Parking Garage Planning and Operation

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FOREWORD

In 1947 the Eno Foundation published *Traffic Design of Parking Garages*, by Edmund R. Ricker, who also revised the monograph in 1957. This publication was the first to relate scientifically the geometry of parking structures to driver and vehicle performance in the interest of efficient traffic operations.

There has been widespread use of Mr. Ricker's publication and many of the new theories and practices recommended in it have been implemented to the extent that they are now taken for granted. However, while the fundamentals have remained the same, the applications of them are changing with time. Thus the Eno Foundation published *Parking*, by Robert H. Burrage and Edward G. Mogren, in 1957 (which included two chapters on garages) and *Parking Garage Operation*, by Robert E. Whiteside, in 1961.

Frequent requests for all of the above monographs have been received by the Foundation up to the present time. This continued interest and expressed concern about garage planning and operations led to publication of this current monograph on the subject.

This fourth monograph on parking garages retains the fundamentals pioneered by the authors of the previous Eno Foundation publications and redefines them in terms of current practices. Thus the Foundation wishes to thank these authors, especially Mr. Ricker, for the framework that they established, around which this book is written.

Recognition is due also to Mr. Herbert S. Levinson and Mr. John J. Cummings, who reviewed the manuscript and contributed many constructive suggestions. The Foundation also wishes to express its deep appreciation to the many city officials and garage managers or operators who provided data for this analysis. Finally, the International Parking Congress and the National Parking Association were most cooperative in providing lists of garages and in urging their members to respond to the study's questionnaire.

The Eno Foundation has published, over the years, 16 monographs on parking. A majority of these are no longer in supply;

therefore, this publication attempts to cover as many aspects of parking as possible. It is hoped that it will be useful in solving current and future urban parking problems.

ROBERT S. HOLMES
President

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Chapter I

INTRODUCTION

Parking facilities are a basic part of the modern community's transportation system. They profoundly influence economic viability, and consequently are a major concern to public administrators, businessmen, shoppers, workers, and in fact to everyone who drives an automobile. Because of its importance, parking has been the subject of numerous papers, monographs, and textbooks, but parking persistently poses problems for every community. In recent years, concern over air pollution and energy conservation have become an added aspect of parking in downtown areas.

Parking facilities are in constant evolution. As the attitudes, values, and desires of people change, so must policies regarding parking facilities.

Trends

Parking facilities actually pre-date the motor vehicle. Of the several forms of parking facilities (such as curb spaces, surface parking lots, and parking structures), parking garage technology has changed the most. The first public parking structure was a livery stable, whose owner rigged a harness to lift carriages to a second-floor storage area. The advent of automobile usage inspired similar adaptations for storing motorized carriages. Early parking garages were principally service-oriented, with automobile storage a by-product.

The automobile boom gained momentum after World War I. Most passenger cars of the period, being open models with fragile finishes and less-than-dependable starting characteristics, were highly susceptible to weather—a condition that caused the enclosed parking structure to grow in popularity. Department stores provided garage parking to attract the carriage trade, and private entrepreneurs found parking garage business particularly lucrative, with profit margins sometimes as high as 40 percent on revenues. The federal government provided the first underground garage in 1927, complete with pedestrian tunnel, to protect U.S. Senators from the elements in their travels between car and office.

By the mid-1930s parking garages were virtually put out of business by evolving improvements in automobile dependability and durability, and the period's severe economic depression. However, times continued to change. Women began driving and using their cars for shopping trips, causing a need for transient, temporary parking. Automobile numbers and usage continued to grow, outstripping curb parking space capacity and creating a need for more off-street parking. Parking meters were used to regulate parking as well as to produce revenues.

Today, facilities for parking are widespread throughout metropolitan areas, with "parking problems" focused in and near major activity centers. Parking remains important in many city centers as a catalyst for downtown stabilization and enhancement. Large self-sufficient commercial complexes, including airports, hospitals, universities, and shopping centers, have created new markets for parking structures. High labor cost has stimulated parking automation, creating a boom era for many kinds of parking products. Highly sophisticated computerized revenue and traffic control systems are a reality. The once futuristic automatic ticket dispenser is as common to parking as the automatic transmission is to automobiles. Even parking meters have significantly changed since their introduction.

Recent trends indicate that the average size of new parking structures is increasing. Structures providing 1,000 to 3,000 parking spaces are a large portion of all parking structures being developed.[1] This is in marked contrast to the 500- to 700-space facilities considered large in the 1960s.

Parking structure development is no longer limited to the central cities of major metropolitan areas. Metropolitan area suburbs, and even a few cities as small as 20,000 population, are developing parking structures ranging in size from 500 to 1,500 spaces.

Hospitals and airports are increasingly developing parking garages that are larger than those being developed in the city center. Compared to parking development trends in the 1950s, when most retail parking was developed by private owners, individuals, and corporations, government is now developing a much larger proportion of the parking supply.

Attitudes toward parking have also changed. Commonly held beliefs that motorists, particularly women, were somewhat reluc-

[1] Richard F. Roti, "The Trend to Larger Parking Facilities," *Parking* no. 3 (July 1977):22.

tant to enter parking garages have generally been proven untrue as familiarity with modern self-service parking garages has increased and designs have improved. People have demonstrated an overwhelming preference for parking their own vehicles—a factor responsible for increased concern for adequate parking stall and other parking garage dimensions. People have become sensitive to environmental protection, and promulgated and proposed regulations have introduced new complexities into parking facility planning and design, threatening drastic limitations on future parking facilities. And, as parking demands rise, issues of energy and environment raise important questions.

One recognized planner[2] observes that the current issue in many cities is "to park or not to park," noting that "it should be *provided* to sustain the urban economy. But it should be *constrained* to increase public transport use and to reduce vehicle-miles traveled. Balancing these potential conflicts is the challenge of contemporary parking policy."

Attempting to provide parking for all demands is the historical approach, but in coming years it may be desirable to place emphasis on more selective demands to maintain the economy, amenity, and mobility of urban centers—to provide parking complementary to the broad spectrum of social, economic, and environmental values.

Contemporary parking garage state-of-the-art has dramatically evolved since the 1870 livery stable adaptation. Much of this evolution has occurred in the past two decades. While improvements have been realized in the ways and means of satisfying parking demands, the situation is continually changing, calling for new approaches.

