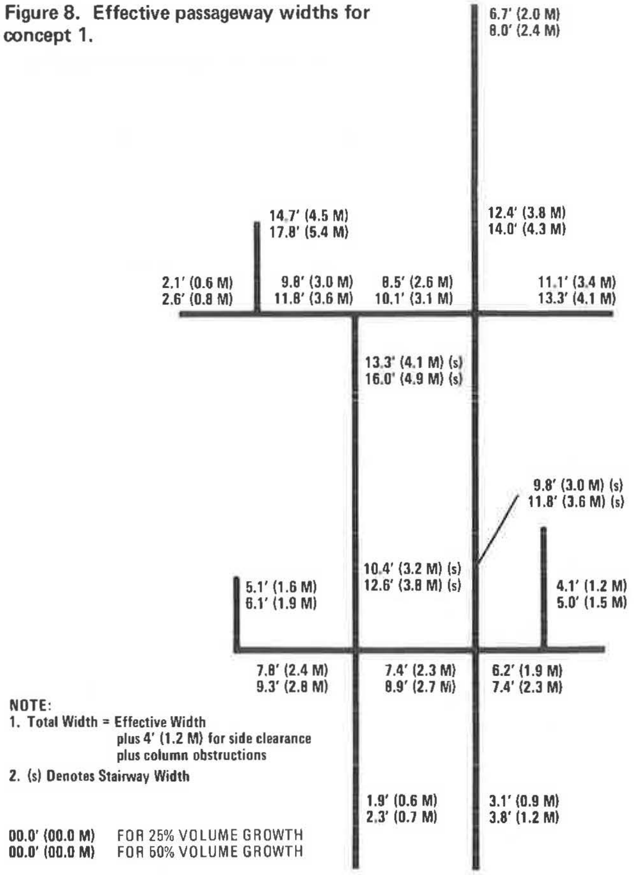


Figure 8. Effective passageway widths for concept 1.

NOTE:
1. Total Width = Effective Width plus 4' (1.2 M) for side clearance plus column obstructions
2. (s) Denotes Stairway Width

00.0' (00.0 M) FOR 25% VOLUME GROWTH
00.0' (00.0 M) FOR 50% VOLUME GROWTH

Existing Pedestrian Volumes

The peak occurs on weekday mornings when people getting off the trains (in platoons) onto the relatively narrow platforms and other pedestrian facilities create the most severe congestion problems. During the morning peak hour (8:00 to 9:00 a.m.), about 49 800 people enter GCT (33 700 from the rail platforms and 16 100 from the rapid transit stations or the street). About one-half of the total daily Penn Central riders arrive in this period. The elements in the pedestrian circulation system that become the most congested during peak periods are the vertical movement elements and the train platforms. Circulation on the platforms is almost exclusively one-way southbound during the morning, but northern access improvements would create two-way flow on platforms that are usually only 4.6 to 4.9 m (15 to 16 ft) wide. In the peak 15-min interval 30 percent of total hourly volume arrives. Short surges (2 min) are even more noticeable. Platform clearance times vary from 2 to 8 min, and the schedule is arranged so that two trains do not unload from both sides of a platform simultaneously. The effect of these surges in terms of volume-to-capacity (V/C) ratios is shown in Table 1.

Existing Travel Patterns

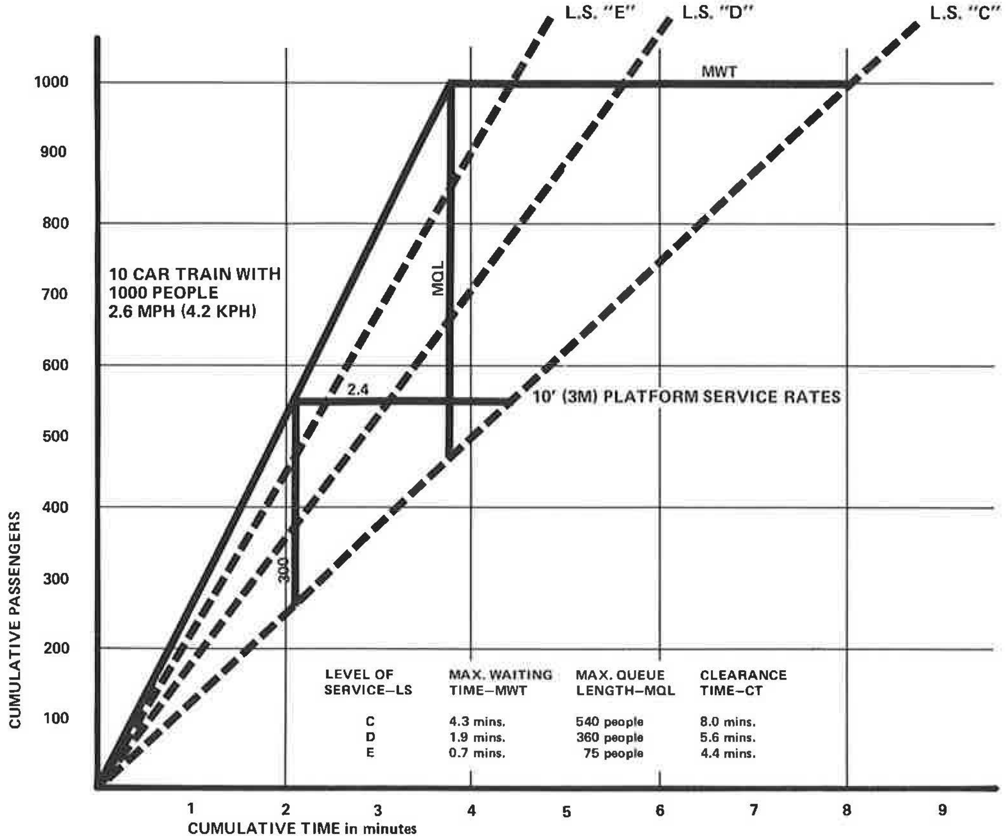
During the peak hour, 62 percent of the railroad commuters and 59 percent of the nonrailroad commuters entering GCT walk to a final destination outside the GCT complex. The geographical distribution is shown in Figure 6 and summarized as follows:

Commuters	Percent	Distance and/or Direction From GCT
Railroad patron	50	⩾4 to 5 blocks—to the northwest (Rockefeller Center) or the northeast
	33	North of Forty-fifth Street
	18	South of Forty-second Street
Others	16	⩾4 to 5 blocks (of these 75 percent are to areas east of GCT)
	35	North of Forty-fifth Street
	29	GCT complex
	8	South of Forty-second Street

FUTURE CONDITIONS

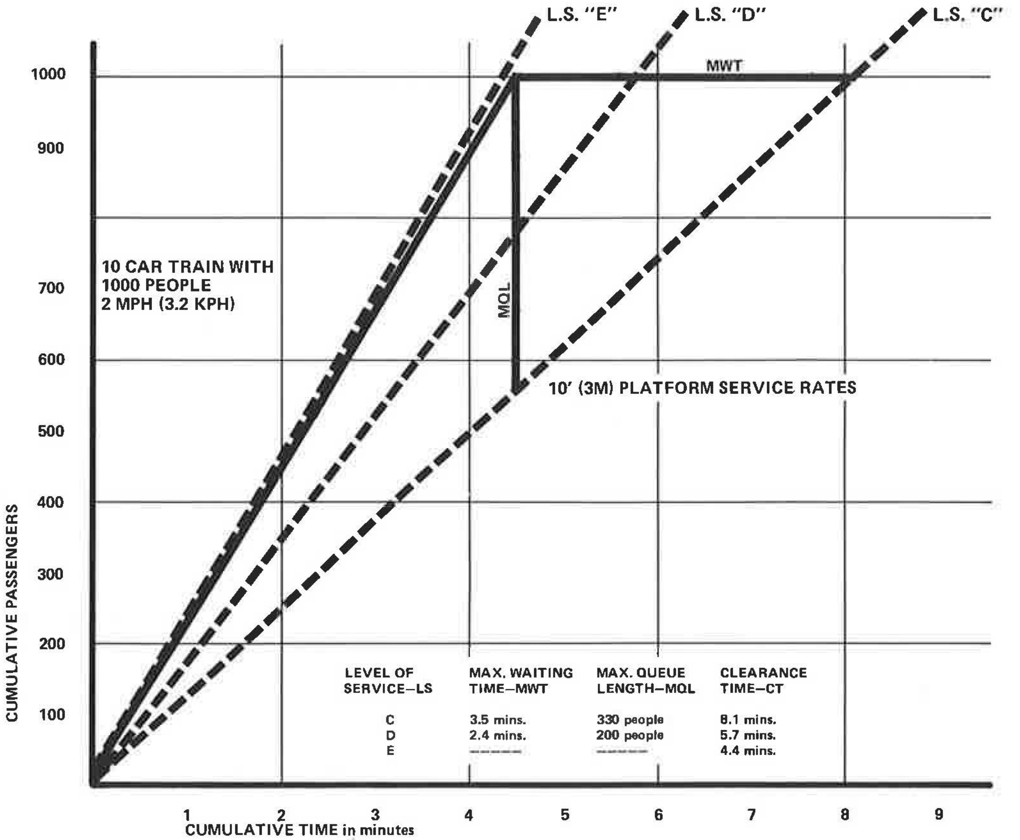
Figure 7 shows the estimated peak pedestrian volumes for the recommended concept. This figure assumes that the future network has been built and is being used by the people now using the terminal, and, in effect, answers the question, If the network were in existence today, how many people would be using each link? These numbers are useful for analytical purposes and for establishing the base from which to analyze future volumes.

Future travel conditions were estimated by assuming 25 and 50 percent increases over existing volumes and then testing the implications of these two assumptions by a sensitivity analysis. This procedure, which is used in cases of uncertainty as to the actual value of a parameter, is to vary the value of the parameter in question and examine the extent to which the changes made affect the results of the analysis. In this particular case, the parameter to be estimated is the peak-hour pedestrian volume and the impact that 25 and 50 percent increases over existing volumes would have on the service provided by different facilities in the pedestrian network. The service provided is measured by V/C ratios. The traditional approach, which uses a demand model, was not followed because of uncertainties relating to staggered work-hour programs, the availability of energy, the 4-d workweek, and the significant amount of technical effort



LEVEL OF SERVICE–LS	MAX. WAITING TIME–MWT	MAX. QUEUE LENGTH–MQL	CLEARANCE TIME–CT
C	4.3 mins.	540 people	8.0 mins.
D	1.9 mins.	360 people	5.6 mins.
E	0.7 mins.	75 people	4.4 mins.

Figure 9. Platform clearance diagram with average walking speed equal to 4.2 km/h.



LEVEL OF SERVICE–LS	MAX. WAITING TIME–MWT	MAX. QUEUE LENGTH–MQL	CLEARANCE TIME–CT
C	3.5 mins.	330 people	8.1 mins.
D	2.4 mins.	200 people	5.7 mins.
E	--------	--------	4.4 mins.

Figure 10. Platform clearance diagram with average walking speed equal to 3.2 km/h.

Table 2. Comparison of existing conditions and those of concept 1.

Evaluation Criteria	Performance Scores Existing	 Concept 1	 Difference	Comments
Provide sufficient pedestrianway capacity[a]				All existing facilities would be helped by provision of northern access
With present volumes	1.30	0.88		
With a 25 percent increase	2.13	1.21		
With a 50 percent increase	2.65	1.50		
Provide for handicapped persons	Access to concourse	Access to concourse	0	Physically handicapped were 0.1 percent and encumbered persons were 2 to 4 percent of persons entering and leaving GCT
Reduce walking distances for northbound rail users	981 m/ person	759 m/ person	222 m/ person	23 percent reduction
Reduce travel time for northbound rail users	11.9 min/ person	9.2 min/ person	2.7 min/ person	
Reduce the impact of northern access on railroad operations				Platform E would be converted to trash operations under concept 1
Number of tracks lost	0	Tracks 11, 13, 22, 31, and 82	Tracks 11, 13, 22, 31, and 82	Trains on both tracks 11 and 13 would have to be reassigned
Rail car capacity lost	0	14 trash cars, FL-9 storage, and 9 revenue cars	14 trash cars, FL-9 storage, and 9 revenue cars	
Reduced people/h seating capacity	0	8400 seats	8400 seats	Assumes 100 seats/car and 4 cars/track/h
Provide connections to proposed LIRR terminal at Third Avenue	—	From Forty-seventh Street	0	
Increase safety and security	—		—	
Internal security	—		—	
Accident potential	—	3100 potential conflicts/min	—	
Potential for personal crime	—	Fewer people in larger area	—	
Provide sufficient street intersection capacity				
Pedestrian green time/ capacity across Park Avenue	—	0.10	0.16	
Vehicle green time/capacity for Park Avenue	—	0.49	—	
Cross street green time/ capacity	—	0.24	—	
Clearance time	—	0.10	—	
Provide for automatic fare collection	None	Possible	—	
Provide links to bus transit system	—	Slightly improved	—	Improved access to M-27 bus route on Forty-ninth and Fiftieth Streets
Provide balanced loading of cars on trains	Skewed	Improved	Better	Improved access to Rockefeller Center
Improve system orientation and comprehension for GCT users	—	—	—	Concept 1 forms grid that is aligned with Park Avenue sidewalks and Forty-fifth and Forty-seventh Streets
Improve potential for commercial stores	—	—	—	Providing commercial stores would mean loss of two additional revenue tracks; market for new space is weak unless crosstown people are attracted in off-peak hours
Capital cost for basic system	—	$14 900 000	$14 900 000	
Railroad capital costs	—	$46 400	$46 400	
Signal work		$18 500	$18 500	
Track work		$27 900	$27 900	
Railroad operating costs/year	—	$56 800	$56 800	Two 5-d jobs for emergency engineer and conductor with two shifts/d

Notes: 1 m = 3.3 ft.
The seventeenth criterion, provide cost-effective improvements, was included in the analyses, but is not listed here because its use applied to the comparison of alternative schemes, rather than comparing concept one to the existing system.

