

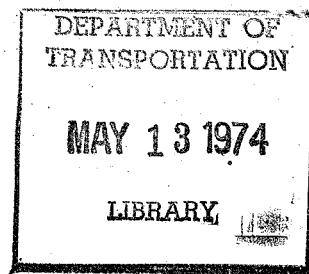
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Research Report



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DESIGN OF OUTLYING

RAPID TRANSIT STATIONS

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Figures 10 and 11 were obtained from the Hamburger Hochbahn AG, Hamburg, Germany; Figure 15 from the Toronto Transit Commission. Figures 5 - 9, 14 and partially 16 were developed by the author of this report, Dr. Vuchic, in preparation for the document [9]. All other figures were developed in the course of this research.

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I. INTRODUCTION

A. The Problem

Rapid transit lines serving low density suburban areas must rely on several types of feeder service since typically a relatively small number of persons can walk to the stations. Bus lines serve the medium density areas as collector-distributors for rapid transit; Park-and-Ride and Kiss-and-Ride are the dominant access modes in low density areas. They greatly increase the passenger shed areas of rapid transit stations.

New rapid transit lines in a number of cities have shown that bus, K+R and P+R*, but particularly the latter two, are very popular. Station parking lots with capacities of over 2,000 spaces have sometimes been filled to capacity requiring enlargement in order to provide maximum accessibility to the line.

Rapid transit stations** with parking areas for several hundred or even several thousand spaces, typically have very sharp peaks of access traffic, present a major, very complex design problem completely different from the designs typical for stations with walking and surface transit access only. Relatively little importance has been given to the design of these

* For convenience in this report, the terms Kiss-and-Ride will be designated as K+R, Park-and-Ride as P+R.

** "Station" refers in this report not only to the station building, but to the facilities, roadways, and parking areas affiliated with it.

stations although the importance of this problem is rapidly increasing. Firstly, investments in stations are substantial and later changes are extremely costly. Secondly, a design which is not adequate for the complex requirements of such objects can create major traffic problems, discourage potential patronage, and have negative environmental aspects on the whole surrounding areas.

B. The Station Design Procedure

Organization of transit station planning and design procedure and role of typical procedure consists of the major steps shown schematically in the diagram in Figure 1.

Transit line planners decide on alignment and location of the station, and determine projected volumes of passengers by access mode, as listed in Box 1 in the diagram. While, naturally, in planning the line and determining the submodal split they have to take into account the local conditions, land use, highway network, etc., they do not make detailed analyses of the immediate area around the station. The designer therefore must supplement these basic data obtained from the planners of the line by the data on the existing and planned facilities relevant to station design (listed in Boxes 2 and 3) from various other sources, such as department of highways, transit agency and city planning agency. Based on these three groups of information, the station designer must put together composite projections of traffic on adjacent streets and highways for each mode (Box 4).

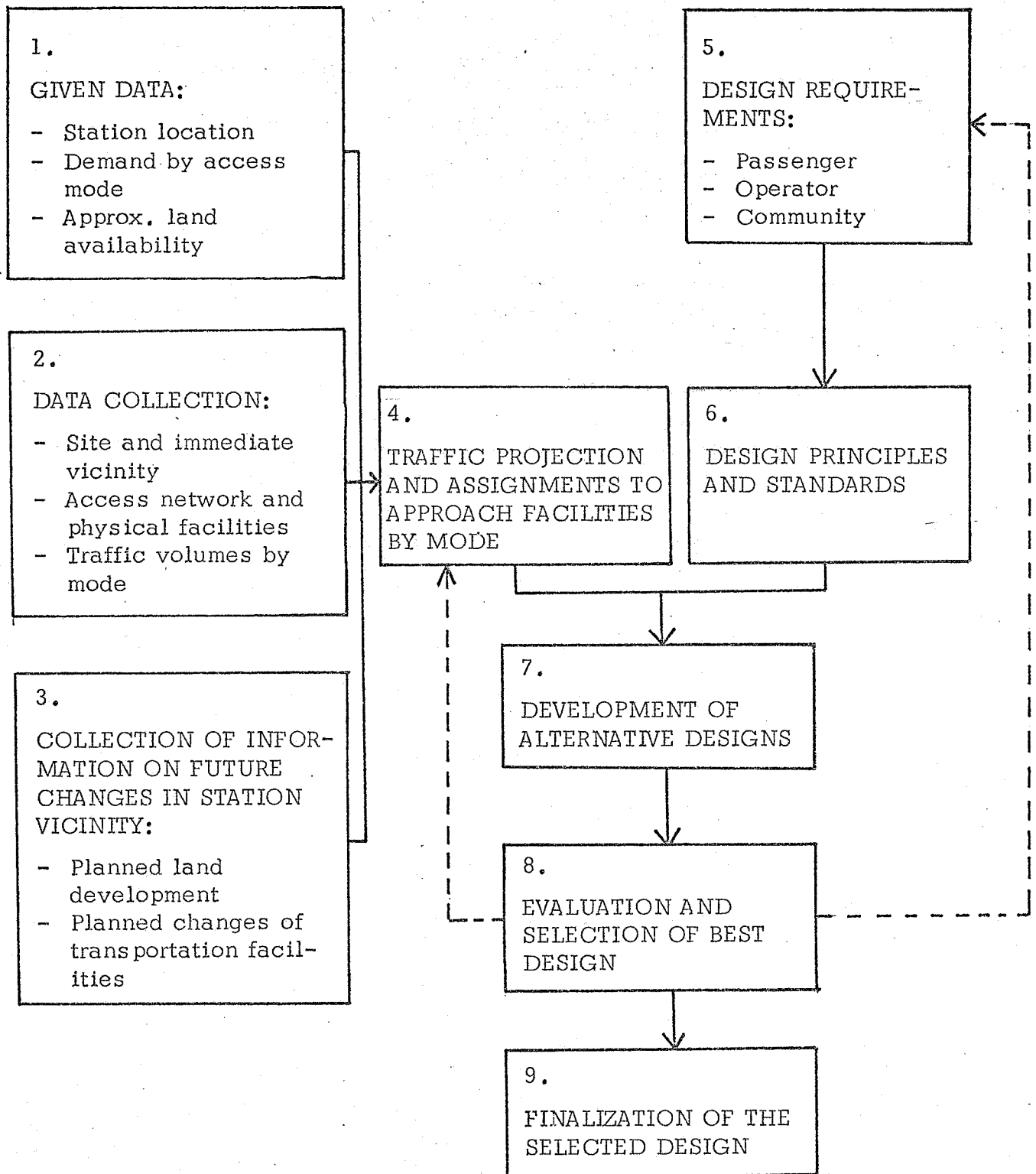


FIGURE 1. Station Design Procedure

On the other side the designer must have a systematic and detailed list of requirements as well as the principles and standards for station design which he directly uses in the design (Boxes 5 and 6).

Combining the data, principles and standards, the designer makes several alternative station designs (Box 7). The next step is evaluation of these designs based on the degree they satisfy the design requirements and principles as well as their adequacies to handle projected volumes (Box 8). After the evaluation the design is finalized (Box 9).

C. Purpose and Scope of Study

This Study has three primary purposes. The first purpose is to define a methodology of design of outlying rapid transit stations in such a form that designers can utilize it in actual planning and design procedure. The second purpose is to collect and systematically present basic principles and standards of design for outlying stations.

The third purpose of the study is to present actual solutions for design of the individual components of stations: the basic traffic flow patterns, relationships of functional areas, geometric dimensions of roadways, surface transit stops, parking areas, and the like. Finally, a complete design of an outlying station based on the developed principles is presented.

The scope of this Study, limited to physical design of stations, basically follows the procedure presented in Figure 1 above. It is assumed that the data in Box 1 are given. Chapter II discusses together the collection

of data listed in Boxes 2 and 3, which the designer must collect.

Derivation of the composite design volumes (Box 4) is also mentioned in that Chapter.

Chapters III and IV, covering respectively design requirements (Box 5) and principles and standards (Box 6) represent the main body of the Study. These two chapters contain a number of innovative approaches, design principles and solutions, which represent the basis for development of alternative designs (Box 7).

The procedure of evaluation and finalization of the design cannot be discussed very well in any general way. Boxes 8 and 9 are therefore not discussed as such; instead, Chapter V presents an "ideal station design" and several examples of very successful designs which have been built in several cities.

II. DATA COLLECTION

The first step in design is collection of data which directly or indirectly influence the planned object. In this case, the data which should be collected can be classified in several categories. They are defined here.

A. Site and Immediate Vicinity

The designer should have at least some influence on the land acquisition and future shape of the station. Since these depend on the cost of land, local conditions, projected demands and sub-modal split of access, the designer must collect information on land costs for each lot which may be considered for acquisition. In addition, data on topography and the general condition of the area (such factors as other rights-of-way, land uses, trends of expansion, etc.) must be obtained. It is also assumed that the designer is given a general orientation about the total investment available for land and construction of the station.

B. Access Network and Physical Facilities

All available data relating to transportation networks land use in the area and to individual physical facilities should be collected. These include maps of the area, detailed designs of individual facilities and existing plans for any significant changes and improvements.

Particularly, detailed data must be collected on the following facilities:

1. Highway and street network with basic dimensions of the facilities in the vicinity, capacities of individual streets, traffic regulation of them, etc.
2. Transit services with routings of feeder lines, type of service and type of vehicles used on them.
3. Pedestrian facilities.
4. Facilities for other access modes which may be utilized in some cases, such as bicycles, organized car pools, shopper buses, etc.

C. Traffic Volumes

Separate data must be collected for three categories of traffic:

- present traffic on existing highways and other facilities;
- projected traffic expected to be generated by planned developments in the area other than the station;
- traffic generated by the station.

For each one of these three categories the following items must be collected and/or developed:

- volumes for each mode;
- average daily traffic (for weekdays and, in some special cases, for other days if peaks may be expected by recreation or sporting or the like).

The next step is to combine the existing traffic volumes for each mode with the volumes projected for other planned developments, and those to be generated by the station. These composite volumes, assigned to individual facilities, must be analyzed for all hours which may be critical. The highest are then used for design.

At most outlying rapid transit stations there are four basic access modes. They are: walking, feeder transit (usually bus), K+R and P+R. In addition to these categories, at some stations a significant percentage of patrons may approach the station by bicycle, motorcycle, taxi or various kinds of shopper buses, dial-a-bus, etc. If usage of any of these modes is substantial, or is anticipated to be substantial, they should be treated separately. Buses and bicycles may require adequate terminal facilities and in some cases special lanes or paths; taxis can usually be handled together with K+R vehicles, but in exceptional cases there may be special terminal facilities for them.