MONOGRAPH PURPOSE AND METHOD OF STUDY

This monograph discusses parking structure planning, functional design, and operation. *Traffic Design of Parking Garages*[3] by Edmund R. Ricker—a pioneer analysis of parking garages—introduced fundamental operational concepts, defined terms, and classified ramp systems. Mr. Ricker's classic work forms the

[2] Herbert S. Levinson, "Parking in a Changing Time" *Transportation Facilities Workshop, Passenger, Freight, and Parking*, American Society of Civil Engineers Specialty Conference, 1974.

[3] Edmund R. Ricker, *Traffic Design of Parking Garages* (Saugatuck, Conn.: The Eno Foundation for Transportation, Inc., 1957).

conceptual framework for this study, with basic fundamentals reviewed in terms of current practice. Modifications to earlier parking garage standards reflect changes in automobile design, parking technology, and market characteristics. Although new building concepts are discussed as they relate to functional design, this study does not address the subjects of structural materials and their selection, or construction procedures.

Study Scope

This study is based on research of some 350 monographs and published papers, augmented by interviews and questionnaires returned by 118 cities in North America that provided information on 274 parking garages. Emphasis is placed on current parking garage practice; however, trends are noted and parking issues are overviewed in national perspective. While this study is based largely on American practice, it is generally applicable around the world. The coverage of parking garage planning, functional design, and operation is not intended to be a complete treatise, but rather a compendium of major points and considerations. An attempt is made to show how parking garage planning, design, and operation relate to people and the urban environment.

Design standards in current use, and illustrative examples, are presented. It should be emphasized that "good" design calls for sensitive application of these standards rather than arbitrary use of standardized minimum or maximum values. A parking structure that is truly efficient and safe in operation, well fitted to site controls, and acceptable to community environment, requires a design carefully tailored to the specific conditions and characteristics the facility is expected to serve.

Study Organization

Chapter II discusses the role of parking in the total urban transportation system as it relates to growing concern over social and environmental consequences, and energy conservation implications in urban motor travel. It also outlines the key studies and analyses relating to identifying needs, evaluating usage, and determining feasibility.

Chapter III presents planning and development guides, design factors, and general parameters. Chapters IV and V deal with the functional design of parking garages and alternative types of interfloor travel systems, while Chapter VI presents pedestrian considerations. Operational practices are related in Chapter VII to economic efficiency and characteristics of demand.

SUMMARY OF FINDINGS

Changing technology and economic conditions have brought about significant changes in parking design and operation, as well as new approaches to garage development and financing. The planning, location, design, and operation of parking garages involves balancing economic, engineering, environmental, and land-use considerations. Urban parking should be viewed as part of a total transportation system relating to pedestrian circulation and transit operation, as well as automobile movement.

Planning and Design

Parking garage development should be carefully related to present and future land uses; it should reflect consideration for patron origins and destinations, and street capacities and circulation patterns. Garage development should be cognizant of and related to existing and proposed public transit facilities, demonstrated parking deficiencies, and community development goals and resources.

Land Use Compatibility. Ideally, parking garages should be distributed near the land uses they serve, subject to the constraint of avoiding land fragmentation. However, as land-use intensity increases and land values rise, it becomes economically unfeasible, and often environmentally unacceptable, to use premium land for parking. Thus many areas of greatest need pose impractical parking locations. Areas with narrow streets, nearby transit services, and high development intensities, such as found in some large cities, should rely on public transit rather than additional parking. Parking garages should be constructed on the perimeter of these areas.

Where adequate public transit is unavailable and/or the downtown economy is dependent on automobile travel, parking garages should be integrated with other land uses to avoid fragmentation of block frontages. The economic and environmental advantages of multiple-use developments make them preferable to free-standing, single-purpose facilities. Consolidation of parking lots into multiple-use structures should be encouraged to intensify the use of available downtown land.

Parking garage size and scale should be compatible with surrounding development. There is a choice of whether to minimize visual impact of a parking facility, or make it a bold statement of parking availability. Either way requires careful design reviews of architectural treatment to ensure an acceptable blend with existing development.

Location and Use. Parking garages should be located and designed to minimize walking distances to final destinations, cruising and redundant travel in search of parking space, and circulation on local or congested streets.

Wherever adequate transit is available to serve long-term parkers, short-term parking should be encouraged through favorable rates and restrictions, provided they do not create serious inequities to garage operators or to persons who must drive. When possible, long-term employee parking should be located on the periphery of the CBD, or at outlying express transit stations.

Parking garages should be located and designed to maximize usage, such as permitting daytime business use and evening recreational parking.

Parking Garage Access. Parking garages should be situated to intercept traffic before major congestion points, minimizing local street travel between garages and express highways. Garage access should be possible from multiple routes.

Where walking distances and times are not excessive, parking garages should be located to permit direct access to freeway ramps or service roads. This minimizes adverse environmental impact and travel on local streets.

Garage access capacities should be designed to serve expected peak traffic and minimize congestion. This requires ample reservoir area on approaches to garage entrances and exits, locating access points an adequate distance from signalized street intersections, and providing a sufficient number of entrance and exit lanes having the necessary reservoir capacity.

Pedestrian Movement. Parking garages should facilitate direct, safe, and pleasant walks between parking spaces and destinations. The pedestrian trip can be enhanced by routes designed to direct pedestrians along commercial frontages, through pedestrian plazas, or over direct climate-controlled connections to adjacent buildings.

Parking Garage Size. The number of parking spaces in a garage should be scaled to the ability of adjacent streets to accommodate garage traffic. Small 100- or 200-car facilities are undesirable as part of an overall parking program, since proliferation of small parking facilities interferes with pedestrian travel and breaks the continuity of block frontages.

Parking Dimensions. Standardized parking dimensions must compromise generous dimensions allowing easy maneuvers with restrictive dimensions providing maximum economy. Standard-

TABLE I—SUMMARY OF SUGGESTED PARKING GARAGE DESIGN PARAMETERS

Structure Size

Most desirable is a parking structure with 500 to 2,500 parking spaces, scaled to the capacity of adjacent street access.

Structure height may be limited by local building codes as well as interfloor circulation constraints. Generally maximum parking structure heights range between 5 and 9 levels (60 to 90 feet) with up to 30,000 square feet of floor area per parking level.

Location Guidelines

Accessibility is a principal factor in parking garage location. Parking garages exceeding approximately 1,200 spaces should have nearby or direct freeway access.