[a] Volume capacity ratios were computed for all links in the system but only the scores for the worst case at level of service C are shown here.

required to develop forecasts. It is believed that a 25 to 50 percent range adequately covers anticipated future travel conditions.

It is possible to determine the physical width required for each link in the future network by using pedestrian volume estimates. The conversion involves the use of a level-of-service concept that equates pedestrian traffic flow with the effective width of a pedestrianway element. The number of persons per minute per meter of effective width for levels of service C, D, and E is given below (2).

Element	Level C	Level D	Level E
Level passageway	41.7	58.3	75.0
Ramp	31.7	45.0	58.3
Stairways	28.3	41.7	50.0

Level of service C for passageways represents a density of 1.4 to 2.3 m^2 (15 to 25 ft^2)/person, D represents 0.9 to 1.4 m^2 (10 to 15 ft^2)/person, and E 0.5 to 0.9 m^2 (5 to 10 ft^2)/person. The future network pedestrian volume assignments were converted to width requirements by using these capacity standards. They are summarized in Figure 8 for growth levels of 25 and 50 percent above present volumes.

An important aspect in the conversion of volume estimates to physical requirements is the recognition of balance in the system. Since the pedestrian system is composed of different kinds of elements with different capacities, the interfaces between the elements must be carefully considered. That is, constraints such as platform or stairway width establish a capacity limit that acts as a controlling element in the system, and the development of excessive capacity upstream or downstream from such a throat is not cost-effective.

Within the balance and physical limits constraints imposed by structural engineering considerations, all of the proposed pedestrian facilities can be built with sufficient effective width to handle the existing volumes plus a 50 percent increase. Some delays and queuing will always occur on train platforms because any given width of platform has a greater capacity than the identical width of stairway. Train platforms will also have some reverse flow problems even though most commuters will distribute themselves inside the trains so as to be near their final destination.

Figure 9 indicates the arrival demand on a typical platform using an average walking speed and assuming that the reverse flow is minimal. As shown, the demand exceeds the capacity, causing delays and queues. The maximum delay or waiting time would be 2.4 min with a queue of 300 people for northbound movements and 2.0 min and 250 people for southbound. However, since the capacity shortage is a more-or-less continuous condition along the platform, queuing, per se, would not occur to the extent indicated, although there would be a slowing of movement speed. This is illustrated by Figure 10.

IMPACTS OF NORTHERN ACCESS

Table 2 compares the existing conditions with those of the recommended concept in terms of the 17 evaluation criteria developed during the study. The significant impacts are

1. Congestion of pedestrian facilities within the terminal, particularly the current queue at the Pan American escalators, will be reduced because northbound commuters will not have to walk into the terminal;
2. Walking distances and door-to-door travel times, especially for rail commuters walking northbound from Grand Central, will be reduced because backtracking will be eliminated;
3. Modifications in present rail operations required to build the new pedestrian facilities can easily be accommodated (the two trash collection tracks can be converted to pedestrian passageways, tracks 11 and 13 can become the trash tracks, and the passenger trains now using tracks 11 and 13 can be shifted to other tracks);
4. An underground connection to the proposed Third Avenue Long Island Rail Road Terminal and the Second Avenue Subway can be provided under Forty-seventh Street, if desired;
5. Automatic fare collection can be provided at a future date; and
6. Trains will be used more efficiently because passengers will be more evenly distributed (commuters with a destination south of GCT will tend to sit in the front cars and commuters with a destination north of GCT will tend to sit in the last cars).

The recommended GCT improvement program can be built in stages. Hence, it will be possible to identify system requirements as related to different levels of growth, and, by monitoring actual growth, the need for successive improvements can be measured. Further, by using the relations between physical facilities and levels of growth established here, the impacts of growth can be estimated. Such relations can be a basis for policy decisions by developing programs that relate growth to desirable and beneficial impacts (either in terms of facilities needed, or to the level of service created).

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2. J. J. Fruin. Pedestrian Planning and Design. Metropolitan Association of Urban Designers and Environmental Planners, Inc., New York, 1971.

Public Policy and Optimal Transportation Planning Strategies

John G. Schoon, Wilbur Smith and Associates
John C. Falcocchio, Louis J. Pignataro, and William R. McShane,
Department of Transportation Planning and Engineering,
Polytechnic Institute of New York

Restrictions on metropolitan core area travel by private vehicles to limit air pollution and to reduce fuel consumption will necessitate extensive programs for change-of-mode facilities on line-haul public transport routes. The parking spaces in the core area must be transferred so as to minimize the total vehicle-kilometers traveled throughout the area subject to technical, public policy, and economic constraints. This creates a need for a master plan that will identify the apportionment and extent of parking and other change-of-mode facilities, including feeder bus service at line-haul public transport routes. This paper briefly describes the salient transportation and parking features in Boston as a background to formulating a generalized public policy and a linear programming approach for the preparation of optimal plans incorporating a defined range of objectives and constraints.

Recent concerns about the air pollution and energy use aspects of transportation have provided a significant impetus to change-of-mode (COM) planning in many metropolitan areas. The technical and public policy aspects of the planning process, however, require a rational analysis method with which to formulate acceptable plans that can be evaluated and compared in the decision-making process.

This paper provides an overview of COM facilities as they relate to downtown access and public policy concerns and attempts to establish relevant objectives and constraints for formulating alternative plans. The paper recognizes that there will be divergent views of what the objectives should be and presents a linear programming approach for providing an array of alternative objectives and their associated optimal solutions. The final section reviews the effectiveness of current planning methods and suggests possible areas for future planning emphasis.

AREAWIDE CHANGE-OF-MODE FACILITIES: TYPICAL CHARACTERISTICS

This section describes recent approaches to parking related to downtown access in Boston and provides an overview of the magnitude and characteristics of COM facilities in a metropolitan area of nearly 3 million inhabitants (1). [Pertinent information for other locations is contained in several recent publications (2, 3, 4, 5, 6, 7) that describe park-and-ride characteristics and particularly emphasize mode-of-access, physical, operational, and demand aspects.]

Commuter Parking Facilities Within the Region

Boston has a downtown core area with approximately 350 000 weekday (7:00 a.m. to 6:00 p.m.) person destinations, of which nearly 55 percent are reached by commuter rail, subway, streetcar, or bus. There is a parking supply of approximately 56 600 spaces available to commuters. The relation of the commuter parking supply to the distance from the core area of the city is shown in Figure 1 (5). There are three principal components.

1. Approximately 35 000 parking spaces (61 percent) are in the downtown area.
2. Over 14 000 spaces (25 percent) (the line-haul rapid transit COM supply) are between 7 and 14 km (4 and 9 miles) from the downtown area.
3. Approximately 7600 spaces (14 percent) (the line-haul commuter rail COM supply) are between 17 and 23 km (10 and 14 miles) from the downtown area.

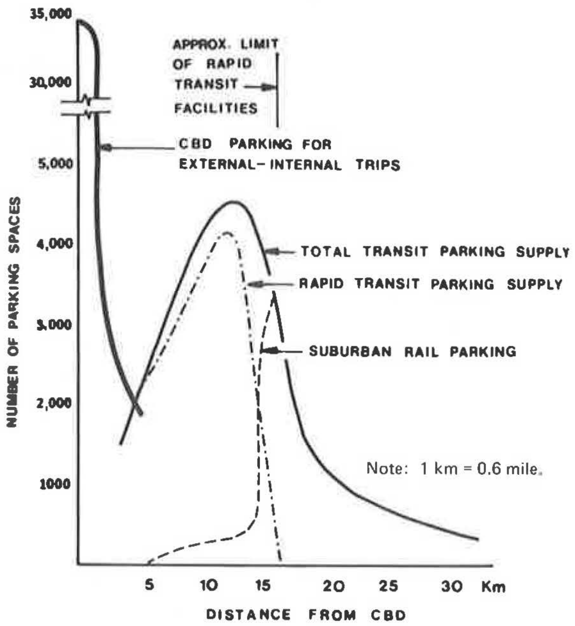
Commuters predominate at the COM facilities and, because of their early arrival, often preempt use by others. COM facility spaces are also occupied by commuters who travel by transit through the CBD to arrive at work locations beyond. Occupancy of the park-and-ride facilities varies from 60 to 100 percent. The areawide distributions of the core-oriented parking supply and its use are shown in Figure 2.

Air Quality Controls

Control actions that have been proposed to achieve the necessary pollution reductions in the Boston region (8)

Publication of this paper sponsored by Committee on Intermodal Transfer Facilities.

Figure 1. Core area access parking components.



include stabilization of downtown parking and increased car pooling.

Vehicle-Kilometers Traveled

The number of vehicle-kilometers traveled (VKT) is a primary determinant of air pollution and energy consumption levels.

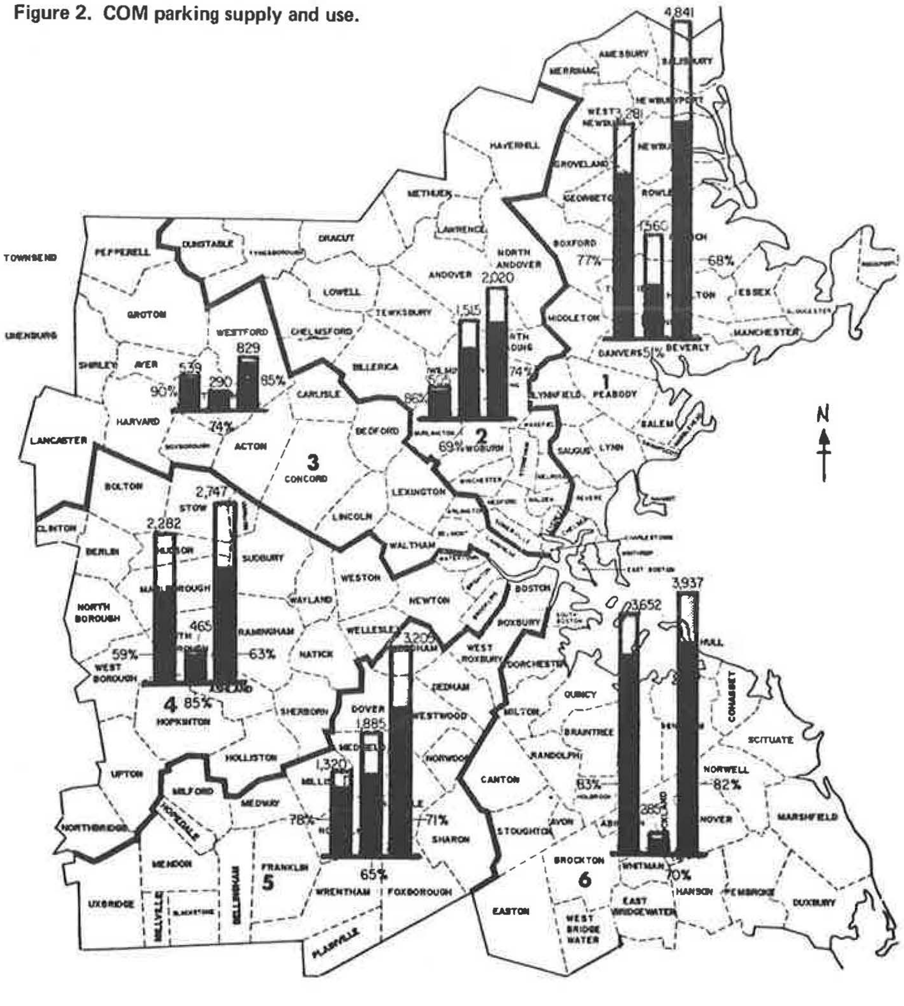
If present trends continue, it is estimated that within the next decade a further 14 000 parking spaces will be required and that there will be an increase in travel of 300 000 km (180 000 miles) daily. This distance is an increase of nearly 30 percent over the distance currently traveled by commuters. However, it would be less than half of this if the 14 000 parking spaces were located in COM areas.

Although the total amount of travel by commuters is relatively small as compared to the total travel of all drivers, it is significant because it is concentrated during peak travel hours and results in high pollution and time delays. It is also the most amenable of all trips for diversion to public transport because of its focus on the CBD.

Planning Directions

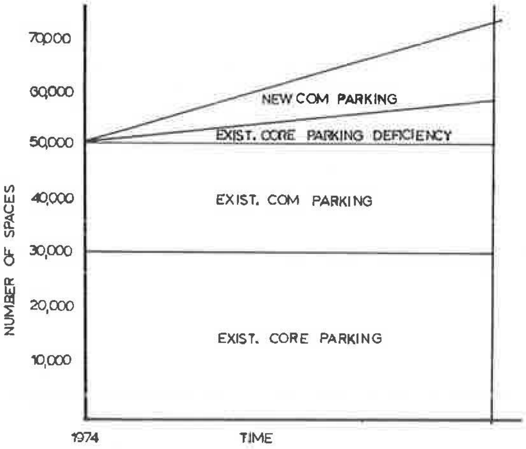
The implications for future commuter parking in the

Figure 2. COM parking supply and use.



region, as shown in Figure 3, are that, if the present level of approximately 30 000 legal spaces is maintained in the core area, the number of spaces at the COM facilities must be increased by about 21 000 to account for the existing estimated deficiency of nearly 7000 spaces and the further 14 000 spaces to accommodate future center city growth. Planning for these must include a consideration of public policy factors such as those described in the next section.

Figure 3. Anticipated core area and COM parking trends.