III. DESIGN REQUIREMENTS AND CONSIDERATIONS

Operation of transportation systems depends very heavily on the operation of their terminals. Delays and irregularities in service can easily be created if terminal operation is deficient; on the other hand, properly designed and operated terminals insure high reliability of system operation.

In addition, since times at terminals affect vehicle travel time on the system, total operating cost is also directly affected by terminal operations.

From the passenger's viewpoint, terminals are not less important. It is known that passengers are extremely sensitive to all mode transfers. Systems which have well designed terminals and coordinated services by different modes have demonstrated good acceptance of transfers by passengers. If on the contrary transferring represents a slow, uncomfortable or unsafe process, it has been observed that a substantial number of passengers will consider that a sufficient reason to avoid use of the whole system. Consequently, it is imperative that extremely careful studies of all relevant requirements be done in the course of station design. These requirements, listed and briefly defined here, are classified by the major concerned parties: passengers, operator, and community.

A. Passenger Requirements

Passengers approaching station by walking have the following basic requirements with respect to station design:

1. Minimum Transferring Time and Distance

Passenger paths between the two modes of their transfer should be as short as possible, and their movement on that distance should be subject to the minimum of delays. Waiting time for the second mode is included in transfer time, but it is basically not affected by station: it is a function of scheduling.

2. Convenience

The transferring process must be convenient for passengers. They must have convenient walking paths, clearly designated bus stops and easily accessible and available K+R or P+R facilities. Passengers must be able to orient themselves and quickly find all information they may need, as well as basic facilities (e.g. telephone, newstand, restaurant, etc.) without great effort.

3. Comfort

The transferring process of passengers should provide as much comfort as possible. This requirement includes such items as aesthetically pleasing exterior and interior of the building, boarding, waiting and parking areas and a minimum exposure to air pollution, noise of traffic and other offensive or abrasive elements. The requirement of comfort also includes minimum physical effort in transferring, i.e. a minimum number of stair-

ways and grades to negotiate and easy boarding and alighting of vehicles.

4. Safety and Security

Design must provide for maximum prevention of hazards to passengers with respect to their safety from traffic accidents, injury during boarding or alighting, slippery surfaces and steep stairways. The physical form of the station, the shape of its corridors and walls, and illumination of the building, and surrounding areas should be such as to deter crime and vandalism and facilitate policing to the greatest degree.

B. Operator's Requirements

All aspects of the station as they concern the system operation are included in this category. A number of them coincide or overlap with passenger requirements. An example of such joint concern is the general requirement for a high quality of service. However, from the operator's point of view there are a number of other requirements which should be satisfied or which sometimes require trade-offs such as minimum cost, adequate capacity and compatibility with the community. The most important requirements are listed and defined here.

1. Minimum Investment Cost

Investment cost is, naturally, one of the basic inputs in providing any facility, and it must be reconciled with other requirements on the system. For required capacity, physical characteristics of the station

and level of service, one attempts to build the station at a minimum cost. Included in this investment are costs of land acquisition and costs of construction of station and all objects and facilities which are associated with it.

2. Minimum Operating Cost

In general terms the operating cost for a station is the total cost of its regular operation and maintenance during a given period of time, usually one year. The number of regular operating personnel, supervisors, policemen and other personnel usually represent the major component of operating cost. This number can be influenced very significantly by the station design. Therefore, such features as types of entrances, ease of visual supervision of the surrounding area and interiors of station, as well as physical characteristics of various materials and mechanical items (such as fare collection machines) are of great importance in determining the resultant level of operating cost. A station can be operated without any regular personnel if the design has been based on full automation. It may require very little supervision and policing if visibility of the whole area is adequate and it may require a minimum of cleaning, maintenance and care if the materials utilized are durable and simple to either maintain or exchange.

3. Adequate Capacity

A basic prerequisite to satisfying requirements for quality of service and to adequately handling the expected volume of passengers is to provide

sufficient capacity for the peak traffic hours. Another requirement of capacity, based on the minimum investment cost and maximum efficiency requirements, is that individual capacities throughout the system be coordinated and well balanced. This insures an even utilization and a minimum of wasted capital on individual station components.

Capacity must be checked for a number of items: starting from adjacent intersections and entrances to the station area by buses and automobiles, through the terminal facilities to the station doors, ticketing areas, corridors toward the platform, stairways and escalators and finally platform itself.

4. Flexibility of Operation

The station design should allow the flexibility to make any reasonable and foreseeable changes in the type of operation. For example, if the ticketing procedure is changed, if charges for parking are introduced or if bus routings are modified, these should be possible without major investments in physical changes of the station and its facilities. Expansion of facilities, particularly parking, should also be foreseen.

5. Passenger Attractiveness

One of the basic goals of a transit system is to attract and serve the maximum number of passengers. Although this number is mostly a function of the general quality of service which has already been included in the preceding requirements, there are some additional aspects which should be given special attention. They include the visual aspects which

facilitate passenger orientation, facility of movement within the area, the "atmosphere" of the whole station (e.g. green areas, benches, fountains, incorporation of minor stores into the station complex), its simplicity for use and other elements which make passengers feel free to approach it and use the system. Although the importance of these items is quite difficult to quantify, there are numerous examples which clearly show that the differences in aesthetic and other aspects of stations have a major effect on passengers (e.g. Toronto and Montreal vs. New York and Philadelphia stations).

C. Community Requirements

The city or the community are interested in having an attractive and efficient transit system and therefore they desire that the station is both attractive to passengers and efficient for the operator. This comment largely coincides with the composite of the requirements listed above. In other words, if all passenger and operator's requirements are fully met, the city's requirements with respect to the type and function of stations will also be satisfied.

In addition to this, the community is interested in both the immediate and long-range effect of the station on its surroundings. The immediate effects include the environmental impact, visual aspects, noise and possible traffic congestion in the area. Long-range effects include type of developments in the vicinity which may be stimulated or discouraged

by the design of the station. Design must therefore include considerations for the relationship of the station with its immediate surroundings.

IV. DESIGN PRINCIPLES AND STANDARDS

Every rapid transit station must be "custom designed". Consequently, prototype designs cannot be produced. However, it is essential that the designer be familiar with general design principles which are valid for overall design as well as for individual components.

A. General Principles

The most important principles which are valid for a basic approach to the design of outlying rapid transit stations are listed here.

Principle 1: Priority should be given to individual station access modes in the following order:

- a. Walking
- b. Surface transit (feeder bus)
- c. Kiss-and-Ride
- d. Park-and-Ride

These are typically the four most important access modes. In some cases, however, several other modes may also be significant. Their priorities would then be:

- Bicycles should enjoy a priority between walking and feeder bus;
- Taxis should have less priority than buses, but enjoy preference over K+R;

- If there are both pay and free P+R lots, a pay lot should have higher priority than a free lot.

Principle 2: Maximum separation of the modes should be provided at all points. While separation of pedestrians from motor vehicles is the most important one, it is also desirable to separate buses from private cars, K+R from P+R, etc.

Principle 3: Minimize total access distance of all passengers between the access modes and the station platform.

Principle 4: Smooth and safe circulation should be provided to and within the station area for all modes.

Principle 5: Easy orientation for access to and movement within the station area should be provided.

Principle 6: Adequate capacity should be provided for each access mode for its design volume. Capacity should be uniform within given physical conditions for the whole passenger flow from access roads to the platform. In the case that there are space constraints, the capacity should be provided to individual modes in the order of their priorities. If capacity for P+R (which is often critical) is insufficient, greater emphasis should be placed on other modes to attract passengers and reduce demand for parking.

These general principles apply to the design of nearly all components. In the following sections these principles are elaborated, applied to individual station components and translated into design standards with illustrated examples.

B. Station Site: Size and Shape

Size of the station site depends mostly on the required capacity of K+R and P+R facilities. The desirable size should exceed the projected average weekly peak parking demand by 5 to 10%, since lots can never be 100% full without considerable inconvenience to users. Area required for parking including intrastation roadways, averages 300 to 450 square feet per space, depending on the geometry of the site, greenery and other facilities in the parking lot. If there is a multistory parking facility, land required is correspondingly smaller.

A K+R area, requiring easier circulation than parking lots, takes more space per stall, but its operation is less sensitive to capacity constraints since the drop-off and pick-up of passengers can be performed at other locations close to the station (at curves on adjacent streets, for example).

The shape of the site is often influenced by the street network and land availability. Since the platform and station structure are typically 400 to 700 feet long and 50 to 60 feet wide, parking, circulation and terminal facilities can be grouped around the long, narrow station. Other factors being constant, the shape should be such that the weighted average walking distance of all passengers is minimal. Since this distance depends on the number and location of entrances to the station building, it is desirable to have more than one entrance

each of which should be strategically placed. This is easier to achieve in stations with full automation because it does not require increased station personnel.

Several examples of station site shapes are given in Figure 2.

C. Allocation of Areas to Different Modes

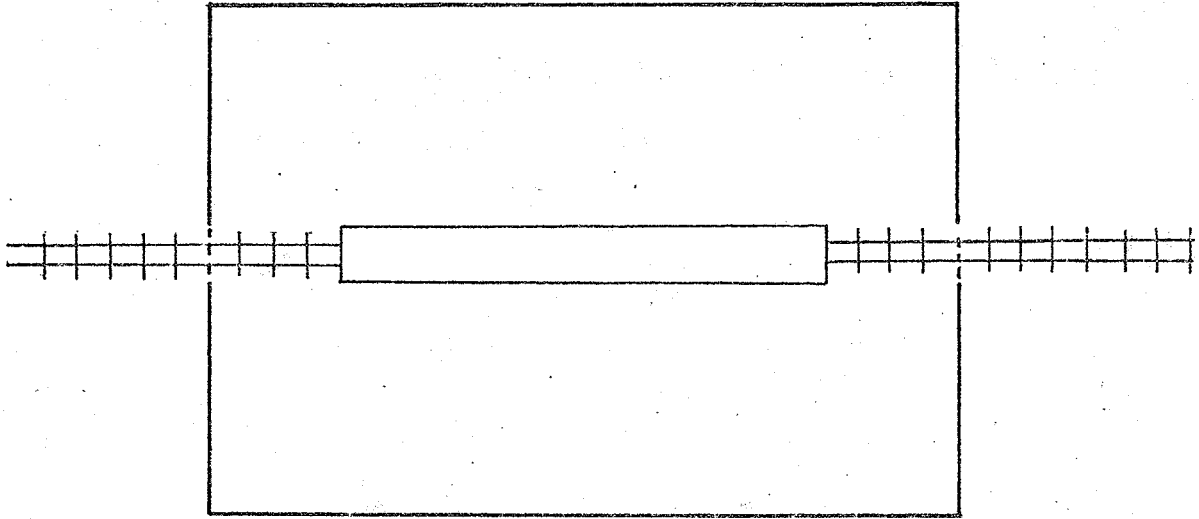
Following the basic principle of giving priority treatment to higher capacity modes (in the order: bus - taxi - K+R - P+R), terminal facilities for buses should be as close to the station entrances as possible (access by walking and bicycles should also be facilitated). Next in priority should be K+R area, while the most distant sections of the station areas should be used for parking.