Acceptable walking distance between parking place and destination is another key location factor, and is influenced by population size and trip purpose. Guidelines for maximum walking distance are: For larger cities (over 250,000 population)

- Long-term parking—1,000 to 1,500 feet
- Short-term parking—500 to 800 feet

For smaller cities (under 250,000 population)

- Long-term parking—600 to 700 feet
- Short-term parking—200 to 350 feet

Entrance/Exit Lanes

Generally a parking garage should be able to fill or completely discharge within a maximum of 1 hour. Special-event surge-type demand facilities should be capable of emptying in 30 minutes.

Maximum lane capacities for parking garage entrances range up to 660 vehicles per hour; for controlled entrance lanes, 400 vehicles per hour per lane is commonly used as a maximum design capacity. Discharge capacities range between 150 and 225 vehicles per hour for each gate-controlled exit lane. General requirements for number of access lanes and reservoir area are:

Entrance lanes

- Short-term parking, 1 per 600 spaces
- Long-term parking, 1 per 500 spaces

Exit lanes

- Short-term parking, 1 per 250 spaces
- Long-term parking, 1 per 200 spaces

Inbound reservoir area

- Free-flow entry, 1 space per entry lane
- Ticket-dispenser entry, 2 spaces per entry lane
- Entrance cashiering, 8 spaces per entry lane
- Attendant parking, 10 percent of parking capacity served by each entry lane.

(continued)

TABLE I—(*continued*)

Parking Dimensions

Parking stalls
Minimum stall widths for self-park operations are 8.5 feet for angle parking and 9.0 feet for 90-degree parking; for attendant-park operations, stall widths range from 8.0 to 8.5 feet. Minimum stall length is 18 feet. Special compact-car stalls are standardized at 7.5 feet wide by 15 feet long.

Aisle width
Minimum widths for one-way aisles range from 11 to 12.5 feet; two-way aisles, from 20 to 22 feet.

Column spacing
Traditionally, columns have been spaced at intervals of three parking spaces. This results in a 28.5-foot spacing, assuming 90-degree parking and 18-inch columns. Because columns are located 3 feet in from aisles, a parking bay or module of 62 feet requires an over-all minimum column spacing of 31 by 28.5 feet. Larger columns, angle parking, and /or more stalls between columns requires spacing to be increased accordingly to maintain adequate clearances.

Clear-span design
Column-free designs may provide structural support spans from 48 to 65 feet.

Floor heights
Minimum clear height is 7.0 feet; however 7.5 feet is most desirable, which provides a 9.5 to 10-foot floor-to-floor height.

Other Considerations

Ramp grades
A maximum grade of 4 percent should be used for sloped portions of sloping floor garages where ramps provide direct access to stalls. Where conventional interfloor ramps are used (either straight or helical), grades should not exceed 15 percent; grades of 7 to 8 percent are preferable.

Lighting intensity
Garage illumination should approximate 2 to 5 footcandles along straight aisles and in parking areas, 50 footcandles immediately inside entrance and exits, 15 footcandles in areas where drivers are expected to turn, and 20 to 50 footcandles in cashiering and waiting areas, and other pedestrian areas.

Passenger elevators
Recommended for parking structures of 3 or more floors. Needs can be generally equated to the number of parking stalls: two elevators for the first 600 stalls and one extra elevator for each additional 600 stalls or substantial fraction thereof.

ized parking dimensions have been established through experience with a variety of parking facilities. Because, standardized parking dimensions are subject to change during the life of a parking structure, the structure should permit a reasonable degree of flexibility if dimensions need to be modified later to meet changing requirements. Thus, clear-span designs should be encouraged to leave parking areas free of support columns.

Smaller compact parking stalls for small cars may be incorporated in garage layouts to increase space efficiency. End aisles have generally been the best locations for compact stalls. However, before including compact stall provisions in a garage layout, the benefits of increased space efficiency should be carefully weighed against the difficulties of assuring that only small cars will use the compact stalls.

Financing and Management

Combined public-private development of parking facilities should be encouraged, allowing land and development costs to be shared. Short-term management of publicly-owned parking facilities by private operators has gained acceptance as a means of utilizing management expertise, often resulting in operating cost savings and improved service.

Financing of new parking garages demands improved marketing techniques to create the highest degree of investor interest in new bonds prior to *and after* their sale. Parking as a self-supporting enterprise is increasingly difficult because of rising construction cost, operating costs, and interest rates. While some rate increases will be mandated by the economic realities associated with building new facilities, it may in many cases be impractical to expect parking charges, per se, to render new projects financially self-supporting. (Based on 1976 data, multiple level parking garage development costs, exclusive of land costs, commonly range between $3,500 and $5,500 per parking stall for above-ground open-wall structures; operating costs typically range from $0.40 to $0.90 per stall per day.)

The problem with inflation is not limited to meeting the much higher financial obligations of new facilities. Many communities are facing the common problem of increases in operating expenses not being matched by increases in gross revenues, even with moderate adjustments to parking-rate schedules, and application of curb-meter revenues to augment their off-street parking revenues.

Under such circumstances, some planners are advocating that the downtown parker be treated in a manner similar to that of the downtown bus passenger. This means adopting an attitude toward CBD parking such as that applied to sewers, water, or other public utility services. It means limiting the user charge to maintenance and operating expenses, while development capital, in whole or part, is provided from the general fund or other capital grant funds without repayment by user charges.

Chapter II

PLANNING CONSIDERATIONS

Parking garages should be planned and developed as part of an overall parking program to meet the needs of the downtown area and other major activity centers, such as airports and hospitals.

The program development calls for (1) clearly identifying relevant transportation policies, (2) assessing parking demands, and (3) formulating and evaluating recommended actions. It is necessary to determine how much parking should be provided, where it should be located, who it will impact or benefit, what it will cost, and how it should be financed.

These factors should be viewed from perspectives broader than parking and transportation feasibility alone, because parking is not only an essential part of the urban transportation system but also is an essential urban land use. Contemporary issues of environmental impact, energy conservation, and community amenity are considerations that should influence both overall parking programs and individual facility development. A real concern in many large cities today—especially those with high employment densities in the city center and heavy reliance on rapid transit systems operating on exclusive rights-of-way—is whether or not to provide *more* downtown parking.

This chapter overviews some of these concerns and sets forth general approaches to parking program development.

Planning and Policy Context

Parking facility development involves a wide range of interests and viewpoints.

The average motorist wants to park near the intended final trip destination, spending minimum time in parking-unparking operations while having complete assurance of safety—all at a minimum cost. Therefore, a fundamental planning objective is to provide safe, efficient, economical storage as near as possible to the parker's destination.