PUBLIC POLICY ASPECTS

The formulation of a master plan may be described as the use of acceptable planning principles and procedures to devise a plan that is responsive to the community goals and objectives established by the agencies responsible for formulating public policy. This requires that the policies of the relevant agencies be adequately defined and that the criteria by which their success is measured be generally accepted as valid.

Planning and Decision Process

The main features of the initial decision process involve a progressive, and often iterative, process that starts with community demand for a master plan, proceeds through the activities of public agency initiation, policy aspects of the planning process, and formulation and evaluation of alternatives, and leads to selection of the plan to be adopted. The principal public policy objectives and their implications are summarized in Table 1 and described below.

From these, it is concluded that since

1. Federal air pollution requirements are mandatory, an upper limit must be imposed on CBD parking to limit the number of vehicles in the CBD.
2. City and state policies will result in a transfer of commuter parking from the CBD to the COM facilities. The policies generally assume that those commuters who have a car available for travel to the CBD will also have it available for travel from home to the COM facilities.

Table 1. Implications of public policies for change-of-mode master planning.

		Implications for CBD Parking and COM Facilities	
Jurisdiction	Objectives	CBD	Areawide
Federal	Limit VKT to reduce air pollution to defined levels	Use of parking spaces in CBD is limited	Areawide COM facilities replace existing CBD parking space deficiency and fill future CBD parking needs
	Reduce VKT to minimize fuel consumption		Number of spaces at COM facilities and locations are allocated so as to minimize VKT
State	Reduce urban blight, loss of property, and CBD congestion; improve quality of downtown environment; and maximize returns from transportation investment	CBD parking, particularly for commuters, is minimized	COM facilities are increased to assist in deemphasizing need for urban freeway construction
	Encourage use of public transport	Access to CBD for nonautomobile trips is improved	COM facilities are increased to complement CBD-oriented transit programs
City	Maintain and/or improve economic viability of city through retail and commercial activities	Provision of limited-duration parking is emphasized to encourage shoppers	Balanced transport system is emphasized to increase viability of center city
	Preserve or increase tax base from usable land to improve city revenue and amenities	Land use for building and development (instead of for parking areas) is emphasized	Deemphasis of CBD parking creates increased need for COM facilities
Suburban communities	Maintain or improve environment within specified community area of interest	CBD parking demand is not significantly reduced	Transference of parking to COM facilities is limited Allocation of COM facilities areawide is affected by specific constraints in each community
	Improve transit access to CBD from specific locations	Demand for CBD parking space is increased because of increased CBD activity	Minimum total areawide parking level can be maintained

Table 2. Selected alternative approaches to COM master planning.

Strategy	Objective	Goals	Constraints	Output
1A	Minimize VKT	Energy conservation and emission reductions	Core parking	Defines minimum VKT based on core parking restrictions and provides basis for computing implementation, user, and total costs
1B	Minimize VKT	Energy conservation and emission reductions	Core parking and implementation cost	Defines minimum VKT based on core parking and implementation cost constraints and provides basis for computing user and total costs
2A	Minimize investment costs	Minimal funding levels	Core parking	Defines minimum investment costs based on core parking restrictions and provides basis for VKT, user, and total costs
2B	Minimize investment costs	Minimal funding levels	Core parking and VKT	Defines minimum investment costs based on core parking and VKT restrictions and provides basis for computing user and total costs

3. Suburban concerns imply that the number of COM parking facilities that should be provided in any given zone will be constrained within upper and lower bounds by several factors that include the attractiveness of the transit facilities, the demand for COM facilities, and the extent of alternative feeder bus, kiss-and-ride, and car-pooling facilities available.

The task for the planner is then to devise a master plan that will (a) indicate the number of COM facilities necessary to replace planned parking supply reductions (or to stabilize the supply despite increasing demand) in the CBD; (b) allocate the COM facilities throughout the region to maximize the desired effects (i.e., to minimize VKT or investment cost), subject to the various constraints; (c) determine the cost implications of any given plan; and (d) provide alternative plans for allocating the COM facilities within investment, user, or total cost constraints.

Evaluation and Selection Process

The various strategies to be examined and evaluated must first be defined. A possible selection of these strategies is shown in Table 2. The features of each of these strategies are as follows.

1. The objective of strategy 1A is to minimize the VKT. The goals are the conservation of energy and the reduction of private vehicle exhaust emissions. The only constraint is a stabilization of core parking for commuters, which will require a number of commuters who use private automobiles at present to change to COM and line-haul facilities in the future. The corresponding implementation, user, and total costs may be computed directly by using appropriate unit costs.
2. The objective of strategy 1B is also to minimize the VKT, but under the effects of a specified implementation cost limit. Thus, the optimal allocation of the COM facilities at a given maximum investment level must be compared with the minimization that would be achieved with no constraints on the investment cost level (strategy 1A). Again, the information from this strategy can be used to provide user and total costs.
3. The objective of strategy 2A is to minimize investment costs since there are always competing uses for the available funds. Core parking is again a constraint. The VKT and user and total costs can be computed based on unit costs.
4. The objective of strategy 2B is similar to that of 2A. It has, in addition to the core parking restrictions, a constraint on areawide VKT to keep energy use and emission levels within defined limits. The results of this strategy can be compared with those of strategy 2A to indicate the differences that result from the constraint on VKT and the necessary increase in cost.

This list of strategies is not comprehensive, but aims only to provide an initial comparison of the implications of attaining certain objectives subject to defined constraints and to indicate further modifications and strategies that could prove to be advantageous.

AN EXAMPLE

An example of areawide planning for COM facilities that is based on the concepts presented and a rational analysis methodology illustrates a possible approach. This example has been kept relatively simple to prevent undue complications in formulating the model and analyzing the results and also to permit an intuitive check of the reasonableness of the results.

Statement of the Problem

A metropolitan area and its existing transit lines with zones X, Y, and Z are located as shown in Figure 4. It is anticipated that within the next 10 years the core area will experience growth that would normally require provision of additional parking spaces to accommodate approximately 12 000 commuters. However, to avoid exceeding acceptable air pollution limits, it is proposed to provide COM facilities along existing transit lines for park-and-ride, kiss-and-ride, and feeder bus service. Planning agencies and governmental authorities require an initial evaluation of strategies 1A, 1B, 2A, and 2B as a guide for more detailed planning.

Systems and Public Policy Inputs

The anticipated travel system characteristics for the area are listed in Table 3. These inputs provide the estimated levels of vehicle occupancy, average trip distances, and investment costs associated with each zone. Constraints on the extent of the facilities in each zone are listed in Table 4.

The Linear Programming Approach

The linear programming approach to problem solving, which involves the search for an optimal solution to a specified objective that is subject to constraints on resources or components of the total plan, is used in this example. The applicable matrix for the four strategies investigated is shown in Table 5 in which the objective functions and the areawide and zonal constraints are listed for each zone and for each strategy. The data illustrated are presented in the format required for linear programming by a digital computer. Several standard program packages exist for these computations.

In any given system of values only one objective can be maximized or minimized (i.e., optimized) at a given time for a given set of constraints. Thus, for each of the four strategies, the linear programming method defines the best, or optimal, solution (in this case, the assignment of specific levels of COM facilities to each zone). This approach may be defined as prescriptive, although the estimated constraints, such as the range of mode-of-access proportions, may be categorized as descriptive in their estimation procedures, especially if current demand analyses methods are used. Other methods of areawide COM planning procedures have recently been documented. These have used a linear regression approach to demand analyses (9) and demand sensitive methods (10).

Summary of Results for the Example

A list of the allocation of COM facilities throughout the area for each strategy and the corresponding VKT and investment cost levels is given in Table 6. This indicates the following salient points.

1. The total persons accommodated by each plan is 12 000 as required. This indicates that, within the stated constraints, each plan is feasible.
2. Strategy 1A provides the minimum VKT (115 500; 69 270 VMT). This results in the maximum cost of $112 200/d.
3. Strategy 2A provides the minimum cost of $92 100. This results in the maximum VKT (146 700; 88 048 VMT).
4. In strategy 1B, in which a cost constraint of $100 000 is imposed on strategy 1A, the allocation of COM facilities results in greater areawide VKT (127 700; 76 600 VMT) than the minimum attainable without restrictions.

Figure 4. Layout of metropolitan area with transit lines (example).

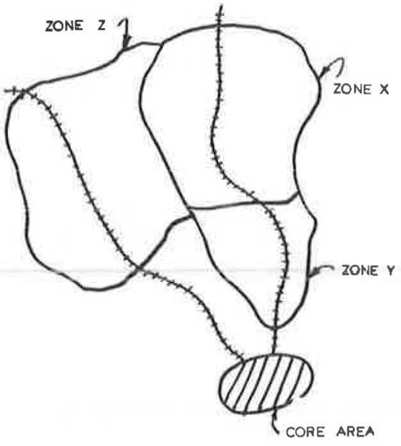


Table 3. Cost and travel characteristics (example).

Item	Zone Values			Units
	Zone X	Zone Y	Zone Z	
Costs[a]				
Park-and-ride	6.8	15.0	11.8	Dollars/vehicle/d
Kiss-and-ride	5.0	10.6	8.6	Dollars/vehicle/d
Feeder bus	–	320.0	–	Dollars/vehicle during peak periods
Vehicle occupancy				
Park-and-ride	1.1	1.3	1.2	Persons/vehicle
Kiss-and-ride	1.0	1.0	1.0	Persons/vehicle (excluding driver)
Feeder bus	–	45.0	–	Persons/vehicle (excluding driver)
Private vehicle travel				
Park-and-ride	20.0	16.0	10.0	Kilometers/vehicle (two-way)
Kiss-and-ride	40.0	32.0	20.0	Kilometers/vehicle (two-way)

[a] Costs are assumed to include capital, maintenance, and operational costs of COM facilities plus a proportionate share of the line-haul public transportation costs associated with the number of users of each type of vehicle and facility.

Table 4. Zonal constraints on size of COM facilities (example).

Item	Zone X Constraints		Zone Y Constraints		Zone Z Constraints		Units
	Upper	Lower	Upper	Lower	Upper	Lower	
Modal split							
Park-and-ride spaces	–	–	–	–	–	–	
Kiss-and-ride use	–	–	–	–	–	–	
Feeder buses	–	–	–	–	–	–	
Total use	–	1000	–	1400	–	1500	Persons
Mode of access							
Park-and-ride spaces	4800	900	4700	1000	4200	600	Spaces
Kiss-and-ride use	300	100	400	150	300	200	Vehicles
Feeder buses	–	–	70	30	–	–	Buses
Total use	–	–	–	–	–	–	
Access street capacity							
Park-and-ride spaces Kiss-and-ride use Feeder buses	4900	–	4500	–	5300	–	Vehicles
Total use	–	–	–	–	–	–	
Community and environmental concerns							
Park-and-ride spaces	4600	500	5700	900	2600	800	Spaces
Kiss-and-ride use	200	100	500	300	400	250	Vehicles
Feeder buses	–	–	–	–	–	–	
Total use	–	–	–	–	–	–	

Table 5. Linear programming analysis format (example).

Item	Zone X		Zone Y		Zone Z		Areawide Value	Applicable Strategy			
								1A	1B	2A	2B
Objective functions											
Minimize areawide private VKT	M = 20P + 40K + 0B +		16P + 32K + 0B +		10P + 20K + 0B			X	X		
Minimize investment costs	I = 6.8P + 5.0 + 0B +		15P + 10.6K + 320B +		11.8P + 8.6K + 0B					X	X
Areawide constraints											
Core parking restrictions (at least 12 000 users reassigned)	1.1P + 1.0K + 0B +		1.3P + 1.0K + 45B +		1.2P + 1.0K + 0B		≥ 12 000	X	X	X	X
Investment costs (maximum $100 000 daily)	6.8P + 5.0K + 0B +		15P + 10.6K + 320B +		11.8P + 8.6K + 0B		≤ 100 000		X		
Maximum 130 000 VKT daily	20P + 40K + 0B +		16P + 32K + 0B +		10P + 20K + 0B		≥ 80 000				X
Zonal constraints											
Modal split	1.1P + 1.0K + 0B	≥ 1000	1.3P + 1.0K + 45B	≥ 1400	1.2 + 1.0K + 0B	≥ 1500		X	X	X	X
Mode of access	1.0P	≤ 4800	1.0P	≤ 4700	1.0P	≤ 4200		X	X	X	X
	1.0P	≥ 900	1.0P	≥ 1000	1.0P	≥ 600		X	X	X	X
	1.0K	≤ 300	1.0K	≤ 400	1.0K	≤ 300		X	X	X	X
	1.0K	≥ 100	1.0K	≥ 150	1.0K	≥ 200		X	X	X	X
			1.0B	≤ 70				X	X	X	X
			1.0B	≥ 30				X	X	X	X
Street capacity	1.0P + 1.0K	≤ 4900	1.0P + 1.0K	≤ 4500	1.0P + 1.0K	≤ 5300		X	X	X	X
Community concerns	1.0P	≤ 4600	1.0P	≤ 5700	1.0P	≤ 2600		X	X	X	X
	1.0P	≥ 500	1.0P	≥ 900	1.0P	≥ 800		X	X	X	X
	1.0K	≤ 200	1.0K	≤ 500	1.0K	≤ 400		X	X	X	X
	1.0K	≥ 100	1.0K	≥ 300	1.0K	≥ 250		X	X	X	X

Notes: M = total areawide VKT daily, I = total investment cost on daily basis, P = number of COM parking spaces, K = number of kiss-and-ride vehicles daily, and B = number of daily peak-period feeder buses. Coefficients of each variable are derived from Tables 3 and 4.

Table 6. COM master plan summary (example).