Examples of area allocations to different modes are illustrated in Figure 3.

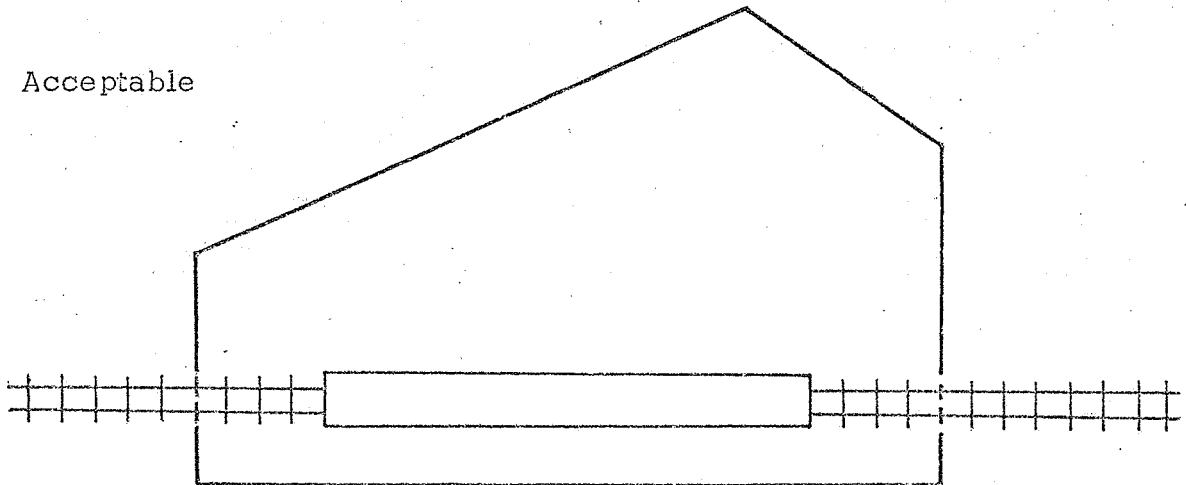
D. Traffic Routing and Access Points

Routing of traffic to and from the station must be analyzed with a determination of access points, since the two elements are interdependent. Two basic factors must be borne in mind;

- Each mode requires a different treatment;
- Each peak hour requires a separate analysis of volumes.



b) Acceptable



c) Unsatisfactory

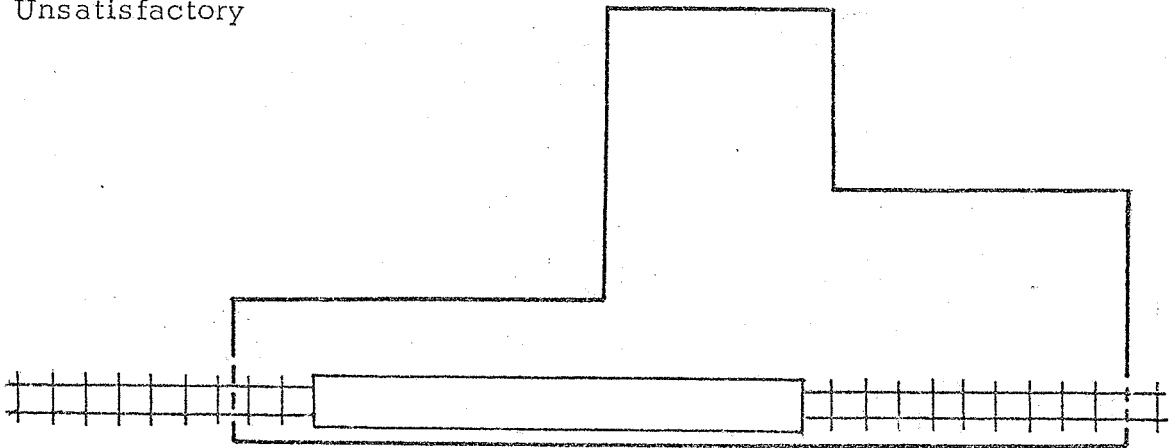


FIGURE 2. Examples of Station Site Shapes

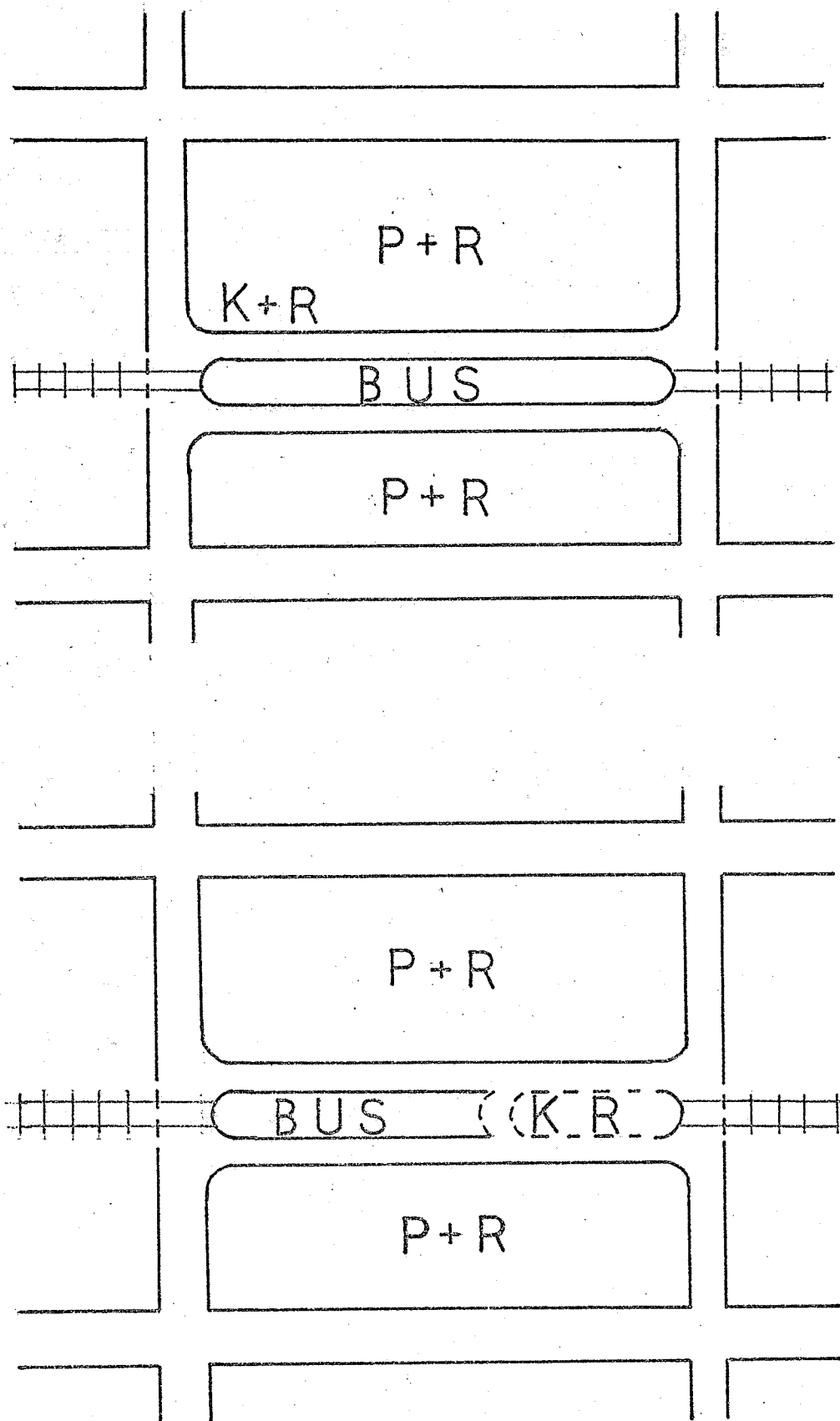


FIGURE 3. Area Allocation to Different Modes

1. Traffic Routing

The basic objectives in designing the routing pattern for all modes are:

- To provide as direct access for each mode to its terminal area as possible;
- To minimize conflicts of station-destined traffic with other highway traffic;
- To minimize traffic conflicts within the station area;
- To provide at least two possible choices for access so that drivers can recover their errors or avoid incidental congestion or blockage;
- To provide smooth, continuous flows within the station area.

Bus routings from each of their approach directions should be direct to the terminal area at the station building. Turnaround and storage areas should be provided if the station is a bus line terminal.

K +R should have direct access to its unloading/loading area. Its flow must provide for return in the same direction, i.e. a turnaround in the station area. K +R traffic is directionally balanced during each peak.

P+R often produces very high vehicular volume and is directionally highly unbalanced during the peaks. Routing for P+R traffic should therefore be based on a careful analysis of its flows.

2. Access Points

The number of access points is determined separately for each mode, subject to geometric and operational constraints of the network and the site. Ideally, buses should have 1 to 2 access points leading them to the station terminal area; K&R should have its own access points

leading to their terminal area; sometimes buses and K+R can share access points without major problems. Capacity of these points should be checked for the projected K+R volumes, as shown below for P+R design.

In determining the design volumes for P+R, each peak volume must be analyzed separately. The morning peak is typically less pronounced than the afternoon peak, but its importance may not be smaller for two reasons: first, people are in a greater hurry and more impatient in the morning than in the afternoon; and second, traffic backups which may occur will take place on adjacent streets/highways in the morning, but will be contained within the site in the afternoon.

The number of entrance/exit lanes for P+R and K+R must be determined on the basis of projected peak-hour volumes on fluctuations within the peak hour (if train headways are long, peaking of demand may be very sharp), and on the capacity of P+R and K+R facilities. The highest 10- or 6-minute (depending on design policy) volume should be computed and used as design volume.

Since demand characteristics vary from one case to another, it is not possible to establish uniform standards for the number of access lanes for any line or any city. In each case a separate analysis is required. A minimum of two access points (4 lanes) is desirable for adequate traffic flow, reliability in emergencies, etc. For larger lots when the capacity requirement governs, one pair of lanes per 300 spaces

is adequate for stations with high peaking. If peaks are less pronounced, this ratio may be as high as one pair of lanes per 450 spaces.

These ratios are valid only if parking capacity is based on the total demand for parking. If the capacity is lower than the demand, the relationship between parking lot size and access lanes is more complicated. The demand may have a very sharp peak and then "disappear" because of the capacity constraint.