Retailers view parking as an economic necessity to their operations. Adequate nearby parking is prerequisite to retail development, whether in the CBD or in outlying shopping malls.

From a pedestrian's standpoint, off-street parking along the main shopping street frontage can be undesirable because it can impede walking paths and reduce the continuity of commercial development.

Public transport operators view downtown parking—especially for work-trip commuters—as competitive to bus and rail transit systems. But they view parking at outlying park-and-ride sites as an essential complement to their transit systems.

Developers of non-retailing structures view parking in terms of economic feasibility. This implies a balancing of the income and costs associated with providing parking, and the effect of providing parking as a support function for the business or governmental operations at the development.

Among government officials, differing attitudes are found toward parking development. Some view parking as a catalyst to new development and investment in downtown areas, while some others regard parking as a less desirable type of downtown land use and prefer to limit central-area parking development.

Balancing these sometimes conflicting objectives calls for careful assessment of demands, needs, and consequences. It is necessary to establish policy guidelines, estimate needs, formulate and assess recommended actions, evaluate financial feasibility, and set implementation priorities. Both long-term and short-term impacts must be considered.

Early Establishment of Objectives and Criteria

The first step in parking facility or program analysis is to identify goals, purposes, and policies. Although there are many similarities among feasibility studies, there also are many differences relative to type of parking project, financing, data availability, and special constraints and considerations. Critical questions such as the following should be addressed early in the analysis:

1. What is the project's purpose; whom should it serve?
2. Is the program compatible with city plans, zoning requirements, other projects, environmental concerns, and the city's broader transportation policies?
3. What are the nature and availability of preexisting data and studies?
4. What methods of project finance are appropriate? (Alternate types of bonds and guarantees, potential bond-issue restrictions, reserve accounts and related interest income, timing of actual bond sale, and interim financing procedures.)

5. Are there any special statutory limitations or other restraints? (Ceilings on outstanding indebtedness, prescribed methods of repayment of debt, interest rate maximums, nonrelated debt currently outstanding, restrictions of previous bond issues, and economic impacts of refinancing programs.)

6. Are there any special controlling considerations? (Public transit development and usage, including future changes; special parking rates to encourage a specific type of parking, or free parking.)

7. What should the architectual concept convey? Should it look like a parking garage, or should it blend with its surroundings?

8. Will there be opportunities for multiple-use development or joint development?

Answers to these and other questions are needed to define the program or project and to prepare a feasibility analysis. The objectives and criteria should be clearly defined at the outset, and the feasibility study should be simple and direct, within the context of broader planning and policy guidelines.

Parking Policy Guidelines

Downtown parking policy analysis should openly and objectively seek answers to questions such as the following:

1. What are the development and environmental goals for the downtown area and surrounding areas?

2. What rational distribution of parking facilities is desired in regard to (a) land-use intensity, (b) demonstrated parking needs, (c) existing or proposed transit services, and (d) available and proposed road access capacity?

3. What are the individual short-term and long-term parking requirements of subareas that might lead to a differentiated policy regarding provision and prohibition of parking?

4. How can parking serve as a catalyst for development patterns?

5. What are the effects of parking on the location and design of transportation system improvements, both existing and proposed?

6. Should parking be provided for all people who want to drive downtown, or should it be rationed in some specified manner?

7. Who should develop, finance, and operate facilities?

Factors that should result in variations among cities in parking policies include intensity of CBD development, relative reliance on public transit, limitations in street capacity, air quality requirements, and community attitudes and antecedents. These factors also will, of course, influence parking management plans, which implement policy. Guidelines such as the following will generally be appropriate:

1. Downtown parking supply should be coordinated with the highway and transit system, as well as the CBD pedestrian circulation system. Parking should be designed to improve mobility while maximizing benefits of existing and future transportation investments.
2. Park-and-ride facilities at outlying locations along express transit lines should be viewed as a complement to CBD parking and, in some cases, as a preferred alternative to all-day parking in the CBD or on its perimeter.
3. Downtown parking facilities should be rationally located in relation to land uses, demands, approach streets, and pedestrian movements.
4. Multiple-use development—the integration of parking with other land uses on the same site—should be encouraged in the city center.
5. Curb parking space represents a valuable resource and should be priced accordingly. Demands on curb spaces for pedestrian street crossings, buses, service vehicles, and moving traffic, generally should take precedence over on-street parking. Pricing and enforcement policies should reflect this philosophy and help to protect revenue potentials of off-street parking facilities.
6. Short-term (shopper, business) parking needs should take precedence in larger cities where transit systems can effectively serve downtown work-trip needs.
7. Parking-restraint plans, as sometimes set forth in Transportation System Management (TSM) and Parking Management Plans, should be highly selective. They should recognize the need to maintain both CBD access and its economy, as well as environmental quality.
8. Zoning requirements for downtown parking should reflect both development intensity and transit service availability. In larger city centers, it may be appropriate to specify *maximum* as well as *minimum* amounts of required parking for certian land uses.

These guidelines are generally consistent with parking management plans which are designed to control parking prices or availability by:

1. enforcement of parking regulation;
2. elimination of on-street parking, especially during peak periods;

3. restricting all-day commuter parking;
4. price regulation of public and private parking spaces;
5. regulation of parking supply; and
6. provision of CBD-fringe and transportation-corridor parking that facilitates transfer to transit or high-occupancy vehicles.

These measures also complement TSM actions designed to (1) improve traffic operations, (2) make appropriate provisions for pedestrian and bicyclists, (3) improve public transportation, and (4) reduce automobile use in congested areas, especially during periods of peak travel demands.

The Parking Program Team

Parking program formulation may involve a multidisciplined team of professionals. The team may include a parking feasibility specialist, engineer and architect, underwriter or investment banker, land developer, legal advisor, and bond counsel. Local government will be involved either as developer or in plan conformance, zoning, and building permit phases. Federal and/or state agencies may be involved in financing, as in use of urban renewal credits for development or U.S. Department of Transportation funding for park-and-ride facilities.

PARKING STUDIES

Parking studies usually are prerequisite to developing new or expanded parking programs. The studies should be designed to:

1. inventory existing parking space supply and measure current levels of space usage (accumulation and space turnover);
2. identify salient parker characteristics (duration, purpose, trip destination, and walking distances to destinations);
3. quantify demands and needs; and
4. estimate facility capital and operating costs, usage, and revenues.