				COM Facilities Allocation						
			Investment Cost	Park-and-Ride		Kiss-and-Ride		Feeder Buses		
Strategy	Zone	VKT	($/d)	Spaces (P)	Persons	Vehicles (K)	Persons	Vehicles (B)	Persons	Total Users
1A	X	22 000	6 600	900	990	100	100	–	–	1 090
	Y	62 500	72 800	3147	4090	300	300	70	3150	7 540
	Z	31 000	32 800	2600	3120	250	250	–	–	3 370
	Total	115 500	112 200	6647	8200	650	650	70	3150	12 000
1B	X	63 500	20 700	2974	3271	100	100	–	–	3 371
	Y	33 200	46 400	1391	1808	300	300	70	3150	5 258
	Z	31 000	32 700	2600	3120	250	250	–	–	3 370
	Total	127 700	100 000	6965	8199	650	650	70	3150	12 000
2A	X	100 000	32 300	4600	5060	200	200	–	–	5 260
	Y	26 700	40 600	1000	1300	300	300	70	3150	4 750
	Z	20 000	19 200	1408	1690	300	300	–	–	1 990
	Total	146 700	92 100	7008	8050	800	800	70	3150	12 000
2B	X	75 100	25 700	3708	4078	100	100	–	–	4 178
	Y	25 000	40 600	1000	1300	300	300	70	3150	4 750
	Z	29 900	29 900	2351	2822	250	250	–	–	3 072
	Total	130 000	96 200	7059	8200	650	650	70	3150	12 000

5. In strategy 2B, when a VKT constraint of 130 000 (80 000 miles) is imposed on strategy 2A, the minimum cost attainable is $96 200 (versus the absolute minimum of $92 100 in strategy 2A).

The allocation of the COM parking spaces generally favors locating them in zone Y, which has the lowest unit investment costs when combined with moderate levels of VKT. This contrasts with zone X, where the comparatively moderate investment costs are combined with high VKT levels.

The relation between areawide investment costs versus VKT implies that between strategies 1A and 2B there will exist a range of allocations conforming to various levels of imposed investment costs and VKT. There will be no feasible solution to the problem within the stated constraints if the lowest acceptable level of total VKT is below that achieved with strategy 1A or if the lowest acceptable investment cost is below that for strategy 2A. This would mean that the accommodation of at least 12 000 persons by means of COM facilities could not be achieved within the stated range of constraints, vehicle occupancies, and costs and that a reassessment of the entire plan would be required.

FURTHER REFINEMENTS

This outline approach to COM master planning has attempted to provide an overall view of the considerations involved and how they may be assembled, analyzed, and presented to assist in decision making. Further refinements may be broadly divided into public policy, analysis methodology, and evaluation aspects of the planning process.

Public Policy

A tentative list of public policy concerns that are involved in the COM master planning process includes (a) a clear and quantitative delineation of the federal, state, city, and local community mandatory requirements that must be complied with to qualify for necessary funding or that are otherwise necessary for success of the areawide plan; and (b) determination of the range of sizes of COM facilities that can be tolerated or that are demanded in the local communities throughout the area of concern. This determination should be made as early as possible. It emphasizes the need for review of all possibilities by local communities before proposals for COM facilities in any one zone are made. It could prevent unnecessary proposals or the concentration of COM facilities that were not wanted by the affected community and that could be more effective and less costly in the total plan if located elsewhere.

Analysis Methodology

The validity of the analysis approach and its underlying assumptions obviously affect the validity of the final outcome. The objectives and constraints are sensitive to variations in their parameters.

1. The linear programming approach is based on linear relations between variables. While this approach simplifies the formulation and solution for initial planning, it is probable that dynamic programming and linear programming techniques that incorporate assessment of random events (linear programming with uncertainty) would prove fruitful. Also, because many investment and service-related functions are discreet rather than continuous, the linear representation is at best an approximation.
2. In the objective function the vehicle occupancy, VKT, and cost parameters could possibly change under varying levels of demand and use, suggesting an iterative approach for more detailed planning.
3. When the constraints are formulated, apart from the public policy aspects, the defined levels of mode of access are the area requiring the most investigation for suitable prediction techniques. In particular, factors affecting the area of influence of specific facilities and how the mode of access is affected by COM capacity restrictions and the time of arrival at certain locations appear to be critical.

Evaluation of Alternatives

Because the intent of the process is to present several master plans with the implications of each summarized, it is imperative that the criteria by which they are to be judged be defined as clearly as possible. Inevitably, difficulties will arise in agreeing on these criteria owing to the diverse and large number of factors involved. The examples of minimum VKT and investment are only an initial attempt that could be augmented by assessment of future user costs, total travel time expenditures, and the quantification of future highway, public transport, and land use development costs.

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No-Barrier Fare Collection

Manuel Padron and Richard Stanger, Metropolitan Atlanta Rapid Transit Authority

This paper reviews a study performed by the Metropolitan Atlanta Rapid Transit Authority on the feasibility of a no-barrier fare-collection system and discusses the potential of this self-service concept in the United States. No-barrier fare collection (often referred to as self-service or automatic) is widely used in Western and Eastern Europe to handle fare-collection requirements. It is not used anywhere in North America, and good information on European experience with it is sparse at best. The assumption that cheating would be rampant in the United States if this concept were employed has unrealistically dominated discussions of it and overwhelmed any rational analysis of its benefits. This study found no large propensity to defraud; it estimated that 3 to 5 percent of daily passengers could be expected to evade fares. This figure is larger than that found in European cities, but can nevertheless easily be handled. The no-barrier fare-collection concept thus appears to have a good potential in the United States, particularly for certain applications. One of these is for integrated bus-rail systems using zone fare structures and another is for light rail systems.

The Metropolitan Atlanta Rapid Transit Authority (MARTA) study of the no-barrier concept of fare collection was a part of a comprehensive fare-collection study. This larger study was logically separated into two parts: The first analyzed the economic implications of selected fare system alternatives; the second focused on the problem of estimating the level of fraud that might be expected with a no-barrier fare system (1).

Although widespread in Europe, no-barrier fare-collection concepts (often called self-service) are little understood in North America. European transit systems have had a great deal of success with self-service and are employing it in increasing numbers. It is a concept that should be studied more in the United States. A priori judgments based on beliefs that Europeans are different or that Americans cheat too much should be tested.

It was known from the beginning that an estimation of possible fraud would be difficult. No such study had previously been done, and it was unclear what factors would have to be considered or what the general methodology for the study should be. Obtaining adequate useful data, especially from Europe, promised to be difficult. However, since the feasibility of a no-barrier fare-collection system is strongly tied to the levels of possible fraud, the estimate of that level must be reliable.

EUROPEAN EXPERIENCE WITH NO-BARRIER FARE COLLECTION

Self-service fare collection has been in use for fewer than 20 years. The experiences leading to its implementation were, and still are, common. Typically, transit fares prior to World War II were flat within a city and vehicles used two-man crews. After the war, labor availability to the transit industry began to decline as the result of an economic boom in the private sector with its higher paying jobs and the lack of operating subsidies for higher wages. Distance-based fare structures were instituted to raise revenues; vehicles still used two-man crews. By the early 1960s, however, labor shortages became acute, and it was obvious that the number of operating personnel would have to be reduced. At that time, and even today, the fare-collection equipment available could not handle the collection of fares over all modes with an integrated regional transit network, especially with fares based on distance. This left only one choice available: the use of self-service equipment by the passengers and random policing by inspectors.

Since the first conversion to self-service operation in Hamburg, acceptance of the no-barrier concept has expanded rapidly throughout Western Europe. It is also used extensively in Eastern Europe and Russia. The reasons given for initiating no-barrier fare collection vary, but can be roughly grouped into several factors of which the predominant ones are financial savings, easing of employee work loads, and overcoming staff shortages (2).

The principal characteristic of a no-barrier fare-collection system is the absence of fare gates. Control of the fare payment is shifted to roving inspectors who may ask passengers to show proof of payment. Only a small percentage of passengers are checked, but a penalty fare (or superfare) is levied on those found to have evaded payment.

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Most of the policing effort is concentrated from the maximum load point of the line inward or at the zone boundaries. All passengers in a selected vehicle are checked. Fare inspectors can check about 50 passengers/h, including the processing of infractions. One violator/inspector/h appears to be a typical rate of enforcement. An individual found without a valid receipt for fare payment has two options: He may acknowledge guilt and pay the superfare to the inspector, or he may challenge. To do this, he gives his name and address and is typically asked to go to a central place to discuss his case. Should he not appear there, or should disagreement still exist, his case is turned over to the courts. The court record of enforcement is the ultimate key to the effectiveness of the overall self-service concept. In all cases, an individual retains his right to due process, but in the European experience guilt is generally accepted and the evader simply pays the superfare.

Fare inspectors may operate individually or in teams of up to six persons. Occasionally, a selected rapid transit station may be checked intensively by up to 40 inspectors. The inspectors may be uniformed or not, and women are quite often employed, as it is generally felt that their presence tends to minimize confrontation and maximize positive responses to enforcement. The rate of checking is low, rarely above 5 percent of the daily passengers. Superfares are generally 20 times the base fare. Detected fraud is similarly low and averages less than 1 percent of the riders on most systems. However, a study by the Paris Regional Transit Authority showed that there, at least, actual fraud could be twice that of detected fraud, and officials of other transit agencies do not consider this discrepancy unreasonable. The analysis in this paper is based on detected fraud, although it is realized that actual fraud may be higher.

Fare payment options vary widely. As a rule, weekly-monthly-yearly passes are used by over 50 percent of the ridership, sometimes by over 90 percent. Multiride tickets are often used as a method of prepayment in conjunction with zone fare structures. Single-ride tickets are issued, often by the driver, but at a premium fare.

Table 1. Typical examples of fraud experience in European transit systems.

City	Defrauders (%)	Passengers Checked (%)	Amount of Fine (DM)	Passengers With Multijourney Payments (%)
Duisburg	0.41	2.2	10	48
Dusseldorf	0.43	2.2	20	55
Flensburg	0.21	3.0	10	70
Frankfurt	3.06	0.8	20	80
Hagen	0.5	3.0	15	66
Hanover	0.3	3.5	20	83
Cologne	1.6	5.0	10	91
Stuttgart	1.05	3.6	10	58
Vienna	0.25	2.2	14	26
Antwerp	0.01	1.47	7	74
Brussels	0.05	1.4	7	68
Liege	0.17	2.28	7	35
Verviers	0.05	5.0	7	40
Grenoble	0.13	2.5	7.5	43
Paris	1.12	1.66	13.0	42
Strasbourg	0.8	3.7	7.5	60
Valenciennes	0.1	11.0	7.5	48
Milan	0.52	2.82	11	—
Rome	1.00	0.09	2	—
Utrecht	0.15	2.5	2	89
Basel	0.3	10.0	4	49
Geneva	0.75	2.3	25	56
Lausanne	0.35	5.0	4	30
Lucerne	0.27	1.2	4	40
Neuchatel	0.2	5.0	8	42
St. Gallen	0.4	7.0	8	58
Winterthur	0.1	10.0	4	68
Zurich	0.48	9.0	4	63

While the experience with no-barrier operation varies from city to city, and detailed information on it is sparse, the following generalizations can be made.

1. Self-service concepts are successful once inaugurated. Not one city that has initiated self-service operation has reversed its decision; fraud rates have been acceptable. The concept is now used to some extent in almost every European country and under a wide range of cultural backgrounds. Table 1 (2, 3) summarizes the reported level of fraud for a selection of cities. (Multitrip tickets and passes are combined solely to show the emphasis on prepayment options used by European systems. The rates of fraud vary between the two payment systems.)
2. The amount of fraud varies by mode, with the least on the bus and the most on rapid transit. Hamburg, for example, estimates fraud rates of 0.6 percent on buses and 1.2 percent on rapid transit. In Munich the fraud rates are about 1.5 percent on buses, over 2.0 percent on rapid transit, and more on the regional S-Bahn.
3. Fraud does not appear to vary significantly by basic socioeconomic group. There is very little variance by income, section of the city, or cultural background. Students and tourists are slightly more troublesome.
4. The speed of surface transit may increase as much as 10 percent due to the rapid boarding ability of self-service. In Copenhagen, the average boarding time per passenger was reduced from 4.5 to 2.2 s. In Belfast, Brussels, Geneva, Grenoble, and Utrecht journey times were reduced 10 percent. This can result in cost saving of up to 10 percent for vehicles, maintenance, and operators.
5. Fare evasion occurs for a number of reasons, not all of which can be attributed to willful violation. The use of passes appears to minimize fraud by requiring only one decision (to purchase the pass) rather than a series of decisions for each trip purchased. Simply not buying any ticket is the means of about 50 percent of fare evasion; invalid tickets, including zone infractions, account for 20 percent and forgotten passes for 10 percent of infractions. Forgotten passes generally have a lower penalty upon proof.
6. The range of cultures that successfully use no-barrier fare collection without a significant deviation in the level of fraud indicate that the influence of cultural differences on the rate of fraud is not particularly significant.

QUANTITATIVE ANALYSIS OF EUROPEAN NO-BARRIER EXPERIENCE

An attempt was made to develop a quantitative explanation of the European fraud levels (especially the German) in order to be able to develop a numerical estimate of the expected rate of fraud in Atlanta. The basic assumption in this effort is that European and American-Atlantan cultural differences are nonexistent. Obviously debatable, this assumption was used because (a) it would probably provide a minimum best guess, and (b) it is necessary for any such quantitative analysis since the cultural and traditional influences are too intangible to quantify numerically.

Available socioeconomic data on European cities are quite limited. Virtually no extensive data could be obtained that directly related fraud experience in transit systems to neighborhood characteristics. A series of indirect transit-related factors, however, were determined for a number of cities since statistical relations (not necessarily causal) that could be used to develop a manner of estimating fraud may exist among them. A speculative model was then constructed of those factors that might provide some motivation to defraud.