With respect to locations of access points, three major factors should be considered. First, access points should not be located directly on major arterials, since they may cause conflicts between through traffic and station-destined traffic. Access points on minor streets allow some dispersal of traffic and better control of it at the intersections with arterials. Second, the access points should be as evenly distributed to different sides of the station as possible to provide a balanced distribution of traffic to adjacent streets and to avoid an overconcentration of traffic at one point. And third, access points and major circulation routes should be located closer to the periphery of the parking area to minimize vehicle-pedestrian conflicts.

Access points for K+R and buses should, on the contrary, be placed closer to the station building to allow passenger loading/unloading to and from the central island.

A schematic representation of optimal access locations is illustrated in Figure 4.

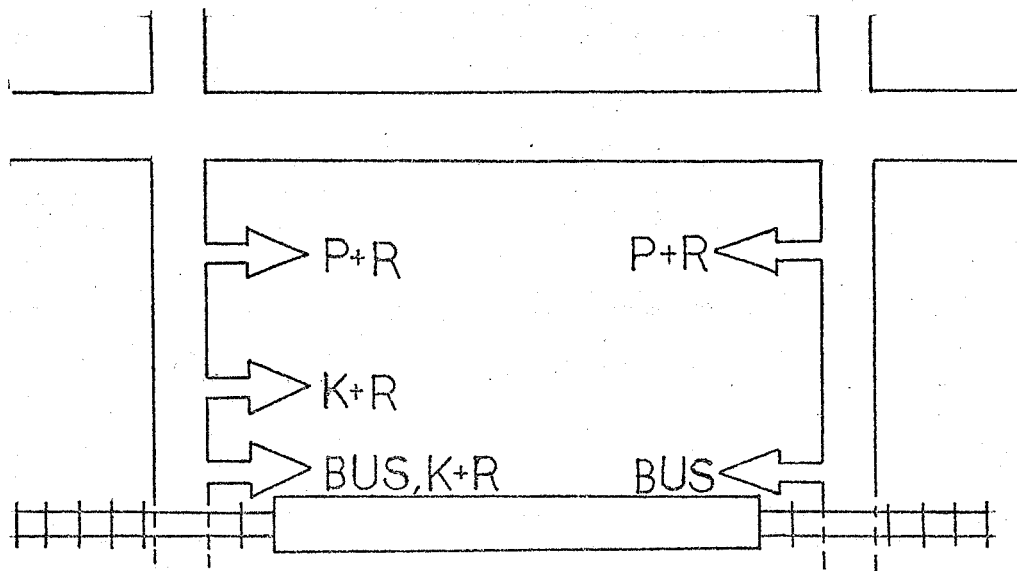


FIGURE 4. Schematic Design of Optimal Access Locations

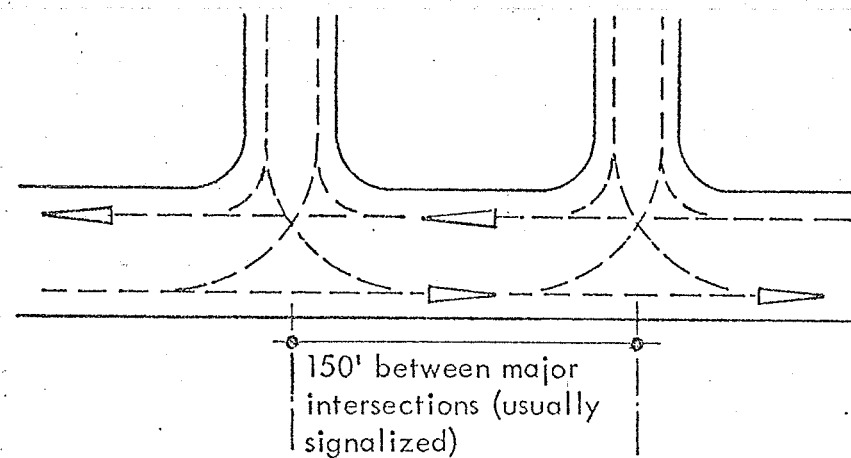


FIGURE 5. Weaving Movement at Access Points

Design of access points is usually similar to a "T" or a four-leg intersection. Reversible lanes can often be efficiently employed because of heavily directional peak flows. Special attention should be given to the provision of adequate storage space for both entering vehicles in the morning and exiting traffic during the afternoon peak period.

Weaving movements often result from two or more access points along the same street. A minimum distance of 150 feet should therefore be provided between all access points, even minor streets (Figure 5). However, a better way of avoiding the problem of weaving traffic is to provide directional access points which prevent the overlapping of flows from different directions, thus avoiding any weaving. This type of solution is shown in Figure 6. The separation of left turns "in" from left turns "out" of the station eliminates the need for 3-phase signal operation and results in increased capacity.

Access points providing only a limited number of movements, particularly right turns in and out of the parking area, can often be provided at several places without geometric problems. If properly located and designed they do not cause traffic flow and safety problems, and yet they can be very effective in reducing volumes at major access points.

E. Pedestrians

In accordance with the basic principles of design, pedestrians should be favored over other modes of access to rapid transit stations.

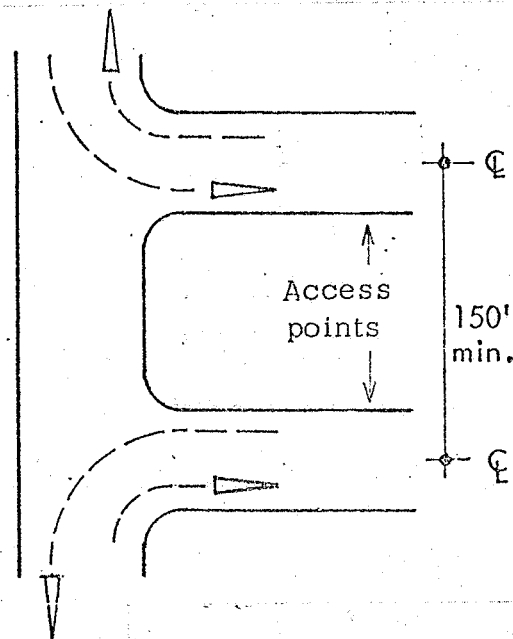


FIGURE 6. Separation of Movements to Different Access Points

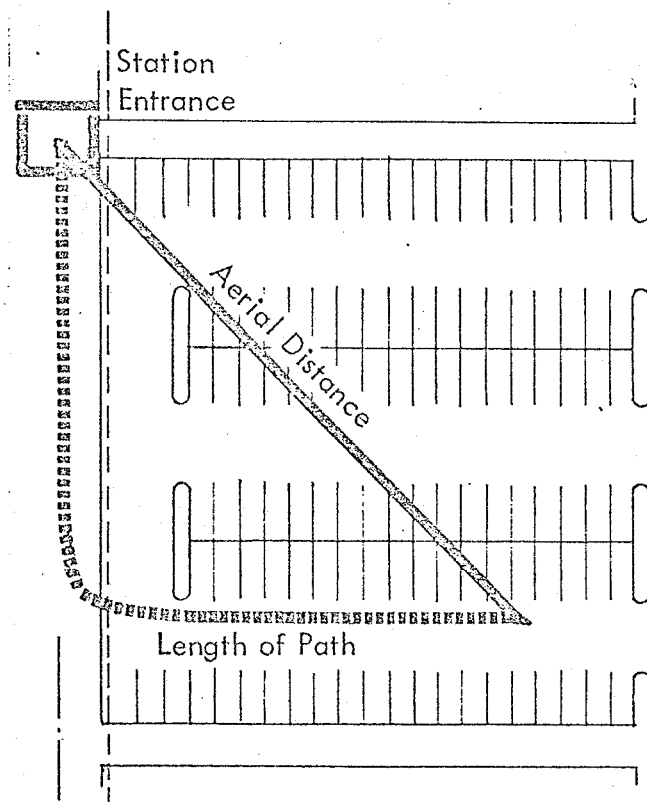


FIGURE 7. Directness of Walking Path

This is achieved by providing a complete continuous network of pedestrian walkways throughout the station area. The network must connect all adjacent streets, residential areas, stores and other locations which attract pedestrians, as well as the whole P+R and K+R areas. The walkways must be separated from automobile and other mechanized traffic as much as is reasonably possible. Their crossings should be carefully designed, well marked and if necessary, controlled by signs or signals.

To minimize walking distances from the surroundings and from the parking areas, it is desirable to have two entrances to the station since passengers accept walking within the station building more willingly than walking through parking areas to the station.

It is known that pedestrians will not follow paths if they are very indirect or inconvenient. It is therefore necessary to provide paths which are as direct as possible. The coefficient of directness, i.e. the ratio between the actual length of the path and the aerial distance from origin to destination of each passenger should not exceed 1.4, but it should be desirably kept below 1.2. Measurement of directness is shown in Figure 7.

It is desirable that walking distances to the most distant points in the parking lots should be kept to less than 800 feet; but in exceptional cases that distance may be as high as 1200 feet or close to a 5-minute walk. Naturally, these values are maximal and they should always be avoided when possible in design. Construction of parking garages should be considered for reduction of walking distances in such cases.

Specific designs of pedestrian paths within parking lots will be discussed in the section on P+R area design. A pedestrian lane width of 27 inches is considered as a minimum, 30 inches being the desirable dimension. Pedestrian walkways should have at least two lanes, i.e. they should be at least 60 inches wide. Pedestrian crossings of streets are usually 9 to 12 feet wide, although very low or very high pedestrian volumes may justify narrower or wider crossings, respectively. Crossings which are more than 50 feet long (across 4 or more lanes) should be provided a refuge area in the street median for better safety and capacity of both the walkway and the street, as shown in Figure 8.

It is extremely important to design individual areas and internal station circulation so that the greatest concentration of pedestrians is separated from the greatest concentration of automobiles. In other words, the main circulation road in the parking area should be far from the station, feeding the lot from the outside, while pedestrians gravitate toward the station building, as shown in Figure 9.