Cost and revenue estimates can then be compared to assess the financial feasibility of an overall parking improvement program. The feasibility study should determine:

1. How many spaces are needed under present conditions?
2. How many spaces will be needed under future conditions?
3. Where should additional spaces be located?
4. What type of patrons will they serve (short- or long-term) and what are their characteristics?

5. What parking rates are realistic?
6. What other transportation considerations are relevant?

Types of Parking Studies

A parking study may be concerned with an individual trip generator or facility, such as a hospital or office building, or with the entire CBD. It should determine not only where motorists can and do park, but also where they would like to park and how their parking practices affect other transportation facilities. Parking studies provide the data essential to develop programs to meet parking needs.

Full-scale, comprehensive parking studies involving extensive data collection through parker interviews and other means, and detailed analyses provide a sound basis for estimating parking usage and determining appropriate actions. A comprehensive study is generally considered requisite for estimating parking usage and needs on a block-by-block basis in large cities. However, parking study cost and complexity can be reduced in smaller cities where a familiarity with the area and its principal parking generators will often permit reliable judgements by using a more limited type of study without parker interviews. A limited parking study may rely on measuring parking usage by hourly accumulation counts of parked vehicles or facility occupancy checks.

Comprehensive Parking Studies. A comprehensive parking study usually includes interviews with parkers in addition to measurement of facility usage. The interviews are designed to obtain information on (1) location where parked, (2) trip purpose and frequency, (3) primary trip destination, (4) length of time parked, (5) parking fee paid, and (6) distance walked from parking space to primary destination.

Determining where parkers desire to park requires interviewing parkers at parking facilities or major trip generators. The location and extent of the interview sample is a prime factor in how comprehensive and expensive the study will be, and the usefulness of the findings. Postcard questionnaires, trip origin-destination studies, and license-plate surveys are sometimes used to collect information, although direct parker interviewing is the most common and reliable method.

Interviews of employees and visitors at major trip generators can provide ancillary information relative to household characteristics, travel modes and attitudes, and pedestrian flows. They also allow parking and trip generation to be correlated with particular types of land uses.

The comprehensive parking study is designed to appraise trends in parking space use, identify any special parking problems, and provide a sound basis for planned actions and feasibility analysis. It normally provides information on the capacity and use of existing parking facilities, characteristics of parkers, location and extent of parking demand, the influence of major traffic and parking generators, future parking needs, adequacy of existing laws and ordinances, limitations of administrative responsibility, and financial capabilities.

Special-Purpose Studies. Special-purpose studies are designed to answer a particular parking question. They may be used to determine the feasibility of removing parking meters in a garage, or to check on methods of parking fee collection or parking regulation enforcement.

Basic data required for estimating parking needs are often available from previous forecasts and surveys. New field surveys should be used only when necessary to collect information to supplement existing data. Detailed descriptions of the conduct of all parking studies, including studies dealing with specific problems such as employee parking, parking lot analysis, and others, are provided in several publications.[4]

Parking Characteristics

Parking studies conducted over the last several decades in major North American cities generally demonstrate similar patterns as a function of urban area population levels and parking facility type.[5] Salient characteristics are summarized herein to provide guides and/or cross-checks for estimating parking needs.

Parking Supply. The relationship between downtown parking supply, parking facility type, and urbanized area population is summarized in Table II. As urban area population increases, the supply of downtown parking also increases, but at a decreasing rate. Further, as urbanized population increases, the proportion of total parking spaces provided on streets decreases from approxi-

[4] *Parking Principles*, Transportation Research Board Special Report 125, Washington, D.C. (1971); National Committee on Urban Transportation, *Conducting a Limited Parking Study* and *Conducting a Comprehensive Parking Study* (Chicago: Public Administration Service, 1958); and D. E. Cleveland, "Traffic Studies," *Transportation and Traffic Engineering Handbook*, Institute of Traffic Engineers (Englewood Cliffs, N.J.: Prentice-Hall, 1976); and P. C. Box and J. C. Oppenlander, *Manual of Traffic Engineering Studies*, Institute of Traffic Engineers (Arlington, Va.: 4th ed., 1976).

[5] *Parking Principles*, Transportation Research Board Special Report 125, Washington, D.C. (1971) pp. 6-15.

TABLE II—CENTRAL BUSINESS DISTRICT PARKING SUPPLY AND FACILITY TYPE AS A FUNCTION OF URBANIZED AREA POPULATION SIZE

		Off-Street Spaces					
				Facility Type			
Urbanized Area Population	*Curb Spaces (percent)*	*Lot (percent)*	*Garage (percent)*	*Lot Spaces Public (percent)*	*Lot Spaces Private (percent)*	*Garage Spaces Public (percent)*	*Garage Spaces Private (percent)*
10,000 to 25,000	43	57	0	18	82	93	7
25,000 to 50,000	38	59	3	27	73	50	50
50,000 to 100,000	35	60	5	42	58	56	44
100,000 to 250,000	27	62	11	52	48	89	11
250,000 to 500,000	20	64	16	66	34	95	5
500,000 to 1,000,000	14	56	30	68	32	87	13
Over 1,000,000	14	55	31	67	33	84	16

Source: Tables 2.3 and 2.4, *Parking Principles*, Transportation Research Board Special Report 125, 1971.

mately 43 to 14 percent, and the proportion of off-street parking in open lots remains essentially unchanged—ranging from 55 to 64 percent. As urban area population increases, the proportion of total spaces provided in parking garages also increases, from 0 to about 30 percent.

Generally, as urban area population increases, the proportion of off-street parking spaces provided for public use also increases, and the proportion provided for private use (limited to employees or patrons of specific generators) decreases.

Parking Facility Usage. Table III shows how usage of different types of parking facilities varies with urban area population. A comparison of the percentage of curb space provided (see Table II) to the percentage of curb space usage in Table III indicates that curb spaces serve a larger proportion of total usage than they constitute of the total supply, irrespective of urban area population size.

For example, in the smallest population group, curb spaces account for 43 percent of the supply but are used by 79 percent of the parkers. Similarly, in urban areas over 1 million population, curb spaces account for 14 percent of the total parking supply and are used by 30 percent of the parkers. This is because curb spaces usually are limited by local regulation to relatively short parking durations, and thereby have more parking turnover than offstreet parking spaces.