1. Economic incentive: High fares, low superfares, and low rates of enforcement all give an economic incentive to defraud.
2. Embarrassment: People will be less inclined to defraud on low-volume modes such as buses, as opposed to high-volume modes such as rapid transit.
3. Proximity to operating personnel: People will be less inclined to defraud when the mode puts them close to the operator (as on a bus).
4. Familiarity with the system: Occasional riders may be more likely to commit fraud.
5. Complexity of the system: There is a greater propensity to cheat if the system is complex in terms of the fare structure, collection devices, and such.
6. Exposure to checking: People will be less likely to cheat if they are more likely to be checked.
7. Quality of the system: There may be an inverse relation between the inclination to commit fraud and the perception of the quality of the system; one is more likely to be caught if one defrauds a system that is run efficiently.

There are doubtless other factors that may be related to the fraud rate. However, the lack of good data prevents a comprehensive assessment of what they might quantitatively be.

Initially, simple correlation coefficients were generated for all pairs of variables in the data set to determine which of them were closely related to one another. The major results were that (a) the intensity of checking may in fact respond to, and not result in, a certain level of fraud; (b) there is a positive relationship between city size and fraud rate; (c) the rate of fraud is higher for cities with rapid transit systems; and (d) complexity of the fare structure does not significantly affect the rate of fraud.

Multiple regression models based on the strengths of the simple correlation coefficients between the fraud descriptors and the various explanatory variables were then developed. The predicted fraud rate for Atlanta based on this model and by analogy with the experiences noted below is 3.48 ± 2.98 or 0.50 to 6.47 percent (95 percent C.I.). While this exercise is not conclusive, it points out the apparent importance of intangible, nonquantitative factors, and it was used as one element in the overall fraud determination process.

ANALOGOUS SELF-SERVICE EXPERIENCES

There are a number of instances in the United States in which the success of the operation relies on the assumption that the user is basically honest. These may be used as proxies to develop a broad picture on the apparent propensity to defraud by Americans. None is directly equivalent to no-barrier fare collection, but there are common elements in these very diverse experiences that allow us to derive some useful conclusions. In seven examples of this type of operation, mostly in the Atlanta area, the experience has been as follows.

Self-service gas stations: In this operation, station pumps are not manned by attendants and the customer operates the pump himself with some indirect supervision. The revenue loss from drive aways is less than 1 percent, which appears to be an equal problem in regular operations.

Telephone fraud: Excluding electronic means, there are several ways of committing telephone fraud, such as direct distance dialing giving erroneous origin numbers and disassociation with a call upon billing. The combined loss of revenue from these frauds is less than 1 percent of gross revenues in the Southern Bell telephone system. There seems to be no correlation between income and fraud; affluent persons cheat as much as low-income persons. However, select groups, noticeably students and young people, military personnel, and truck drivers who use coded messages, have a higher incidence of attempted fraud. The apparent effect on enforcement, which ultimately is the threat of the loss of one's telephone, is difficult to ascertain.

Newspaper vendors: Less than one-half of 1 percent of the newspapers sold through locked boxes are reported stolen by the Atlanta Journal-Constitution. The enforcement procedures used to combat fraud are weak since persons taken to court are usually dismissed with no fines.

Tollway facilities: Many states use self-service lanes at toll plazas and at remote locations. The remote lane has virtually no manned supervision, nor does it provide equipment for making change. Automatic lanes at toll plazas are monitored by nearby manned lanes. The fraud rates below include nonpayment due to jammed machines and leaving before the red-to-green light changes. Fraud rates at automatic lanes are typically under 1 percent and a maximum of about 2.0 percent. Fines range from $10 to $200 and are usually about $25. Publicity often is an additional deterrent measure. Fraud rates at remote lanes are higher because of their very low supervision: These lanes are close to true honor situations. The rates are typically 5 to 10 percent. Fines are similar to automatic lane fines. Approximately one-quarter to one-third of this fraud appears to result from lack of the correct change.

Central stall box honor parking: There are several central stall box lots that use an honor approach in Atlanta. In these lots, a locked rack of boxes is provided, each with a coin size slit and a number that corresponds to a parking space. The rate of fraud is 10 percent or less, but much of this fraud appears to be related to the predominantly off-peak nature of the operation and the possible confusion over whether payment is necessary.

Shoplifting: The basic philosophy of department store self-service operation is an assumption of trust. A recent study by the National Retail Merchants Association placed the revenue loss from all sources at 8.7 percent of sales, of which 30 to 40 percent is attributed to the public, including professional thieves. The remaining 5.2 to 6.1 percent loss is attributed to employee theft and bookkeeping error.

Barrier transit systems: Several of the new rapid transit systems operate stations with few or no personnel. In spite of obvious physical barriers in the form of fare gates for entering and exiting, there are elements of an honor approach involved. Fraud rates for these systems appear to range from less than 0.5 to 2 percent although at times they are higher. This range does not vary greatly between the simple turnstile fare gate system and the more sophisticated systems, and none of these systems has found any noticeable variation in the rate of fraud between income groups.

Two conclusions can be drawn from an analysis of these analogous honor situations: (a) The level of fraud is always fairly low, never higher than 10 percent and generally lower than 2 to 3 percent, and (b) there are no factors that would appear to explain in a quantitative sense the reason behind the rate of fraud.

SOCIOLOGICAL FACTORS RELATED TO FRAUD ESTIMATION

This and the next section discuss the sociological and psychological factors that may help us to understand how people confront the possibility of committing fraud. The low rate of fraud in European no-barrier fare-collection systems under so many different cultural conditions and the low rate of fraud under a wide range of analogous self-service operations in the United States seem to indicate that there are basic sociological or psychological factors that transcend cultural differences.

The most important single conclusion from the data on employee crime, self-reported criminal behavior, and information on customer crimes against large-scale organizations is that normal, respectable people can and do engage in systematic criminality. The important point, however, is that while most of us at some time commit illegal acts—be it parking without feeding the meter, or bus transfer abuse, or employee theft—far fewer of us do so regularly. Probably less than 1 percent of us are either inveterate cheaters or incorruptibly honest.

There does not appear to be any basis for concluding that any group or minority will commit substantially less or more fare evasion than another. Some groups, however, are known to be more prone to commit fraud. The only such of relevance to transit use are adolescents and students who invariably commit more small crimes in any area and in any country than does the public at large. Females are generally more law-abiding than males (although this is changing as society moves toward more sexual equality), and most studies report that females are more conforming and compliant to authority than males. (In Munich, however, many defrauders are female shoppers during the off-peak period.)

The size, wealth, and impersonality of big business and government are attributes that make it seem excusable, according to many people, to steal from them. They won't miss it or I already paid for it in the high profits of the company and the large amounts of taxes I had to pay are frequent rationalizations.

PSYCHOLOGICAL FACTORS RELATED TO FRAUD ESTIMATION

One would assume that the more checking the less fraud, but studies show that this may not be the case. Constant, persistent monitoring probably causes people to feel too self-conscious and consequently leads to irritation and annoyance. Finally, it may even lead to pathological consequences if carried out over prolonged periods.

Sommer (4) offers evidence that the tendency of the public is to counteract attempts by officials to design public facilities that appear impregnable. The result is simply that more ingenious ways are devised to commit theft and vandalism. Similarly, excessive checking or a very high level of superfare may lead to more fraud as a form of rebellion.

Theoretically, the penalty for fraud is the size of the sanction if one is caught. There are also subjective penalties. These include the embarrassment at being caught in front of other riders. This should be greater when a person is caught in front of acquaintances and makes the sanction greater in a bus where commuters know one another better than they do on a more anonymous train. A rider may also feel a greater risk on a bus with 50 passengers than on a train with 500, regardless of the objective risk. These factors may explain why fraud is lower on buses than on trains.

Public transit passengers, especially in buses and surface vehicles, are not anonymous. People ride the same route every day and know each other by sight. The passengers are intimate strangers, who never speak on the bus but who would greet one another if they met elsewhere. They are subject to pressure from their fellow passengers, and public transit is a place where the rules are unstated but very strong. This is all part of the pattern of not making a wave in front of all those others who are watching. To be caught and punished for committing fraud would most definitely make one stand out as being different, and being different is undesirable. The social penalty of being caught may be as effective as the financial penalty.

What happens when a person is caught in the act of doing something wrong? Many people quickly pay the superfare to minimize the embarrassment, often to the extent of having the fine amount readily available at all times. Some, however, argue over the payment. The standard practice in these cases is to separate the defrauder from others (by getting off with him at the next stop, for instance). Quite often, this results in quick payment, but the threat of police arrest is a secondary and effective next resort. If the representative is seen as doing a legitimate job, he is unlikely to arouse personal animosity; but, if he is seen as overstepping his bounds or acting in a personal rather than a professional manner, he is more likely to arouse antagonism.

If all other factors are held constant, fraud can be expected to increase as the fare increases since people will be less able to pay the fare. This effect is not likely to be a smooth one as people have ideas that certain amounts of money are appropriate for certain things. In addition, there is evidence that, if a situation becomes progressively more adverse, people resent it more than they would have if the situation had initially been as adverse as it eventually became. This is because the resentment is compounded by a sense of loss. The same response may result from increased transit fares.

ESTIMATE OF FRAUD

The estimated rate of fraud developed in this study is derived from the following arguments.

1. Assuming complete identity between European and American cultures, one would expect a range of fraud between 0.5 (the average for the 28-city sample) and 2.0 (a figure approaching the upper limit of fraud, even for large cities) percent.
2. Although it is difficult to explain, most Americans feel uncomfortable in assuming that they are as honest as Europeans. However, it is doubtful that Americans are many times more dishonest. The low rate of fraud over the wide range of cultures discussed above is a positive indication of this belief as is the apparent universality of the psychological embarrassment factor.
3. By extensive marketing of the prepayment of fares through passes, it is possible to have as many as 65 percent of the passengers use passes. Since valid pass holders cannot cheat, single-trip ticket holders will commit almost all the systemwide fraud. But in order for this to occur, as many as 25 percent of the single ticket buyers would have to cheat each and every day, and this event appears highly unlikely.
4. The experience with analogous honor situations in the United States, although varied and not directly related, shows a general level of fraud below 5 percent.
5. The quantitative estimate of fraud, although based on a model with obvious limitations, gives a range of expected fraud between 0.5 and 6.5 percent.

From this, it was concluded that the expected rate of fraud will most probably be 3 to 5 percent of the daily

Table 2. Comparative system costs in May 1975 dollars.

System	Costs ($000)			
	Capital	Operation (O)	Maintenance (M)	O + M
No-barrier	4 872	1831	360	2191
Token	7 120	1423	528	1951
Pass-ticket	9 332	1403	661	2064
Carnet-ticket	10 335	1589	681	2270
Pass-token	8 775	1271	596	1867

Note: The above costs are based on the two-county unextended rapid transit system consisting of 39 stations and one busway to 1995. The fare level is $0.50 nominal value.

ridership. This assumes that (a) the attitude of MARTA, reflected in the implementation of such a system, is that the no-barrier concept works best not through strict punitive measures and high enforcement, but because its patrons react positively toward positive incentives; (b) there is maximum use of prepaid passes, which offer readily apparent convenience and the sales of which are well marketed; and (c) that the checking and enforcement policy is fair, impartially administered, and explained in detail and in advance to all riders.

MARTA FARE-COLLECTION STUDY

The analysis of the no-barrier fare-collection system was one alternative in a comprehensive study of possible fare systems. The final candidate systems evaluated were no-barrier, token, pass-ticket, carnet-ticket, and pass-token.

The pass-token system was the one selected. There were two main reasons for not choosing the no-barrier system. The first was the decision to operate initially under a flat fare structure. This structure negates most of the real advantages of the no-barrier concept as it drastically reduces the cost. Also the future MARTA transit system will incorporate a great deal of integration of bus and rail modes, and it is questionable whether machines alone could handle the control requirements with graduated fares; European experience leads one to think not. The second reason follows from the first: Given a flat fare structure and the MARTA system characteristics, some barrier systems are operationally more economical than is the no-barrier alternative. The recommended pass-token system is one of them. Table 2 gives a summary of the comparative system costs.

POTENTIAL FOR NO-BARRIER FARE COLLECTION IN THE UNITED STATES

At present there are no self-service systems in operation in the United States and this may be the major obstacle facing the implementation of this concept. On the plus side, the concept offers the following.

1. Flexibility. No-barrier fare collection is adaptable to any conceivable fare structure and mode. It is especially suited to multimode, complex zone, or graduated fare structures that are beyond the state of the art of fare-collection hardware. It can easily handle special group discounts, promotional tickets, and special marketing features.
2. Passenger Appeal. The simplicity and convenience of the no-barrier system are very attractive to system users. First of all, dispensing with barriers is psychologically attractive in a world already overly protected. It also speeds passenger access to stations and vehicles. The ticket or pass is used throughout the trip; separate transfers are not needed. The presence of inspectors gives the system a more human touch and a greater perception of security. Finally, no-barrier fare collection, by allowing for multidoor loading of buses or light rail, speeds the service offered and reduces the cost of operations.

The no-barrier concept presents some disadvantages.

1. Wages. This system is labor intensive since it relies on teams of inspectors as a means of control.
2. Legalities. It is unclear what legal problems are involved in on-the-spot penalty procedures. There is a general misconception, for instance, that the right to due process is seriously compromised by the on-the-spot penalty.

Nevertheless, any fare-collection study in the United States should consider the no-barrier concept as a serious alternative. In the right circumstances it will be of obvious superiority and could be the only feasible alternative. Special attention should be paid to these applications.