Undercrossings or overcrossings for pedestrians are seldom economically feasible in suburban areas due to low passenger volumes. However, at the station entrance the concentration of pedestrians can increase and sometimes reach volumes which justify a grade separation. Compared with an overpass, the tunnel or undercrossing for pedestrians has the following advantages and disadvantages:

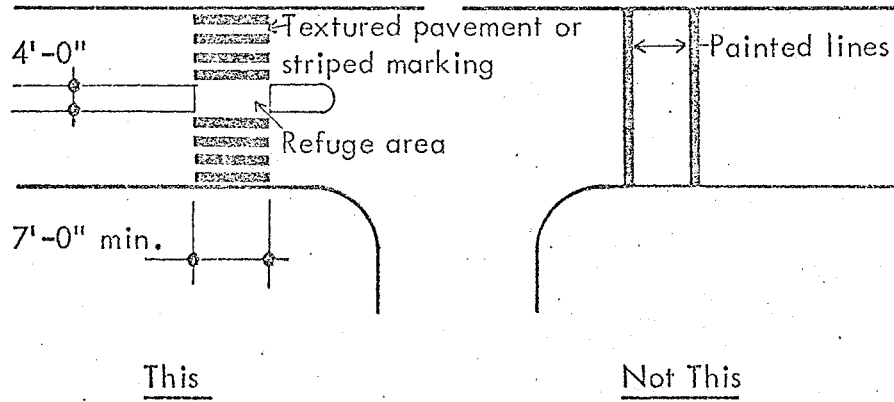


FIGURE 8. Recommended Pedestrian Crossing

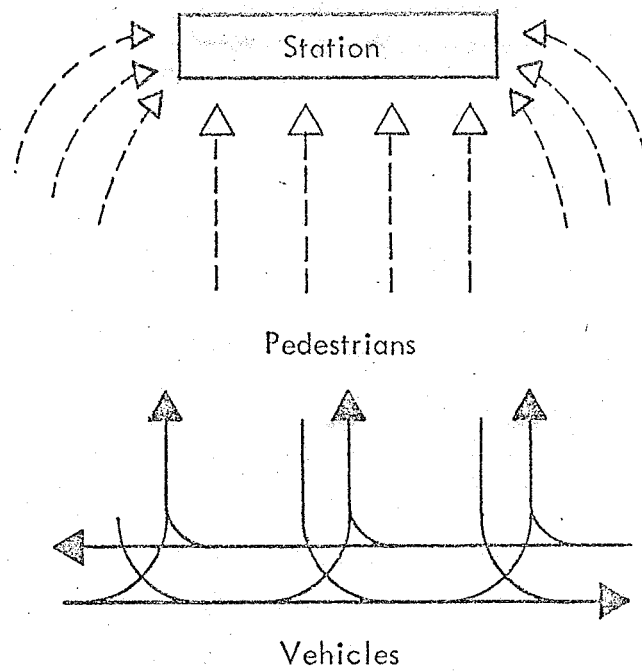


FIGURE 9. Separation of Vehicular and Pedestrian Flows

- + It requires a smaller vertical distance to negotiate, since the height of pedestrian instead of height of highway vehicle governs.
- + It is protected from the weather.
- + It is easier to install escalators.
- + It can be better incorporated among internal areas in the station.
- It is more costly to build and to maintain.
- It may present security problems.

F. Bicycles

All suburban rapid transit stations should have bicycle racks at which transit patrons can lock their bicycles. In many cases if the use of bicycles is not heavy, no other facilities are required; however, if there is a potential for greater use of bicycles, efforts should be made to encourage their use, since their use may result in a reduced requirement for parking and result in considerable savings in station construction and operation. Special facilities for bicycles include bicycle paths and sometimes special crossings with signalization. The paths can vary from a special marking on a street to special designed and built bicycle paths with an alignment not necessarily paralleling highway alignment. Bicycle paths can negotiate much tighter curves and steeper grades, thus requiring little space and construction costs. The minimum width of a two-way bicycle path should be 5 feet, but a more desirable minimum dimension is 6 feet.

G. Feeder Transit

Since feeder transit vehicles (in most cases buses , although most of the following analysis does not depend on that mode) bring large numbers of people , transfer between feeder and rapid transit should be made as easy as possible . Bus routing and terminal locations should therefore be designed for reliable operation and passenger convenience .

1. Access Routes

Access routes for buses from major arterials into the station areas must be carefully analyzed . Very often it is desirable to provide either separate turning lanes or special bus signals for turning movements into and out of the station . The routes should then approach the station with a minimum of turns and interference with other flows . Their boarding areas should be immediately adjacent to the station building .

The number of bus loading bays depends on the following factors:

- The number of bus feeder routes;
- The frequency of service on each route;
- Passenger boarding and alighting times , which depend on bus capacity , type of fare collection and design of the loading areas;
- The required reserved spaces for storage of buses ; and
- Provision for future increase in the number of bus routes .

2. Feeder Line Stops

It is desirable to provide a separate bus bay for each route . However , if some routes have very low frequency , they can often share common bays ,

thus reducing the total length of the bus stopping area. Some increase in capacity can be achieved by separating the arrival from the departure areas, since in that case buses can be kept in the storage area during terminal recovery times. Boarding and departure times can be maintained with greater precision.

3. Routing of Buses in the Station Area

Since regular bus stops on two sides of the street would necessarily require that pedestrians in one of the two directions cross the street to come to the station, this arrangement is not satisfactory at stations with considerable volumes of passengers arriving by bus. The design should provide that the buses drive into a special area where passengers can alight and board. When the station is alongside an arterial and bus routes just pass the station rather than terminate at it, their stopping zone can be either in a wide median or on one side of the street, with the two directions criss-crossing themselves, thus allowing that all passengers be discharged to or picked up from an island. From the island it is desirable to have stairs up or down into the rapid transit station. If the station area is narrow and long, it can accommodate only buses passing through it. In most cases, however, some bus routes terminate at the rapid transit station and it is therefore necessary to have a loop arrangement. Again the entering buses cross the path of the exiting buses and circle around the island in a clockwise direction. At stations to which more than one bus route arrive, it is desirable to have a closed round roadway which permits arrivals from

more than one direction and departures in the same direction with a continuous one-way flow in the station. This roadway can be a rectangle, such as is shown in the illustration from the Billstedt station in Hamburg (Figure 10), or an oval roadway (Wandsbek, Hamburg - Figure 11) with very similar operation. The circular roadways must be at least two lanes wide to allow passing, and there must be an additional lane for storage of buses waiting during their terminal times or prior to the peaks. The oval shape allows better visibility of bus stops for all routes from any points along the island, while the advantage of the rectangular island is that the vehicle paths are more regular and the driving of vehicles as well as their approach to curves are simpler. Either of these two types allows for bus arrivals to one side, where alighting takes place; then the buses are placed in the storage areas and called back at the time of their scheduled departures. The benefits of this are that there is a one-way flow of passengers on the island and a better utilization of curb loading capacity.

In some cases, when the number of buses is very large, it may be difficult to accommodate the needed number of bus bays around a single island. In that case two islands may be provided, with such dimensions that buses can drive around either of them. Bus boarding and alighting areas are thus doubled, with the problem that pedestrians must either cross the middle roadway or special stairways (escalators) must be provided for them from each of the two islands. The suggested design is shown in Figure 12.

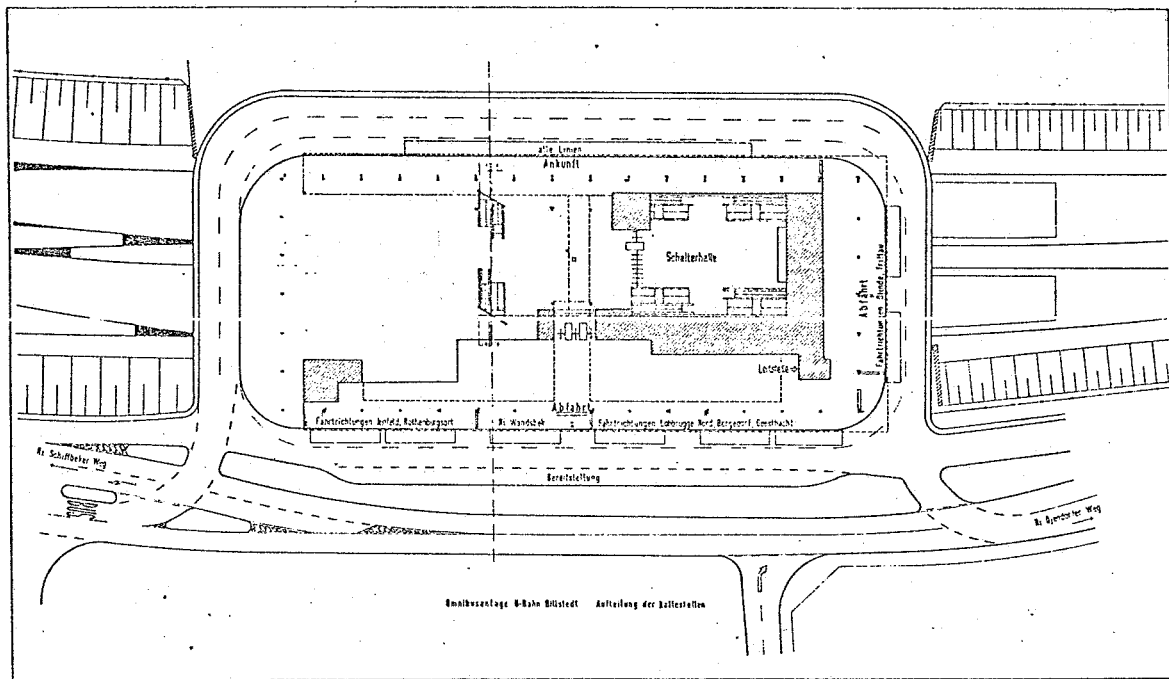


FIGURE 10. Rectangular Bus Island (Hamburg - Billstedt)