Off-street parking in the smallest urban areas shown in Table II accounts for 57 percent of the total parking supply, yet serves only 21 percent of the parkers (see Table III). As urbanized area

TABLE III—PARKING SPACE USE CLASSIFIED BY FACILITY TYPE

	Type of Parking Facility Used		
Urbanized Area Population	*Curb (percent)*	*Lot (percent)*	*Garage (percent)*
10,000 to 25,000	79	21	0
25,000 to 50,000	74	24	2
50,000 to 100,000	68	31	1
100,000 to 250,000	52	42	6
250,000 to 500,000	54	34	12
500,000 to 1,000,000	33	39	28
Over 1,000,000	30	54	16

Source: *Parking Principles*, Transportation Research Board, Special Report 125, (1971), p. 11.

population increases, off-street parking space usage also increases. This is particularly true for parking garages. In urban areas over 1 million population, off-street parking represents 86 percent of the parking supply and accommodates 70 percent of the parkers.

Trip Purpose and Parking Duration. Parker characteristics are largely influenced by trip purpose. Parking duration is the length of time parked, and is a function of trip purpose as related to urban area population. Table IV compares various trip purposes and corresponding average parking durations for urban areas of different population totals.

As urban area population increases, the parking duration for all trip purposes tends to increase. The proportion of business and "other" trips typically remains relatively constant regardless of population size. Short-term parking with durations of up to one-half hour are most affected by urban population size. Work trips, with parking durations averaging nearly four times that of other trip purposes, are least affected by urban population size.

Parking Accumulation and Turnover. Parking accumulation is the number of vehicles parked at any given time, and is a measure of instantaneous parking demand. Parking turnover rate is a measure of parking space usage. The turnover rate is determined by dividing the total number of parkers in a time period by the total number of legal parking spaces available.

Parking accumulation generally reaches a peak between 11:00 A.M. and 2:00 P.M. in downtown areas. During this peak period, approximately 75 percent of all work-trip parkers, 25 percent of all shopping-trip parkers, and 20 percent of all business-trip parkers, are accumulated.[6]

Table V provides turnover rates for different types of parking facilities as found for an 8-hour period between 10:00 A.M. and 6:00 P.M. Curb parking turnover averages three to four times more than off-street parking. Parking garages typically have lower turnover rates than parking lots for reasons that include lower parking charges at lots, parker preference for open-lot parking over garage parking, and a larger supply and more dispersion of lot spaces—often enabling shorter walking distances, which is directly related to shorter parking durations.

Walking Distance. Walking distance (the distance measured along a normal walking path from a parker's chosen parking space to the

[6] Wilbur Smith and Associates, *Parking in the City Center*, prepared under commission from the Automobile Manufacturers Association (New Haven, Conn.: Wilbur Smith and Associates, May 1965) p. 14.

TABLE IV—TRIP PURPOSE AND PARKING DURATIONS

Urbanized Area Population	*Proportion of Parkers by Trip Purpose* Work	Shop	Personal Business (percent)	Other	*Average Parking Duration* Work	Shop	Personal Business (hours)	Average All Trips
10,000 to 25,000	21	38	23	18	3.5	0.5	0.4	1.3
25,000 to 50,000	21	27	35	17	3.7	0.6	0.5	1.2
50,000 to 100,000	20	24	31	25	3.3	0.6	0.8	1.2
100,000 to 250,000	26	21	34	19	4.3	1.3	0.9	2.1
250,000 to 500,000	30	19	33	18	5.0	1.3	1.0	2.7
500,000 to 1,000,000	47	13	25	15	5.9	1.5	1.7	3.0
Over 1,000,000	41	10	30	19	5.6	1.1	1.1	3.0

Source: Adapted from Tables 2.7 and 2.9, *Parking Principles*, Transportation Research Board, Special Report 125, (1971), pp. 12-14.

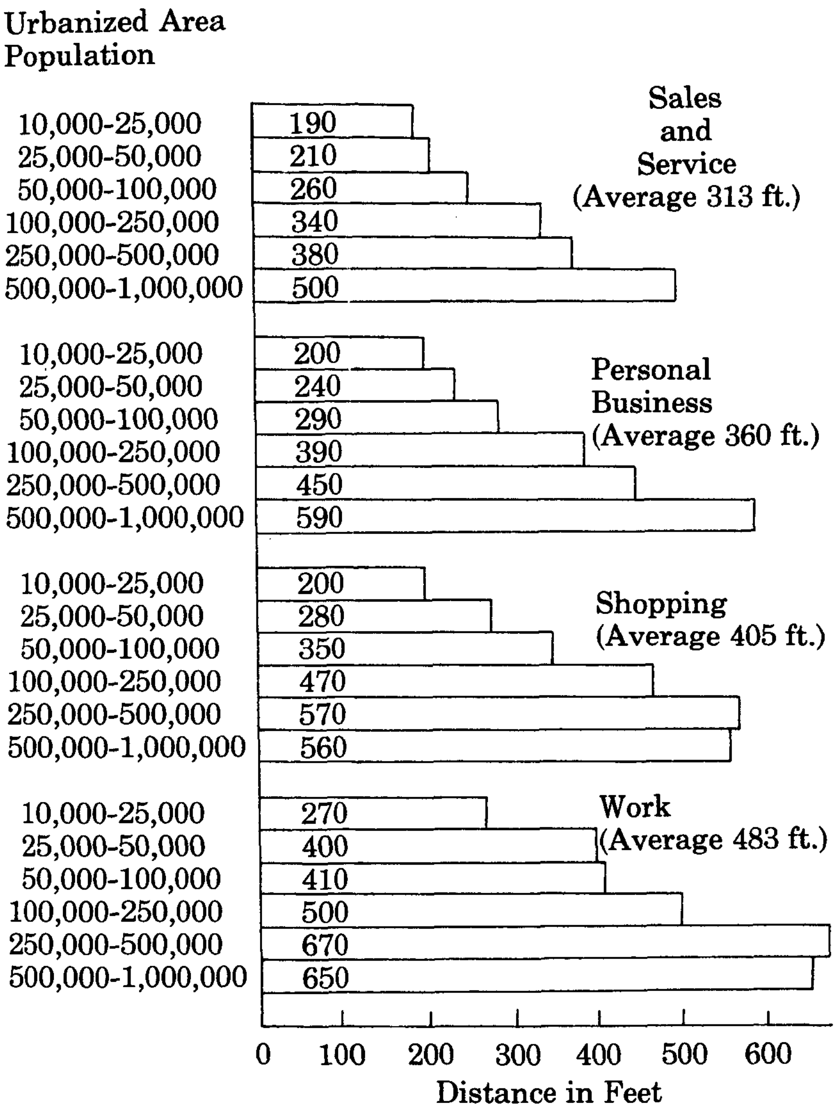


FIGURE 1. Average distance (in feet) walked from parking place to destination classified by trip purpose.
Source: Adapted from Table 2.11, p. 15, *Parking Principles*, Special Report 125, Highway Research Board (1971).