1. Zone-fare rapid transit with integrated bus service. The capital cost savings on sophisticated equipment are substantial in such a situation. While operating costs may be higher (although this is not necessarily true under a distance-based fare structure), no-barrier fare collection offers such substantial benefits in the areas of passenger appeal, convenience, fare policy flexibility, public relations, and possibly security that it must be given serious considerations.
2. Light rail networks. Unlike rapid transit, light rail access control through barriers becomes impossible. Compounding the problem, the vehicle is too large to have front door, single-aisle loading. No-barrier fare collection is a natural for light rail systems.
3. Bus systems (especially those with distance-based fare structures). Controlling zone fare structures in a bus is an annoying problem, because it requires either payment at exiting only (at the front door) or stopping the bus at the zone boundary to collect the surcharge. Graduated fare structures are almost impossible with conventional bus fare-collection practices.

The extensive use of passes or prepaid trip options is almost a necessity for no-barrier fare collection as they lessen fraud and at the same time provide convenience to both the user and the operator.

CONCLUSION

This paper tries to shed some light on an aspect of transit operations that has found almost universal success in Europe but remains unknown in the United States. Although not a panacea by any means, no-barrier collection may be an attractive solution to fare-collection problems arising from the increased integration of modes, greater emphasis of transit market differentiation, and the potential growth of light rail systems.

The fraud estimation study performed by MARTA, rough as it may have been, did not reveal any propensity for large-scale cheating. This issue has unrealistically dominated discussions of the no-barrier concept and overwhelmed any rational analysis of its benefits. This appears unwarranted, although some doubt will remain until a no-barrier system is successful in the United States.

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Abridgment

Central-Area Bus Terminals: Planning and Design Guidelines

William F. Hoey and Herbert S. Levinson, Wilbur Smith and Associates

Central-area bus terminals are an important means of improving the efficiency of express bus service. In the United States there are major terminals in New York City, Chicago, San Francisco, Los Angeles, and Cincinnati, and one is proposed for Philadelphia. They range in size from the 10-berth, one-level Dixie Terminal in Cincinnati to the 184-berth, three-level Midtown Terminal in New York City (Tables 1 and 2). They are usually located between expressways and the CBD and are removed from points of high land value.

Terminal patronage reflects the CBD employment density and the tributary area served. New York City's Midtown Terminal serves over 100 000 passengers/d in each direction; the Transbay Transit Terminal, 44 000; the George Washington Bridge Terminal, 20 000; Cincinnati's Dixie Terminal, 5000; and Los Angeles' Southern California Rapid Transit District Terminal, 2000. The corresponding peak-hour (one-way) volumes are 33 000, 13 000, 4200, 1800, and 500 persons respectively.

PLANNING GUIDELINES

Bus terminal planning and design must reflect the particular needs of each specific situation.

Community Size

Major central-area bus terminals are cost-effective only in special situations such as in large cities. They gener-

Table 1. Principal central-area bus terminals in the United States.

Terminal	Development Cost[a] ($)	Type of Service	Construction Date	Contiguous Transportation Facilities	Access Connections	Ancillary Land Uses	Remarks
Port Authority, New York	58 000 000	Commuter and intercity	1950	Subway, local bus, and automobile parking	Direct ramp connections to Lincoln Tunnel	Retail convenience goods and restaurants	1080 cars; saves buses 30 min over previous operations
George Washington Bridge, New York	15 300 000	Commuter and intercity	1963	Subway and local bus	Direct ramp connections to George Washington Bridge	Retail convenience goods and restaurants	Located over Cross Bronx Expressway
Greyhound, Chicago	8 000 000	Mainly intercity	1952	Subway, local bus, and curb parking	Tunnel and ramp connections to Garvey St. and Wacker Dr.	Retail convenience goods and offices	Designed to allow office building over station
Transbay, San Francisco	11 000 000	Intercity and commuter	1960	Streetcar, bus, and automobile parking	Direct ramp connections to San Francisco-Oakland Bay Bridge	Retail convenience goods	Taxis also used terminal prior to 1960
Dixie, Cincinnati	N.A.[b]	Commuter	1921 (rail), 1936 (buses)	Local bus and automobile parking	Direct ramp access to suspension bridge over Ohio River	Retail, offices, and restaurants	Former interurban rail terminal shared by rail and bus 1936 to 1950; bus only since 1950
Market Street East, Philadelphia	N.A.[b]	Intercity and commuter	Planned	Subway, railroad, streetcar, local bus, and automobile parking	Direct ramp connections to Vine St. Expressway	Retail, offices, and hotel	3000 or more parking spaces planned

[a] Data on maintenance costs and revenues are unavailable.

[b] N.A. = Not available.

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ally should be located in conjunction with rail rapid transit lines, busways, and contraflow bus lanes and are useful mainly where the urban area population exceeds 750 000 and the downtown employment exceeds 50 000. Terminals in medium-sized communities usually are part of transportation centers, where intercity bus services and parking facilities are complementary components of a larger development.

Smaller, simpler terminals are more useful for the off-street loading of express and suburban buses in medium-sized cities. These do not require exclusive access roadways, but many require bus priority treatments to avoid delays and backtracking (Figure 1).

Location

Terminals are sensitive to location. Freeway access by free-flowing grade-separated ramps and bus roadways is essential for a major terminal (Figure 2). They should be within a 5-min walk (400 to 500 m or 1200 to 1500 ft) of the highest employment concentrations in the area. Secondary distribution by efficient local public transport (buses, subways or light rail, and taxicabs) is essential for a major terminal and desirable for any terminal.

Land costs are critical: Unless air rights development potentials can sustain high costs, bus terminal land costs are limited to about $\$3/m^2$ ($\$10/ft^2$).

Bus Volume Concentrations

Terminals may be appropriate wherever the on-street operations of terminating buses will disrupt general traffic. Where buses operate through the center of the city on continuous routes, a downtown busway or exclusive bus street may be more cost-effective. Off-street terminals generally should be considered whereever there are 20 to 25 peak-hour terminating buses and more than 1000 passengers. Intercity, commuter suburban, or express bus services are usually better suited to terminals than is local bus service.

Cost, Revenue, Demand, and Economic Feasibility

Terminal planning should include detailed estimates of demand, capacity, revenues, and costs. Space demand criteria should consider the specific operating needs of each individual carrier. The design should allow for expansion of capacity, including adaptability to new bus sizes, types, and technologies. Revenues from ancillary land development are especially important.

Scale of Development

Off-street bus terminals should provide at least 5 loading positions, but few cities will need more than 20 to 30 berths to serve both intercity and suburban requirements.

Basic Functions

The bus, passenger, and baggage functions within central bus terminals are closely interrelated (Figure 3). The bus arrival-unloading-layover-loading-departure sequence is the heart of the terminal operation on which the various other functions depend. The baggage and parcel functions serve mainly intercity bus operations and can be minimized for urban and suburban commuter services.

DESIGN GUIDELINES

Internal terminal design should separate vehicle and passenger movements, carefully reflecting their specialized circulation and geometric requirements. A basic design constraint is the need for buses to load and unload on their right sides. Table 3 (1) summarizes bus terminal design criteria.

Separate Intercity and Commuter Services

Intercity and commuter buses should have separate platforms to reflect their differing service patterns and berth occupancy requirements. Intercity buses have long layover times to allow for passenger loading and baggage and parcel unloading. Moreover, intercity bus services may operate extra buses—up to twice the number of scheduled runs—in seasonal peak periods. Closely stacked sawtooth platforms should be used.

Commuter buses need higher peak-hour capacities, but their baggage and parcel requirements are minimal. Passenger unloading and loading areas should be clearly separated to minimize confusion, conflicts, and bus dwell times. Linear or shallow sawtooth loading platforms should be used to allow pull-through bus movement and to permit several buses to queue at the same platform simultaneously.

Berth Requirements

Berth space requirements should reflect both scheduled and actual peak-period bus arrivals and departures. The berth loading capacities shown in Table 4 (1) provide a planning guide. Bus unloading capacities are approximately the same as loading capacities for free-fare or prepaid loading conditions. Free, prepaid, or pay-on-exit operations can accommodate 1600 to 1900 passengers/h/berth with single entrance doors or 2400 to 2900 passengers/h/berth with double entrance doors, with queuing. Multizone fares, where tickets are sold or validated by the bus driver, reduce capacities to as low as 250 to 500 passengers/h/berth, and intercity bus operations may reduce capacities to as low as 50 to 100 passengers/h/berth.

General Design Features

General design guidelines include the following.

1. Ramps, lanes, and runways should be designed for the largest foreseeable buses including double-deck and articulated ones.
2. Intercity and commuter buses should have separate platforms, and the latter should have separate loading and unloading areas.
3. Each major route or corridor should have its own loading area; ideally no more than three routes should use any one platform location.
4. Holding and bus storage areas should be separate from loading and unloading platforms for commuter buses.
5. Loading platform widths for simple operations may be as narrow as 2.4 m (8 ft), but where there are substantial queuing and circulation of passengers the platform should be at least 3.7 m (12 ft) wide. Obstructions (such as stairwells) on the platform may require wider platforms).
6. Raised platforms, sheltered from the weather, are a needed passenger amenity. Platform elevations and curb heights of 13 to 20 cm (5 to 8 in) are usually satisfactory.

Table 2. Traffic loads in central-area bus terminals.

Terminal	No. of Bus Levels	No. of Bus Loading Docks	No. of Passengers[a]		No. of Buses[a]		Average Bus Occupancy		Average No. of Buses per Dock		Average Bus Layover Time	
			Daily	Peak-Hour	Daily	Peak-Hour	Daily	Peak-Hour	Daily	Peak-Hour	Daily	Peak-Hour
Port Authority, New York	3	184	105 500	32 600	3350	730	27.4	44.1	18.2	4.0	1.32	0.25
George Washington Bridge, New York	2	43	20 000	4 200	850	108	23.5	39.0	19.6	2.5	1.22	0.4
Greyhound, Chicago	1	30		10 000		—	—	—	—	—		—
Transbay, San Francisco	1	37	44 000	13 000	2200	350	20.0	37.2	59.5	9.5	0.40	0.16
Dixie, Cincinnati	1	6[b]	5 000	1 800	195	48	25.4	37.5	32.5	8.0	0.16	0.08
Market Street East, Philadelphia	2	70	N.A.[c]	5 900	N.A.[c]	170	N.A.[c]	35	N.A.[c]	2.4	N.A.[c]	0.42

[a] One-direction-only bus volumes.

[b] Also four unloading and six loading docks.

[c] N.A. = Not Available.

Figure 1. Off-street central terminal concept for a medium-sized urban area.

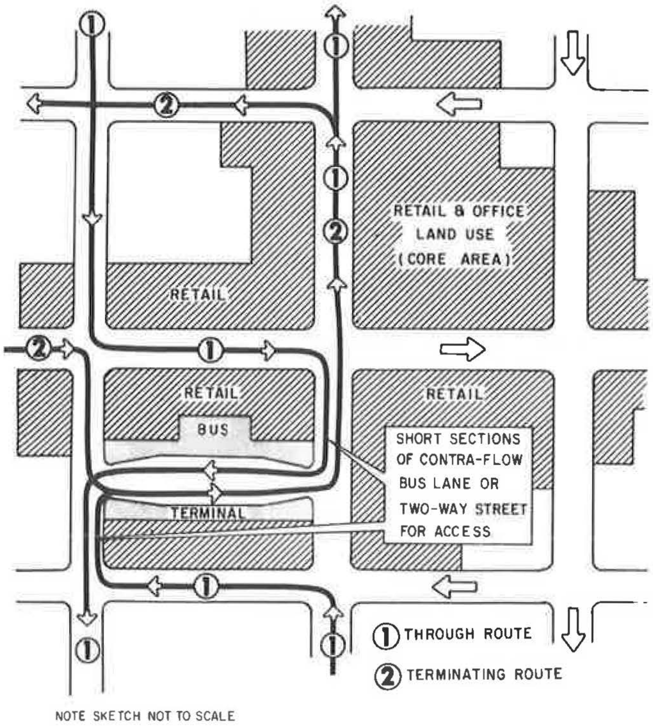


Figure 2. Generalized CBD terminal location concept.

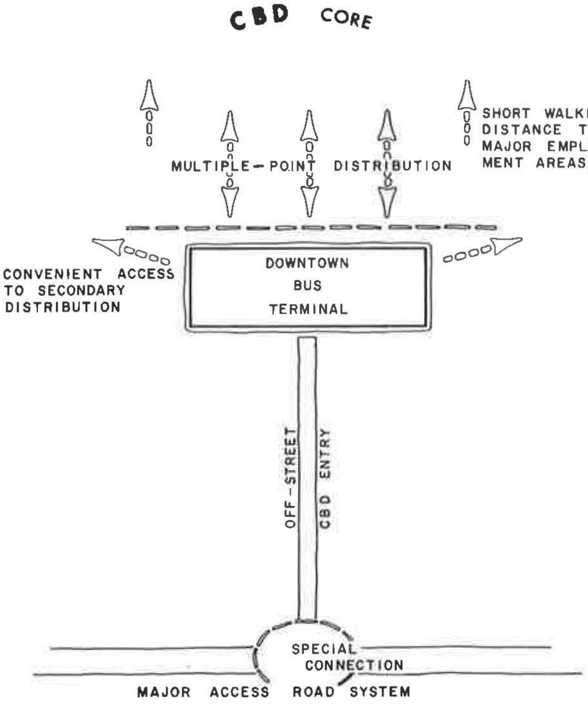
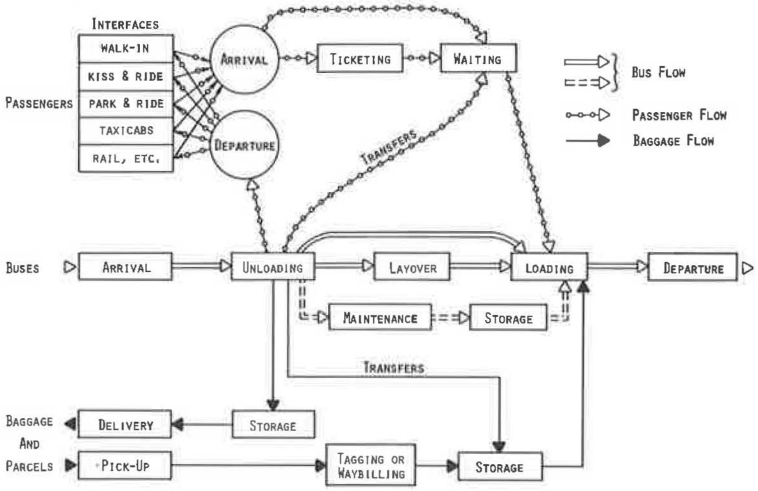


Figure 3. Bus terminal functions.