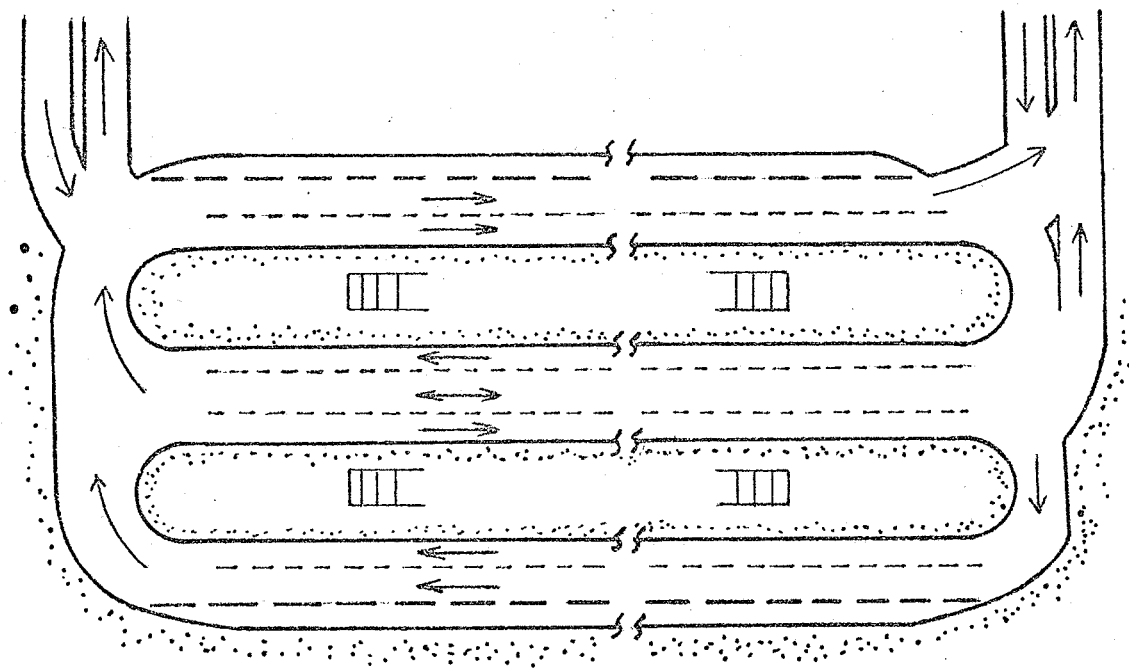
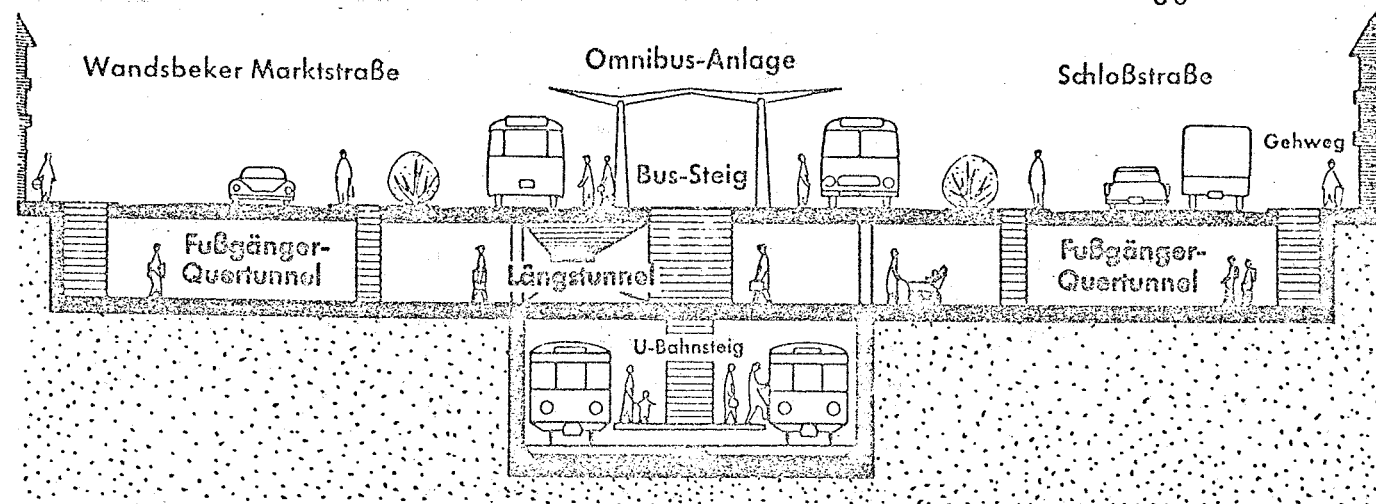


FIGURE 12. Suggested Double-Island Design



Fußgängertunnel-Anlagen



Kennzeichnung

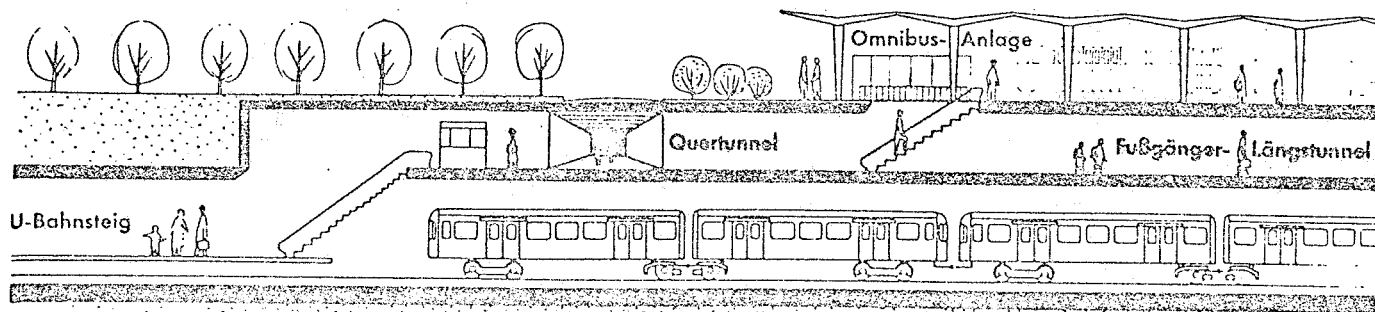
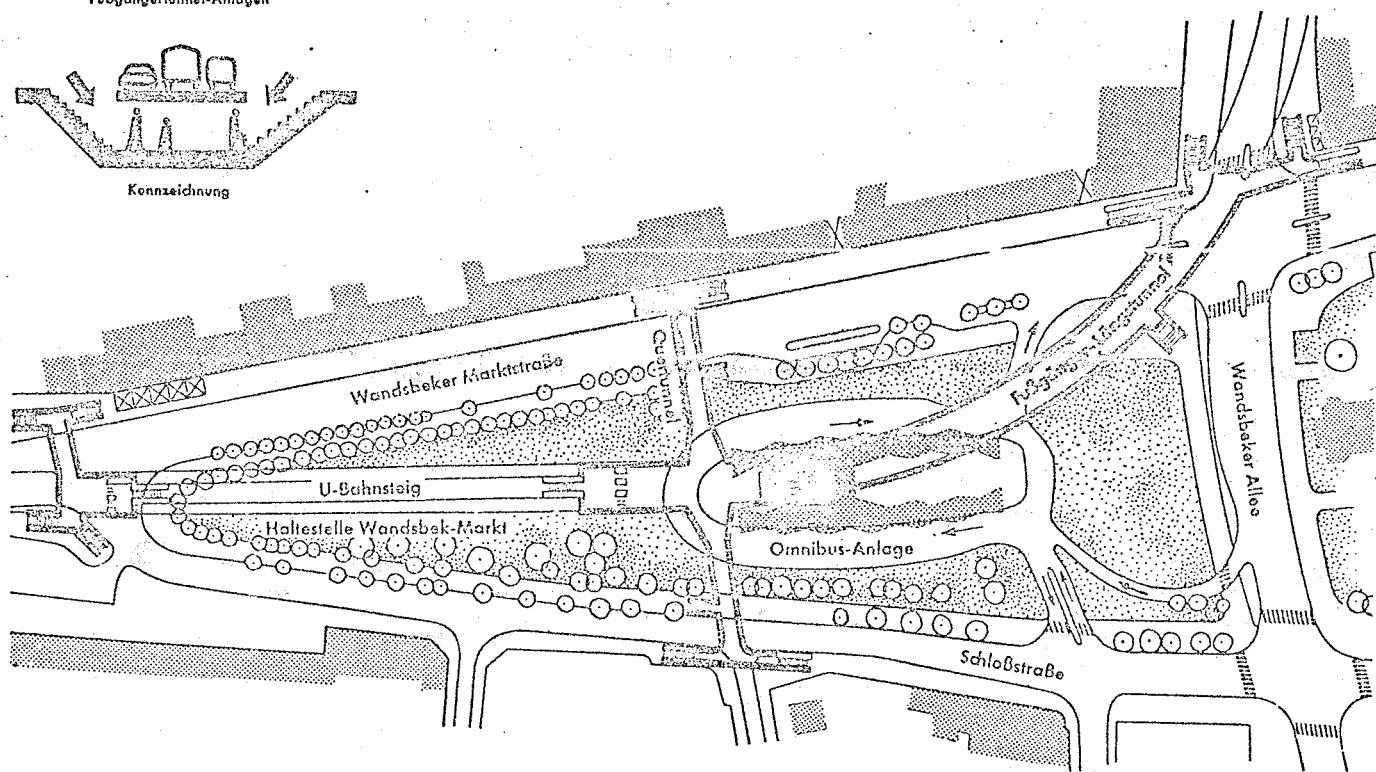


FIGURE 11. Oval Bus Island (Hamburg - Wandsbek)

Although straight or lightly curved curbs can serve as boarding areas, the problem of bus arrivals exactly to the curb always exists because of their geometry so that considerable spacing between buses cannot be utilized. The design which permits better utilization is the sawtooth pattern applied with success at several Cleveland Transit System stations. They are adjusted to the geometry of bus arrivals and departures and their dimensions are shown in Figure 13. This design also allows good visibility of all stop locations by the passengers standing in the vicinity.

While driving bus lanes should regularly have a width of 12 feet, their lanes for stopping may have only 10 to 11 feet. Minimum turning radii of different models of standard 40-foot long buses are:

Inside rear wheel: 19 - 29 feet

Outside front wheel: 36 - 44 feet.

Lengths of buses of different capacities and the needed curb lengths for one or two adjacent stops of these buses are given in Table 1.

TABLE 1. Curb Lengths for Bus Stops with Independent Arrivals/Departures

Approximate Bus Seating Capacity	Typical Bus Length F	Curb Length		
		Single Stops		Double Stops
		E	E	T
≤ 30	25	125		150
30 - 40	30	130		160
40 - 46	35	135		170
≥ 46	40	140		180

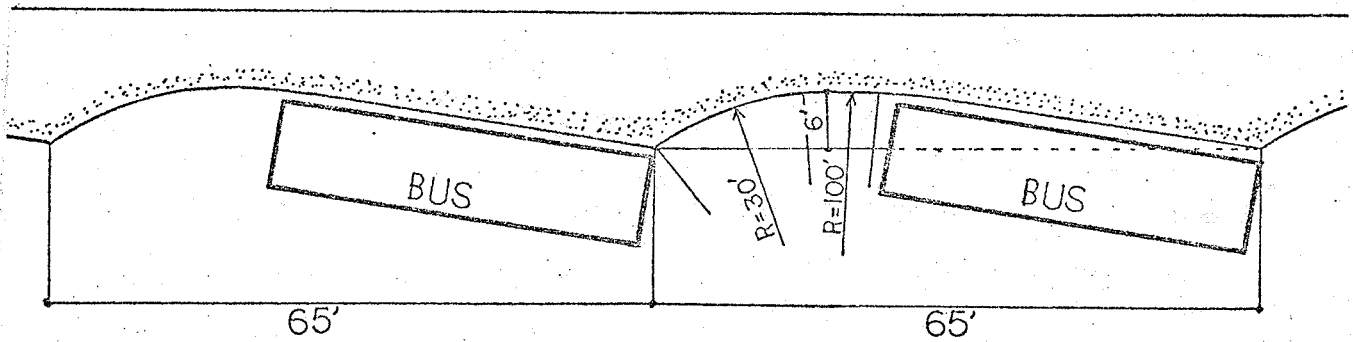


FIGURE 13. Saw-tooth Bus Loading (Cleveland - modified)