TABLE V—PARKING TURNOVER RATES CLASSIFIED BY FACILITY TYPE: 10:00 A.M. TO 6:00 P.M.

Urbanized Area Population	*Average Turnover Rate by Type of Parking Facility*			
	Curb	*Lot*	*Garage*	*All Off-Street*
10,000 to 25,000	6.7	1.8	0.3	1.8
25,000 to 50,000	6.4	1.5	0.6	1.5
50,000 to 100,000	6.1	1.7	0.8	1.6
100,000 to 250,000	5.7	1.6	1.0	1.5
250,000 to 500,000	5.2	1.4	1.1	1.4
500,000 to 1,000,000	4.5	1.2	1.4	1.2
Over 1,000,000	3.8	1.1	1.0	1.1

Source: Table 2.14, *Parking Principles*, Transportation Research Board Special Report 125, (1971), p. 16.

nearest door of the parker's trip destination) varies by trip purpose and urban area population size. Most parkers are willing to walk further to a work destination than for any other trip purpose. Average walking distances, regardless of trip purpose, tend to increase as urban area population increases. Figure 1 illustrates average walking distances by urban area population, classified by trip purpose.

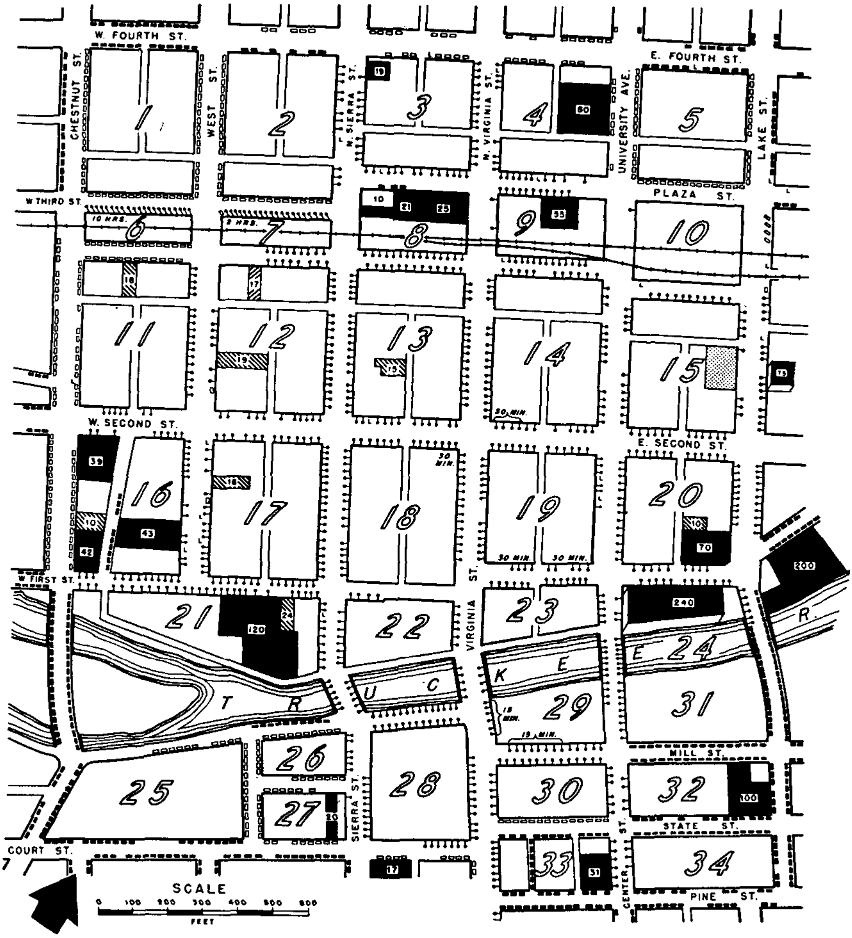
Estimating Demands and Needs

The following study and analysis procedures are generally necessary to estimate parking needs.

Parking Inventory. Parking supply characteristics of existing facilities—both curb and off-street—are obtained from an inventory that lists capacity, physical features, operating features, regulations, and fee schedules.

Auxiliary information may be collected and included with the parking inventory. Such information might include identification of vacant land or other areas potentially suitable for parking development. Data on land use (building square footages and potential for parking generation), market values based on assessed valuations, and data on transit usage and patronage trends are often useful. The parking inventory provides an excellent opportunity to identify major traffic controls and restrictions affecting access to existing or potential parking sites.

The parking inventory classifies parking spaces by time and use restrictions, and as public or private spaces. All existing spaces in



EXISTING PARKING FACILITIES

On-Street

'''' Metered 15 min., 30 min., 1, 2, 3, hr.s
--- Unmetered unlimited time
=== Unmetered one hour
0000 Unmetered one hour angle

Off-Street

Private unrestricted lots
Private restricted lots
Commercial lots
Municipal lot, free
Commercial garages
Truck loading zones

Numbers on lots and garages indicate capacity.
Time limit of parking meters one hour unless otherwise indicated.

FIGURE 2. Typical inventory map for curb and off-street parking. Source: Burrage and Mogren, *Parking*, Eno Foundation (1957), p. 65.

the study area are inventoried, including legal parking spaces, no-parking zones, truck loading zones, taxicab stands, and informal parking spaces.

Study areas are usually divided into districts, analysis zones, street blocks, and/or smaller subareas. A master coding system is used to identify individual parking facilities by block number and by an assigned facility number, which are tabulated on an inventory form and/or noted on a large-scale work map (Figure 2).

Parking Demands. Parking demands in existing major activity centers are determined by identifying the trip destinations of parkers (usually during the period of peak parking accumulation) as obtained from interviews. These demands then are compared with the effective parking space supply in a given block or analysis area. "Effective supply" usually is considered to be 85 percent of off-street spaces and 90 percent of curb spaces. (One hundred percent space occupancy rarely occurs because of delays involved in motorists entering or leaving parking spaces or cruising in search of vacant spaces.)

Adjustments then are made to balance surplus spaces in a block or analysis area with space deficiencies in an abutting block or analysis area.