7. Access for handicapped persons should be considered in terminal design, and will improve the capacity and convenience of the terminal for ablebodied persons.

8. Ancillary facilities should reflect the balance between intercity and commuter passengers.

Implementation Factors

Terminal implementation brings with it questions of administration, finance, multiuse development, and cost sharing. These are important considerations that will influence the viability of bus terminals in any given city center.

Table 3. Bus terminal design standards.

	Standard		
Characteristic	Minimum	Desirable	Remarks
Bus lane width			
For buses 2.4 m wide	3.0 m	3.4 m	Consider possible future bus widths and ceiling or column configurations that may govern bus paths
For buses 2.6 m wide	3.4 m	3.7 m	
Bus runway width	3.4 m	6.9 to 7.4 m	Two lanes wherever feasible; extra clearance at entrances and exits; additional bypass lane where empty buses enter terminal in large numbers
Ramping (entrances and exits)	Depends on vehicles	Depends on vehicles	Determine by tests; sag curves will affect vertical clearance needs
Headroom	3.7 m	4.6 m	Consider possible use of double deckers within service life of facilities; desirably should be consistent with Interstate highway clearance standards
Side clearances	At least 0.3 m	Sufficient for smooth flow at entrances and exits	Consider sight distance needs of buses exiting into traffic where this is necessary
Berth length (parallel)			
Single buses	21.5 m (0.9-m tailout)	24.5 m (0.65-m tailout)	Requires 6.9-m runway width
Queued buses	13.7 m/bus	15.2 m/bus	Additional length if buses lay over in platforms (undesirable)
Platform width	2.5 m	3.7 m	Obstructions (such as columns or stairwells) necessitate greater width
Waiting room area	1.4 m^2/person	1.9 to 2.2 m^2/person	These factors apply to intercity passengers; waiting area can be minimized where commuters dominate the passenger flow
Ticketing	One position/25 to 30 waiting room seats	Depends on character and amount of patronage	Cash fares collected by drivers reduce ticket sales needs but may slow operations within the terminal
Baggage room area	Depends on terminal type	4.6 m^2 for each intercity bus berth	Commuter bus operations need minimal baggage facilities

Table 4. Bus terminal berth loading capacities in relation to fare-collection procedures.

	Type of Fare-Collection Procedure				
	Free, Prepaid, or Pay-on-Exit		Pay on Entry, Fare Box With Single Doorway Entrance Channel		
Characteristic	Double Door	Single Door	Single Coin or Token	Odd-Penny	Multizone
Passenger headway	0.8 to 1.2 s	1 to 2 s	2 to 3 s	3 to 4 s	4 to 6 s[a] 6 to 8 s[b]
Doors used	2[c]	2[c]	1	1	1 1
Dwell time to load 50 passengers[d] (33 through heaviest used door)	30 to 40 s	30 to 65 s	100 to 150 s	150 to 200 s	200 to 300 s[a] 300 to 400 s[b]
Minimum bus headway					
Queued buses[e]	50 s	75 s	160 s	210 s	310 s[a] 410 s[b]
Single buses[f,g]	100 s	125 s	210 s	260 s	360 s[a] 460 s[b]
Equivalent berth capacity					
Queued buses	72 buses/h	48 buses/h	23 buses/h	17 buses/h	17 buses/h[a] 8 buses/h[b]
Single buses	36 buses/h	29 buses/h	17 buses/h	14 buses/h	10 buses/h[a] 7 buses/h[b]
Equivalent passenger load					
Queued buses	3600	2400	1150	850	600[a] 400[b]
Single buses	1800	1450	850	700	500[a] 350[b]
Effective berth capacity					
40 percent in peak 20 min					
Queued buses	2900	1900	900	680	480[a] 320[b]
Single buses	1400	1200	580	560	400[a] 280[b]
50 percent in peak 20 min					
Queued buses	2400	1600	770	570	400[a] 270[b]
Single buses	1200	1000	570	470	330[a] 230[b]

[a] Prepurchased tickets registered on bus by driver.

[b] Cash fare, driver makes change, and fare box prints receipt for passenger to show on exit.

[c] Assumes 67-33 split between front and rear doors.

[d] Assumes 50-seat buses loaded to seating capacity for express runs. Standees can be accommodated on relatively short express runs, but seating capacity is considered more realistic in view of the competition with private automobile comfort.

[e] Assumes that the next bus is always waiting behind the loading bus and can pull in and be ready to load in 10 s (i.e., linear platforms).

[f] Assumes that the next bus must be summoned from a holding or storage area, involving a 60-s delay and/or recovery time (linear or shallow sawtooth platforms).

[g] With lower times, capacities would approach those for queued operations.

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Measuring Service Delivered by Transportation Terminals

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The purpose of this paper is to introduce a procedure for deriving an index of the adequacy of a design to provide a particular service, and to apply it to the evaluation of passenger transportation terminal designs.

Such an indicator is desirable for the objective evaluation of which of several alternative configurations is the best, in terms of the fulfillment of user needs and the facilitation of service, and of which alternatives are equivalent and may therefore offer higher service yields for given dollar investments.

For the construction of this indicator, the concept of the service rendered by a transportation terminal or facility is defined as the rendering of assistance to the users of the facility to satisfy their needs and purposes. What is the meaning of this assistance in terms of the needs it is supposed to help, how and where is it desired, and how can we go about measuring it, not for a single need or a single step, but for all of the needs and actions required to achieve the user's purpose? Let us follow a passenger in his path through a transportation terminal and consider what he does from the moment he arrives to the moment he departs. Passengers at the terminal are departing on a trip or arriving from one, or transferring between modes of conveyance. (Other users of the terminal are sightseers and people waiting for or seeing off friends and relatives, but we will not concern ourselves with these aspects of service.) To reach a conveyance, the user must walk through corridors, open doors, climb stairs, or use escalators; stop at certain transaction points; and wait in lines and in waiting rooms. The goal is to go from the means of arrival to the means of departure in the most expeditious way.

Some interferences such as ticket checking or baggage claiming arise in the user's path out of necessity, others such as passport and health controls out of regulations, and others out of conveyance characteristics such as the size of an aircraft or the length of a train or boat. But some arise from design fitness: Corridors may be longer than needed, piers or platforms may be awkwardly arranged and require avoidable changes of level or direction, transaction points may be of insufficient capacity, and passenger flows may be hindered or made turbulent by obstacles and cross flows. Information may be insufficient and lead to uncertainty as to where to go and to aborted trips, ventilation may be poor, and many other avoidable events may interfere with a pleasantly flowing service. Good service obviously requires that unavoidable hindrances be minimized and that necessary ones be organized so as to keep interference and delay to a minimum. All of the design features and impacts on service flow and organization should be reflected in the evaluation index. The index should show that if a hindrance is removed the service is improved; that if it is added service is worsened; that if help is added where needed the index is improved; that if a superfluous delay occurs the index is worsened. Finally, the index should combine all these occurrences in a logically and intuitively satisfactory way that may be tested against user valuations and refined until index and valuations consistently agree.

To begin the evaluation, we follow the users' path through the terminal and perform a simplified time and motion analysis of everything they must do, what, where, when, and why. From a general knowledge of biology and psychology, we have an understanding of the user, of his or her needs, general preferences, physical and emotional tolerances to various events, sizes, and perceptual mechanisms. This understanding will provide a foundation that can be developed into specifications of general needs and wants—emotional, bodily, or sensory—that may be present in the situation. It is then a simple matter to consider, for each act required of the user, how its performance relates to each of his or her needs and preferences. We can at each act indicate whether any particular need has been involved and if so whether it has been helped or aggravated. We can tabulate these evaluations by listing the needs and indicating the sequence of acts in ordered columns. This table will show how the system performs for that user, at each act and over the complete sequence of acts of the passage through the terminal.

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Difficult procedures, poorly thought out arrangements, or unsuitable environments may impair the performance of required acts. Arrangement suitability should therefore enter into the evaluation of a service arrangement. To do this, we extend our tabulation of act-and-need incidences by preparing a separate table for each element or feature of the environment that may influence the performance of an act, entering in the proper cells a +1, a 0, or a -1 to indicate our judgment of its influence as helpful, indifferent, or detrimental to this performance in respect to the need under consideration. All incidences of superfluous acts upon needs will be counted as negative with respect to the needs regardless of how well designed the elements in question.

The result of this procedure is now a set of check-off lists for each stage in the process that detail, for each need and act or operation required, the help or hindrance received from each pertinent environmental feature. We can now count for each act and feature combination the total of needs that were influenced and whether or not these were helped.

Let us assume that a user's needs consist only of personal safety, freedom from effort, freedom from hindrances, and a pleasant ambience. Suppose that he or she must pick up two suitcases at an airline terminal, walk 160 m (500 ft), and open a spring door to a taxi stand by the sidewalk outside the building. The interior is air conditioned. Outside, on a humid summer day, the temperature is 27°C (80°F), and the passenger has to wait 5 min for a taxi. The interaction among passenger needs, the environment, and the actions required is shown in Table 1. We obtain counts of 1 out of 3 in the first, second, and fifth operations; 1 out of 4 in the third; 2 out of 3 in the fourth; and 2 out of 2 in the last.

So far we have not taken time into account, but this is an essential element that must be introduced into any comprehensive measure of service. If we time the walk from the point of entry to the point of exit by two alternative arrangements, we usually prefer the shorter. However, if the times are equal, but the one with the longer distance has a pedestrian conveyor that cuts the effort of carrying luggage, we usually prefer the one with the conveyor. Thus, the goodness or quality of a particular arrangement is directly proportional to the number of needs served and inversely proportional to the time required to provide the service.

The needs fulfilled and satisfied change from act to act, and, in order to compare arrangements from one to another, we should take the proportion of needs served out of the total aroused, rather than the simple total. This will modify the basic statement of what is goodness to the statement that the goodness of an arrangement is directly proportional to the proportion of needs served out of the total aroused or present and inversely proportional to the time taken to complete the action.

We can now count in each table, for each act, need, and feature combination, the number of needs active and the number helped, and form the ratio and divide it by the time taken. Fifty percent of needs satisfied at, for example, passport control in 10 s gives an index of service 0.05. All needs satisfied in the same time could give a rate of service delivered ratio of 0.1/s, which measures that 10 percent of the needs aroused are satisfied per second of service for a service lasting 10 s. A service delivery index of 0.05 shows that, at the end of the 10 s, half of the needs that occurred had been left unmet or been aggravated. This service is thus only half as good as the previous one. We can also obtain an indication of the influence of time on service. If the action requires 20 s instead of 10 for the same service, with all needs satisfied, the index of service delivered will become 0.05. This rate of service delivered is the same as that of the first case in which only half the needs were served but the service was twice as fast.

This implies an exchange of need coverage for service speed. Is this rate of trade-off acceptable? The only way to learn is to run a series of experiments in which the service delivery values are controlled and the reactions of users observed. In the same way, we could introduce various importance ranks to weigh the service delivered index to reflect the needs that were left unmet.

Another problem arises from the use of time as a denominator. We can have, for example, 1 out of 100 needs served in 0.001 s to give a service delivered index of 0.01/0.001 = 10. This is logically so, but is it practical? What human act can be completed in 0.001 s? A thought? It is doubtful. Psychological experiments about sensory perception have established that there is a threshold of time awareness below which things are perceived as continuous (1). The existence of this time threshold implies that any action occurring in less than this time interval is perceived as a part of the preceding one. Hence for any action to be differentiated from the preceding one, it must endure for more than the threshold of time awareness. This threshold has not been precisely established but is of the order of 0.05 s.

The next requirement is a measure of service delivered over the sequence, reflecting the service delivery achieved for each individual action. Because the measure of service for the single action is the rate at which a proportion of the needs present at that action were helped, the average rate for all of the actions is a reasonable measure for the sequence, and since we are using rates, we must use the harmonic average, which is the ratio of the number of actions averaged to the sum of the inverses of their coverage rates. For example, if we have only two actions to perform, and one takes 10 s with half of the needs satisfied, and the other takes 20 s with all of the needs satisfied, the harmonic average of the two is [2 (0.05) (0.05)]/[(0.05) + (0.05)] = [2 (0.0025)]/0.1 = 0.05.

For comparison, how efficient is each action? If we divide by the number of actions, we obtain 0.05/2 = 0.025. At each act required from the user we have served 0.025/s of service of the proportion of needs aroused. This rate of service delivery can be compared with the rate of service delivered at any other service arrangement regardless of its complexity, and we can then judge which action sequence is best in terms of service delivered per required action. We can combine any number of actions and, following the same procedure, any number of stages to obtain an index of their service delivery.

By continuing this procedure over all of the paths followed by arriving and departing passengers, we can obtain the service delivered indexes for each path. By taking the average over all paths, per action, we obtain an index for the whole terminal. This allows us to compare its adequacy of design with that of other terminals. By applying the procedure during the design phase of a new terminal, or the modification of an old one, it is possible to determine the way modifications in form or reorganizations of space will affect the resulting service offered.