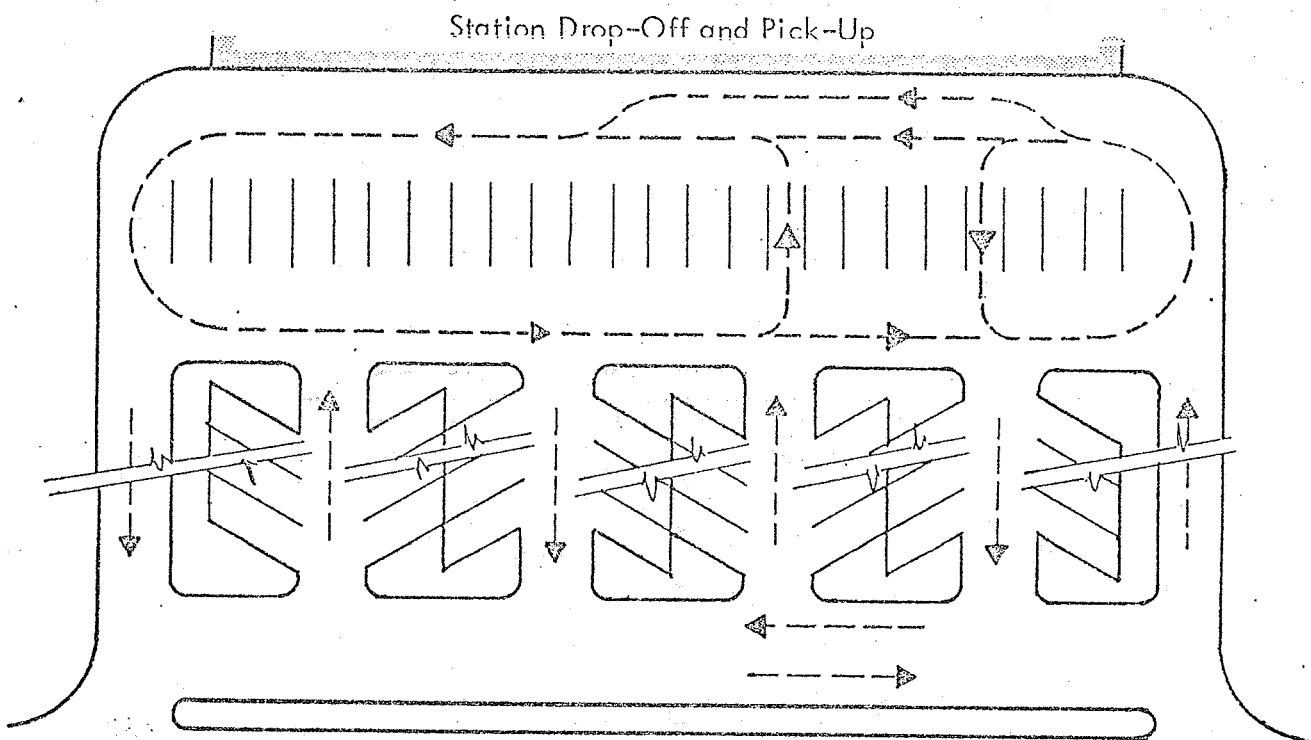


FIGURE 14. Layout for K+R and Short-term Parking

H. Kiss-and-Ride and Taxis

While taxi as a mode of access to rapid transit stations is in most cases rather limited and can be handled by a specially reserved curb, K+R has become a major access mode at many outlying rapid transit stations. A survey of the Cleveland Rapid Transit System showed that at the West Park Station there were 15% of passengers who came by K+R. The San Francisco BART study estimated that K+R will represent 10 to 30% of all patrons, while the Lindenwold Line has as many as 43% of all riders approaching the station by K+R. Shirley Busway records 8% K+R patrons.

K+R has two distinctly different functions. In the morning passengers are dropped off. This procedure is very short, averaging 10 to 30 seconds, unless the passenger waits for the train in the car which is the case of some suburban railroads with very long headways. The drop-off function can therefore be satisfied by sufficiently long curb space close to the station entrance.

The pick-up function in the afternoon hours is different, because the driver usually arrives some time before the passenger. It has been observed that the waiting time is often up to 15 minutes. The average waiting is longer on high frequency lines because approximate times are agreed upon for the meeting, rather than the exact train, which is the case on the lines with long headways. The K+R pick-up in the afternoon requires therefore not only a curb zone, but also a special short-term

parking area which should be easy to drive in and out of because of the likely very high turnover of cars. Thus K+R areas should be designed as angle parking and allow the driver to pull into the stall and then drive forward out of it, avoiding the backing up procedure. This, naturally, requires considerably greater space per stall, so that it can be afforded only when ample space is available. Another important consideration is that the driver in the car should desirably have a view of passengers coming from the station and vice versa, that passengers from the station can easily see the waiting cars.

Based on these characteristics of the drop-off and pick-up procedures by taxi and K+R, the following principles should be observed:

1. There should be one K+R area easily accessible for automobiles from all directions and by walking to the station building.
2. A drop-off and pick-up zone, preferably with loading on the right hand side, should be sheltered. Where possible, the aerial structure should be used for this purpose.
3. The K+R area should be laid out for one-way traffic and permit convenient return to the direction of arrival.
4. A parking area for persons waiting to pick up passengers should be located close to the pick-up zone to give good visibility of the station exit, and permit easy recirculation.
5. The K+R lot may be used for short term parking (shoppers, etc.) during the day, but must be cleared from approximately 4:30 to 7:30 p.m.

6. K+R parking stalls shall be a minimum of 9'-0" x 18'-0".

An interesting example of the design which permits continuous flow of K+R traffic is shown in Figure 15. The design provides that the driver who does not find his passenger remains in the station area and can either park or make another circle. This design, proposed for the Finch Station in Toronto, provides also the drive-through parking stalls for K+R and taxis.

I. Park-and-Ride

P+R is another access mode which is being increasingly used for access to outlying rapid transit stations. There are stations at which more than 50% of the transit passengers use P+R, while the average for the whole Lindenwold Line amounts to 37%.

Capacity for P+R facility is rather difficult to plan with any degree of precision. Due to the cost involved in land acquisition and construction of a P+R facility overdesign should be avoided; on the other hand, inadequate capacity in a number of cases has proved to be a bottleneck in the full use of the transit line, thus limiting its effectiveness. Whenever possible, the station should have P+R capacity based on a careful estimate of demand, while additional land should be purchased immediately for potential expansion of the facility. While the cost of a P+R facility is rather high, it is much more economical from the social point of view to provide that facility in the outlying area rather than have potential patrons drive and park in the city center.

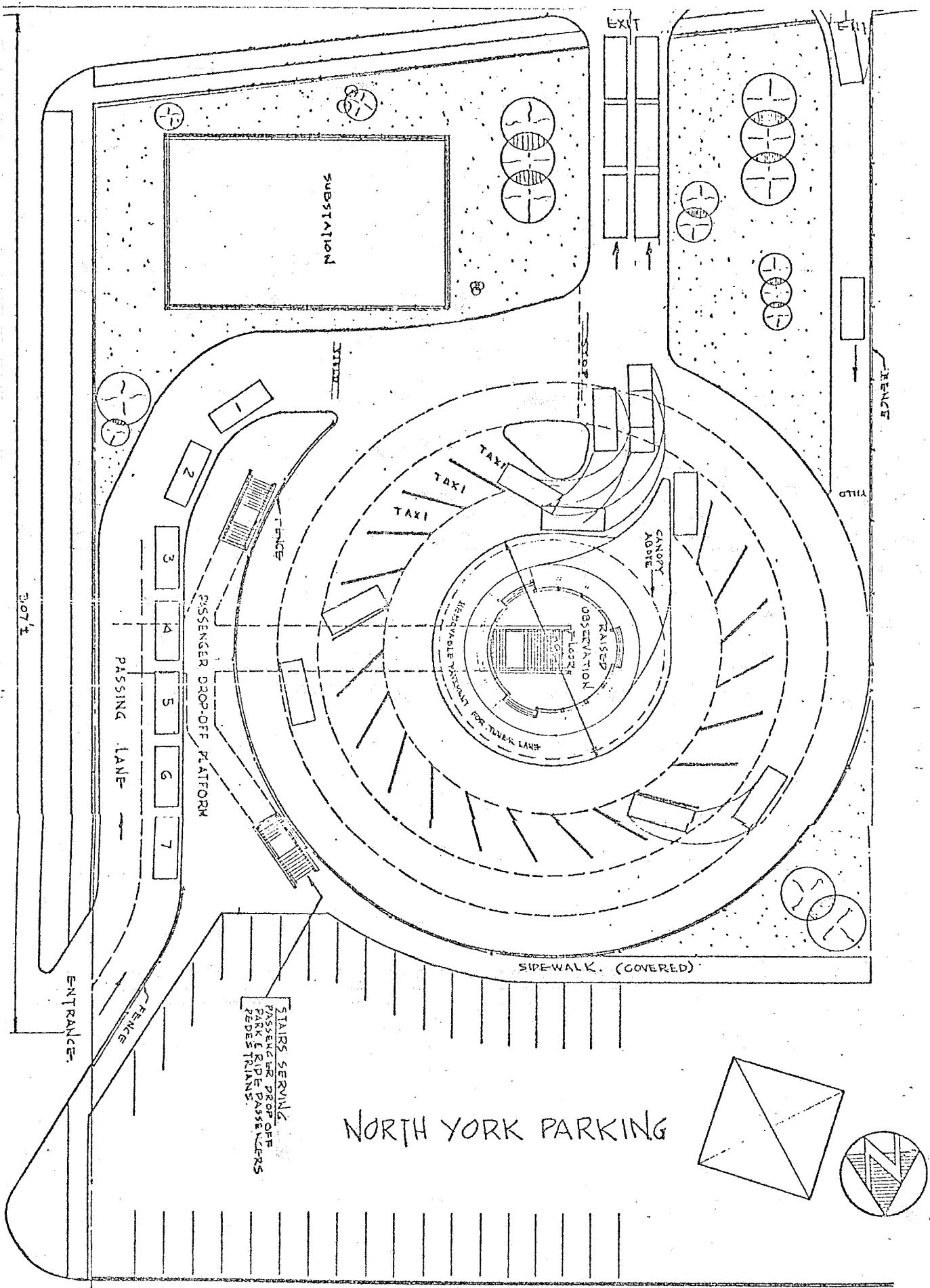


FIGURE 15. An Example of K+R Facility (Toronto)

The average space needed for a parking stall varies with size of the facility and type of design. Well-designed parking facilities will seldom have less than 350 square feet per space including circulation roads, pedestrian facilities, etc. With some restrictive geometry or green islands and other additions to the parking area, the average space can easily reach 450 square feet.

The parking area should be as close as possible to the station without displacing the other access modes, all of which have preferential treatment over the P+R. Typical values for access from P+R area to the station average 300 to 900 feet, while the maximal values, based on a survey by Lassow [3]* vary from 600 to 1200 feet.

Access points to the P+R area should be far from the station to minimize conflict between modes as discussed before and shown in Figure 4. The direction of aisles should be orthogonal to the station to facilitate pedestrian walking along the aisles. If this is not possible, pedestrian walkways can be created across the aisles by well-marked 5-foot wide paths. Except where special conditions require angle parking, right angle parking should be used in all P+R areas because of its simpler circulation and lower area requirement per space

Dimensions of parking aisles and stalls should be smaller than dimensions of parking facilities of shopping centers and other areas. The reasons for this are low turnover of cars, parkers arrive in sequence rather than randomly so that the parking maneuver is easy and most

* Numbers in brackets refer to items listed in Bibliography.

parkers are regular users. Based on these factors the following dimensions are considered advisable for P+R areas at rapid transit stations:

TABLE 2. Recommended 90° Parking Dimensions
(From Petersen [5])

	K + R	P + R - "generous"	P + R - "acceptable"
Stall Width (ft)	10	8.67	8.33
Aisle Width (ft)	66	64	62

When parking demand is extremely high, as is typical for outer terminal stations of rapid transit lines, the question is whether the parking area should be expanded or a parking garage should be built. A number of considerations must be included in the analysis between these two alternatives. Compared with a surface lot, a parking garage has the following advantages (+) and disadvantages (-):

- + Requires less area;
- + Provides shorter walking distances;
- + Offers protection from weather;
- + Prevents creation of large parking surfaces in the city which disperse activities: allows better integration in urban environment;
- + On hilly terrain may be conducive to better utilization of space;
- + Facilitates collection of parking charges;
- Involves higher construction costs;
- May create security problems;
- May involve higher maintenance costs;
- Usually all drivers must pay for parking;
- Access capacity is generally lower.

IV. EXAMPLES OF STATION DESIGNS

For the purpose of integration of the design principles and standards presented in this report, and for their translation to practical design of stations, several examples of well-designed stations are presented in this Chapter. Two of these stations (Wandsbek and Billstedt in Hamburg) provide for pedestrian access and transfer from surface transit only. Both stations have been in operation for several years with very satisfactory results. Two other stations (Finch Station in Toronto and Fruitvale Station in Oakland) have all four access modes: pedestrians, bus, K+R and P+R. They are in the stage of design or early operation. The fifth example is an "ideal" design which has been developed in the course of this research.

A. Wandsbek Station, Hamburg

In operation since 1962, Wandsbek Station, shown in Figure 11, is a major transfer point between rapid transit and fifteen suburban bus lines. Most of the bus lines terminate at this station. The transfer area consists of an island directly above the rapid transit station. While pedestrian access from the surrounding streets is provided for through other entrances on opposite sides of the streets, all bus passengers are discharged on or picked up from this island. Escalators connect the island with rapid transit stations below it.

The oval roadway has sufficient curb length for bus stops of different routes and adequate storage lanes for buses waiting for their schedules.

The design provided for buses to go from any unloading to any loading area.

B. Billstedt Station, Hamburg

By its function, Billstedt Station is rather similar to Wandsbek since it is primarily oriented to transfer from bus feeder (12 routes). Difference in design is that bus roadway is rectangular, with the advantage that the curbs are straight and permit easier geometry for bus approach and departure. Operationally, the buses can maneuver in the same way as in Wandsbek. A major difference from Wandsbek is that Billstedt also has a very attractive direct pedestrian access via an overpass. A major shopping center located in the immediate vicinity is connected to the station via this overpass built exclusively for that purpose.

Operating experience and public acceptance of both of these designs have been very good.

C. Finch Station, Toronto

Although Finch Station is not very large and complicated, it is included in this report because of its unique treatment of the K+R and taxi area. This facility, shown in Figure 15, provides for circular flow of K+R vehicles with drive-through parking stalls for waiting vehicles. The capacity of the whole facility is relatively small.

This design has been proposed for Finch Station on the Yonge Street Subway Extension which is presently under construction. No practical experience from this design is therefore available.

D. Fruitvale Station, Oakland

The site for this BART station has been obtained by relocation of the street which was previously passing immediately next to the station. It can be seen from the plan of the station in Figure 17 that the site shape is ideal on one side of the station, while on the other side there is only a bus and K+R roadway. The interesting features of the design include the proper allocation of areas: bus is separated from other traffic and comes directly to the immediate vicinity south of station entrances; K+R areas are also adjacent to the station while outer portions of the site are dedicated to P+R.

Most of the traffic approaches the station on the East 12th Street, both from east and west. These traffic flows are directed into the site in such a way that they do not intersect each other. This can be seen quite clearly on the treatment of the K+R area which has long frontages for pick-up and drop-off of passengers on both loops on the north side of the station (an additional K+R area is provided on the southeastern part of the station to utilize frontage which could not be used for any other purposes). The two K+R frontages on the north side utilize not only the curb along the station but also both sides of the pedestrian island which permits direct uninterrupted connection for pedestrians from the station to the crossing of the 12th Street and into the city streets. This traffic flow pattern provides for a minimum number of conflicting movements on the adjacent intersections.

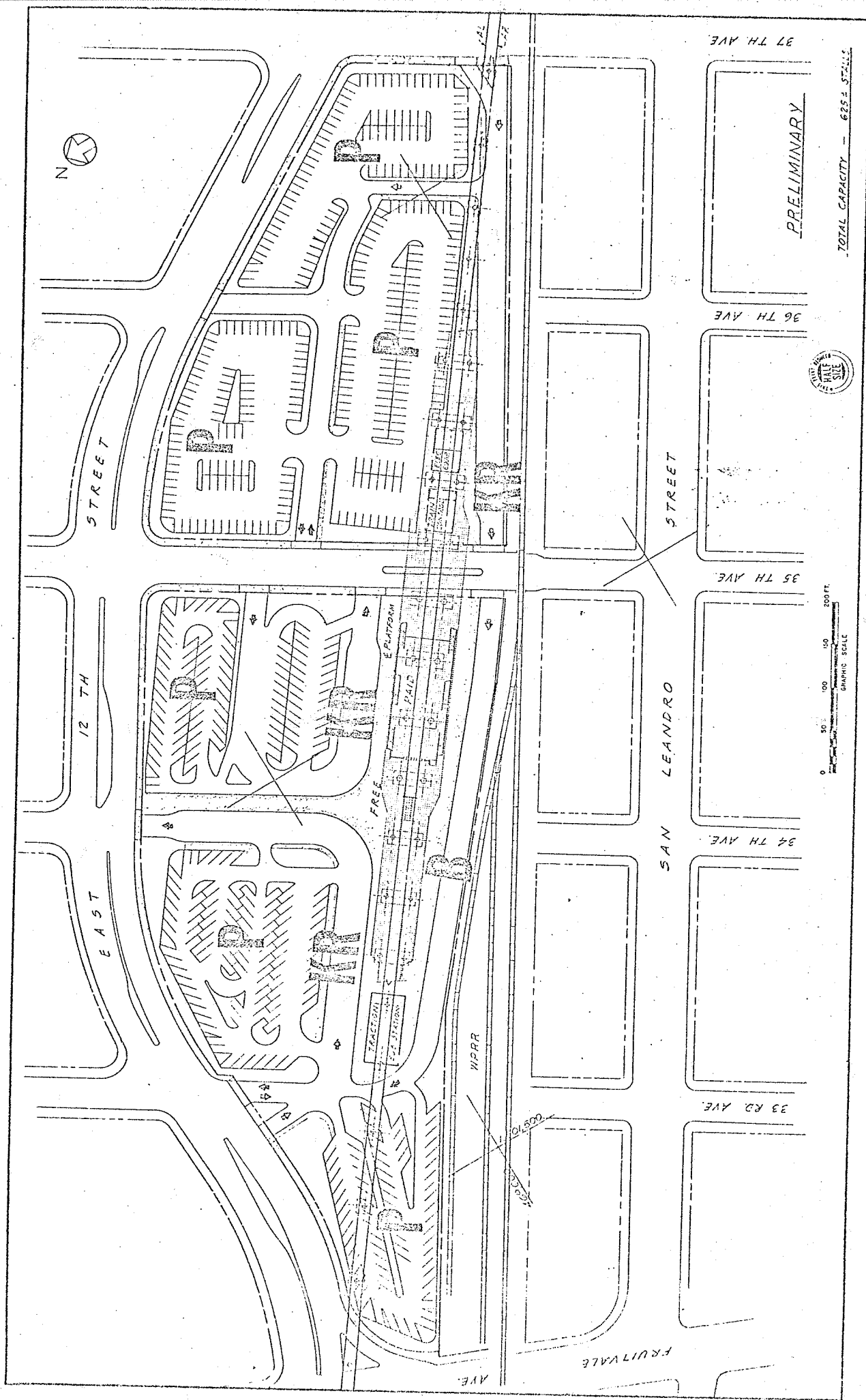


FIGURE 16. Fruitvale Station (BART - Oakland)

E. An "Ideal" Station Design

The design presented in Figure 18 is hypothetical, although its general form somewhat resembles one of the BART stations. The purpose of this design is to illustrate integration of the principles and standards developed in this study into a complete station design under favorable conditions.

It was assumed that the station coincides with a 700-foot long city block and that this site consists of an area between the station and a major arterial on its eastern side and a minor street on its western side. Thus the whole block is taken up by the station. All access points, with the exception of one right-hand entrance, are from the side streets, one of which has four lanes. Buses have roadways directly along the station with stops close to the entrances; K+R vehicles enter together with buses but then branch off into their specially designed area. The eastern bus roadway is shared on both ends by vehicles entering and exiting the P+R facility. The design is such that it would not be likely that buses would suffer from congestion at these points.

P+R facility consists of several areas with aisles perpendicular to the station axis for easier pedestrian movement. Some of the aisle dividers separate the parking area into several sections at the "inner" sides of the parking areas. The purpose of these dividers is to prevent cruising of automobiles in search of parking spaces along those areas where pedestrian concentration is the highest. The cars can enter any of these sections but cannot go from one to another. At the same time, these continuous barriers

carry continuous pedestrian ways throughout the station area.

Although it is not likely that this "ideal" design will ever be applicable in its entirety to a rapid transit station, many of its sections and design details can be used for design of portions of nearly any station.

It should be noted that this particular "ideal" station design incorporates very generous parking dimensions which would be applicable primarily to areas with low cost of land. For locations with higher land cost and/or high demand for parking, dimensions suggested by Petersen [5], given in Table 2, are recommended.

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