Table 2 presents the calculation of the service delivered index for the two stages of the example in Table 1 and the rate for both stages. The decimal figures in the two lowest rows are the fraction of need coverage per 5 s per action. If all needs are covered without changing the times, these values will become 0.040, 0.014, and 0.010 respectively. This is still not very good because of the long times involved, but is an improvement.

These simplified calculations of service apply only to design or layout. They do not consider the numbers of passengers exposed to the various service delivered

Table 1. Act-and-need interactions.

	Stage 1 Operation (Air Conditioned)			Stage 2 Operation (Hot and Humid)		
Needs	Lift	Walk 160 m	Push Door	Put Down	Wait	Board
Safety	-1	-1	-1	1		
Effort	-1	-1	-1	1	1	1
Hinders			-1		-1	
Ambient	1	1	1	-1	-1	1
Total (+)	1	1	1	2	1	2
Total not 0	3	3	4	3	3	2
Time (s)	2	120	2	1	300	60

Table 2. Service delivered index calculation.

	Stage 1 Operation			Stage 2 Operation		
Index Factor	Lift	Walk 160 m	Push Door	Put Down	Wait	Board
Need service ratio	1/3	1/3	1/4	2/3	1/3	1
Time (s/5)	0.4	24	0.4	0.2	60	12
Coverage rate	1	1	1	1	1	1
Stage service delivered	3(0.0134)			3(0.0052)		
Overall service delivered	6(0.00374)					

values of the paths through the terminal. The overall service delivered can be calculated by multiplying the path value by the number of passengers using it, adding for all paths, and dividing by the total number of passengers to give a weighted facility service delivered average. Such averages are useful in determining the overall service offered to the public and the generated public image.

The service delivered index can be used to compare service efficiencies in the same way in which engine efficiencies are compared. The efficiency ratio of service will be the ratio of service delivered to that of a reference level of service that could have been obtained by covering all needs at all actions in ideal action times. This is not a practical standard; a more useful one is to establish standard times for excellence of performance for each action, and calculate the corresponding service delivered values with all needs fulfilled. This could be related to the actual service delivered index and would give a measure of achievement against that which is difficult but attainable.

Consider the improvement of service for the two-stage illustration given above. The main sources of disservice are having to carry the suitcases a long distance and having to wait for a taxi in the summer heat. We cannot improve the taxi wait, but we can install a high-speed walkway that cuts the walking time to the entrance from 2 min to 0.5 min. This will give service delivered index values of 0.048 and 0.00469 for stage 1 and overall respectively. If we now take, for the same illustration, the standard of service that all needs should be served, the standard for stage 1 will be 0.147; for stage 2 it will be 0.014, and for the overall service, 0.013. Thus, although the conveyor greatly improves service, we have still achieved only 33 percent of the standard desired for stage 1, 37 percent for stage 2, and 36 percent of the desired overall standard.

The service delivered index also allows the computation of an index of the effort or strain implicitly imposed on the user by the service arrangement design and organization. This effort index does not add to the information already incorporated into the service delivered index, but it is derived from it by using the gap between the standard of excellence and the actually delivered service and taking this gap as an avoidable increase of the passenger's effort (2). Such an index of effort and strain is useful in relating design features to passenger psychological strain perception and thus to passenger perception of service rendered by the facility.

High cost is not necessarily a consequence of good service design. The relationship between goodness or quality of service and the cost of providing it is not a strong one. It can be expected that, as more and more needs are covered, cost will go up, but, given a fixed level of service, this may be achieved by several possible arrangements that differ widely in cost. The service index is thus a useful tool for the evaluation of service delivered per dollar invested. If, in the computation of the index, we introduce the satisfaction of aesthetic and symbolic needs, we may avoid building a very efficient but drab and uninteresting structure. We may also avoid building an interesting, daring, and beautiful structure that encloses a poor service arrangement. The cost of each design alternative can be prorated to the serviced passenger index to obtain the dollar per served passenger cost for each design, thus facilitating selection of more cost-effective designs.

The procedure can also be used to evaluate long-distance transportation alternatives, but it is not yet sufficiently developed for application to the choice of transportation mode for the journey to work.

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Abridgment

Means for Improving the Steering Behavior of Railway Vehicles

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Railway transportation has two basic advantages that provide powerful incentives for expanding its use. First, the railroad can be considered an open-face roller bearing. Heavy loads are moved with very little friction. Second, the operation of transportation vehicles in trains is economical in terms of the labor and land required, and the wind resistance of a train is very low.

One of the leading concerns of the designers of early coal hauling systems was the reduction of the rolling resistance by moving the vehicle wheels up out of the mud (1). The high cost of a hard running surface led to the use of curbs, and in time the guidance was transferred to the wheel in the form of a flange. The first cars were two-axle wagons that operated much better on straight track than on curves. The curving problem and the need for more axles led to the invention of trucks that swivel with respect to the car body. This reduces the curving problem by reducing the angle of attack between the flange and the rail, but the two axles are still parallel and at least one of them continues to have an angle of attack.

Flange wear can be a problem on straight track also. With a metal wheel and rail, alignment is very critical. For example, it is difficult to obtain adequate precision for independently rotating wheels such as were used on the early vehicles. The solution to this problem was the development of rotating axle wheelsets in combination with a tapered wheel tread. The self-aligning tendency of such wheelsets acts to prevent flange contact on straight track and helps to reduce flange pressure in curves. Unfortunately this steering moment also causes a hunting oscillation of the wheelsets at high speeds.

Wheel and rail manufacturers have made many major improvements in the metallurgy of these items over the years, but there is little opportunity to make further improvements, and the interaction of the wheel and rail must now be improved.

CURRENT ACTIVITIES

Three specific means to improve the steering behavior of railway vehicles are under development.

1. An all new truck is being tested by the research department of the Canadian National Railways (Figure 1) (2, 3, 4). This design provides for a steering motion of the wheelsets in curves and a damping of the wheelset hunting. This truck was designed with the aid of computer studies of curving and stability, and the tests are confirming the computer predictions in both areas. The running position of the axles under loaded car conditions is nearly radial in curves up to 6 deg, and there is a substantial reduction of the angle of attack in sharper curves. No wheelset instability has been observed at speeds up to 124 km/h (77 mph), the fastest test run performed to date.
2. A modified conventional freight car truck now designated the DR-1 (Figure 2) is being tested on the DOT test track at Pueblo. The parameters of this truck that govern curving and high-speed stability are virtually identical to those of the Canadian National test truck, but because these trucks use standard truck side frames, the radial curving is limited by the existing side frame clearances to about 4 deg of track curvature. However, there is still a substantial reduction of the angle of attack even in sharper curves, and therefore much lower values of flange forces than for conventional trucks.
3. A high-speed transit car that uses a positive steering arrangement in addition to the basic construction feature of the two truck designs described above (Figure 3) has been designed. The addition of the positive steering provides a greatly expanded range of radial curving and lowers the flange forces below the values achieved with the freight car designs.

All of these designs use load-carrying members similar to the side frames of conventional three-piece trucks. In addition, they use two members called steering arms, each of which is attached to the bearings of one of the axles. The steering arms are connected to one another in the center of the truck. This connection is flexible in the sense that it permits the yaw motion of the individual axles that is required for the axles to be radial in a curve:

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It is rigid in the sense that it transmits the forces generated by steering (and traction and braking) from one axle to the other, while allowing only small independent yaw movements of the axles.

All of these designs incorporate flexible means for transmitting weight from the side frames to the axles without excessive restraint on steering motion. In the simpler designs, this stiffness is the primary source of yaw stiffness. In trucks designed for transit cars, it is supplemented by the positive steering arrangement.

In all of these designs, the steering motions within the truck take place across elastomeric members that are not subject to friction and wear. The stiffness of these members has been chosen to give the desired curving and high-speed stability with the worn wheel profile that will exist for most of the service life of the vehicle so that the performance of these vehicles should not vary materially during their lifetime.

TRUCK STEERING MECHANICS

The steering problem can be summarized as consisting of two parts: the wear and noise associated with operation around sharp curves (Figure 4) and the wheelset hunting behavior. Recent theoretical studies and test work indicate that these problems can be solved.

In the mid 1960s, an increasing number of investigators (5, 6, 7, 8) began to analyze the dynamics of wheelsets and the flange-free steering of rail vehicles, and a series of experimental and theoretical studies with truck steering (9) was begun. All of these investigators agree that the wheel tread profile or conicity is an important component in determining the curving and stability characteristics of any truck, that low conicity reduces the hunting problem, and that high conicity increases curving capabilities and reduces wear.

However, the truck designer is really not free to choose a profile. There is a tendency for a common worn-wheel profile to develop that is independent of the initial profile. This profile has a slightly hollow shape that matches the profile of the rail head. Other profiles will have higher contact stresses and will wear more rapidly. A truck designer must accept this profile and choose the other parameters available to accommodate it.

The two major parameters that can be selected arbitrarily are the interaxle lateral stiffness and the interaxle yaw stiffness. Wheelset stability requires greater interaxle lateral stiffness than is available with a conventional three-piece truck. To improve curving ability, the interaxle yaw stiffness must be lower than that of conventional trucks. (Most theoretical studies of these two parameters are limited to the region of flange-free operation because of the mathematical difficulties involved in representing flange contact.)

The experimental studies of curving, however, have considered flange contact and show that, with high values

Figure 1. New steering-type freight car truck (Canadian National Railways).

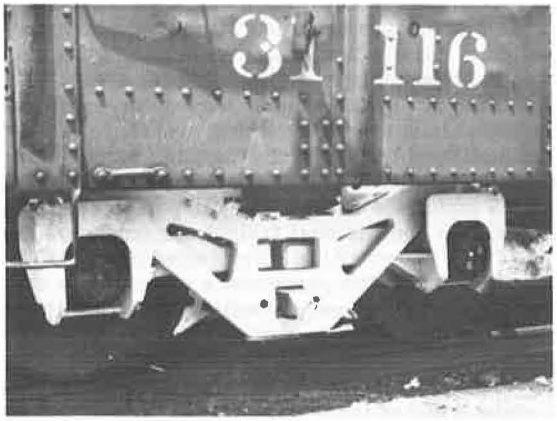


Figure 2. Three-piece freight car truck modified to include steering arms.

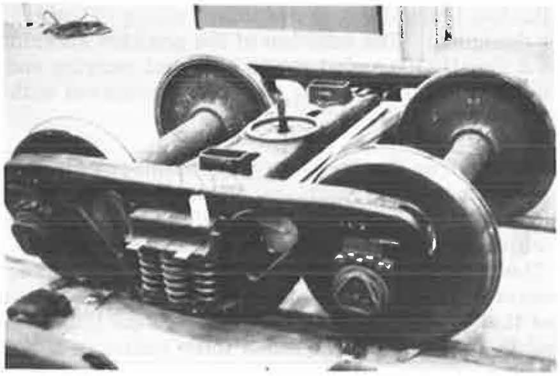


Figure 3. Model of radial type transit truck using a steering linkage.

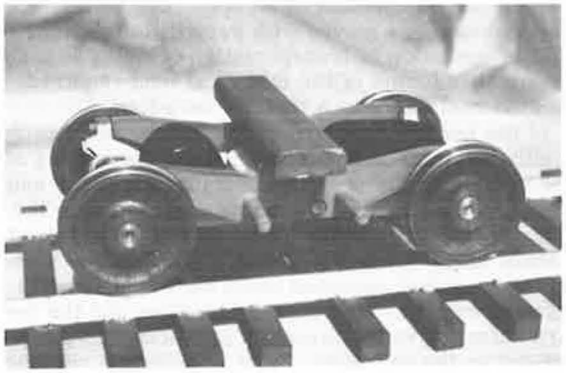
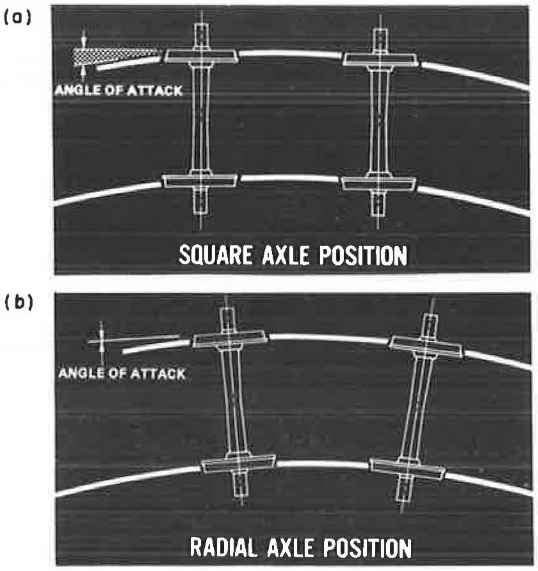


Figure 4. (a) Wheel-axle position of square truck, showing angle of attack; (b) wheel-axle position of radial truck, showing elimination of angle of attack.



of interaxle lateral stiffness, a pair of wheelsets tend to align themselves radially even with flange contact if the wheel conicity is insufficient to permit the individual wheelsets to run freely in a radial position. This self-aligning effect can be used by itself in a simple truck to provide the steering, or in a more sophisticated truck to refine the precision of a steering linkage.

It has also been shown experimentally and analytically that steering arms must be used to obtain the desired high value for interaxle lateral stiffness. If the axle restraints are only to a rigid frame, the contribution to the interaxle lateral displacement made by the rotation of the frame against the finite yaw stiffness between the frame and the axles will be so great that the interaxle lateral stiffness will not be high, even if the lateral stiffness between the ends of the axles and the frame is made infinite.

CONCLUSIONS

The accumulated experimental and theoretical data on the steering behavior of railway car trucks indicate that the truck designs described in this paper can effect a considerable reduction in wheel wear, rail wear, truck component wear and fatigue, car body component wear and fatigue, derailments, noise, traction power consumption, and constraints on the layout of rail transportation systems.

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