A somewhat different approach is generally applicable for estimating parking space requirements for new developments, such as a suburban office building or an individual department store. In these cases, unit parking space demands for similar types of structures can serve as a guide, because the measures that specify parking needs in anticipation of usage are closely connected with generator characteristics, land area and/or floor space, travel characteristics of persons attracted, and other factors.

The parameters used in estimating parking demands for various types of land uses, and suggested parking ratios, are shown in Table VI. This table provides a guide for (1) estimating parking needs for specific land uses, and (2) establishing zoning requirements for parking.

Parking ratios reflected in Table VI have a relatively wide range. Parking studies have observed, for example, that office building parking space needs range from 0.2 to 5.3 spaces per 1,000 square feet of gross floor area (GFA)[7] for different buildings. This range

[7] Based on David K. Witheford and George E. Kanaan, *Zoning, Parking, and Traffic* (Saugatuck, Connecticut: Eno Foundation for Transportation, Inc. 1972), p. 83; and Paul C. Box, "Parking Generation Studies," *Highway Research Abstracts*, Highway Research Board, 32, no. 4 (April 1962). (2.9 to 4 spaces for suburban offices).

TABLE VI—TYPICAL PARKING DESIGN RATIOS AND ZONING REQUIREMENTS

	Range in Number of Spaces per Indicated Unit		
Land Use	*Unit*	*Range of Zoning Requirements*	*Range of Parking Design Ratios*
Single-family	dwelling	1-2[1]	1-2[2]
Duplex/multifamily	dwelling	1-2[1]	1-2[1]
Apartment house	dwelling	0.4-1[2&3]	0.7-2[4&5]
Hotel/motel	dwelling units	1 up[3]	N.A.[6]
Office	1,000 sq. ft.	variable[7]	2-5[4&5]
Retail	1,000 sq. ft.	1.5-5.0[3&5]	2-8
Restaurant	seat	0.25 up[3]	0.33-0.50[5]
Manufacturing/warehouse	employee	variable	0.33-0.50[9]
Museums/libraries	1,000 sq. ft.	N.A.[7]	N.A.
Auditorium, theater, or stadium	seat	0.08-0.25[5]	0.25-0.33[5]
College/University	student/staff	variable[8]	0.5-0.7[5]
Church	seat	0.10-0.33[5]	0.20-0.33[5]
Hospital	bed	0.25-1.50[3&5]	1.0-1.4[5&1]

N.A.—Not Available

Notes:

[1] J. B. Fordham, Chairman, Joint Committee on Urban Traffic Congestion and Parking, *Parking: Legal, Financial, Administration*, The Eno Foundation for Highway Traffic Control, Saugatuck, Conn., 1956.

[2] Wilbur Smith and Associates, *A Study of Residential Parking Requirements, Los Angeles, California*, 1963.

[3] David K. Witheford and George E. Kanaan, *Zoning, Parking, and Traffic* The Eno Foundation for Transportation, Saugatuck, Conn. (1972) p. 86.

[4] Varies depending on location—higher ranges apply to non-downtown locations.

[5] Wilbur Smith and Associates, *Parking in the City Center*, Automobile Manufacturers Association.

[6] Besides the number of dwelling units and the location, several other factors can directly affect parking demands such as the attraction of dining facilities, retail sales areas, meeting or conference rooms, and exhibition halls within the hotel facility.

[7] In the study conducted by Witheford and Kanaan (see Source 3) one space per 300 square feet gross floor area was recommended as a minimum for zoning standards.

[8] The Wilbur Smith and Associates study (see Source 5) indicates the range of parking space needs at 2.9 to 4 spaces, based on P. C. Box, "Parking Generation Studies," *Highway Research Abstracts* (April 1962) vol. 32, no. 4, (for suburban offices).

[9] G. Baker and B. Funaro, *Parking*, Reinhold Publishing Corp., New York, 1958.

[10] W. S. Smith, *Access and Parking for Institutions*, The Eno Foundation for Highway Traffic Control, Saugatuck, Conn., 1960.

reflects both transit service availability and employment density in the buildings. Because of these ranges, care should be exercised in applying the ratios to specific kinds of land uses.

Estimates of parking demand per unit of floor space or employment should be developed from parking studies within the specific urban area under study. Thus, likely variations between communities, as well as between areas within the same community, may be identified and reflected in parking ratios (parking space demand per given unit of land use), representing demand rates.

Estimating Demand at A Single Generator. To illustrate how parking demand can be estimated for a specific generator, consider this example: How many parking spaces are needed for an office building containing 400,000 square feet (37,160 square meters) of gross floor area and located in a central business area well served by public transport?

The solution process begins with determining a suitable ratio of employees per 1,000 square feet (92.9 square meters) of gross floor area (GFA). The employee ratio is based typically on national averages, local studies, or a combination of these data. For purposes of this example, four employees per 1,000 square feet of GFA is assumed.

At this point, an estimate must be made as to how many employees will drive, participate in carpools, or use public transportation to arrive at the proposed building. Since the building is served by public transportation, it can be assumed that fewer employees will drive than if the building were located in an area of lower population density (urban fringe or suburban area) and/or had a lower degree of public transportation availability. This example assumes that 60 percent of the employees will come by automobile, and an average employee car occupancy of 1.5 persons. The space need per 1,000 square feet GFA is:

$$\frac{0.60 \times 4}{1.5} = 1.60 \text{ parking spaces/1,000 square feet GFA.}$$

To this must be added an estimate for visitors. Assuming one visitor per 1,500 square feet (139.35 square meters) of GFA, or 0.75 space per 1,000 square feet of GFA as a planning criteria, combined employee and visitor parking demand equals 2.35 spaces per 1,000 square feet of GFA. Reducing this factor by an estimated percentage to represent 10 percent absenteeism yields a final factor of 2.115 spaces per 1,000 square feet of GFA. Applied to the 400,000 square feet of gross floor area, parking needs are computed to be 846 spaces, or 850 spaces (rounded).

Parking Rates. Existing parking fees charged within a study area can define acceptable rate schedules for a proposed parking facility, and also can serve as a simple gauge of parking demand. This is because the highest fees are usually obtainable where demands are greatest and land values are highest. Thus a direct relationship exists between decreasing demands and lower parking fees away from the business activity centers (parking generators).

Plotted on a map of the area, points of equal parking fees may be connected, as shown in Figure 3. Such parking fee contour maps have shown close agreement with more conventional indices of parking demand. Areas where high parking fees indicate the demand to be greatest are the most desirable in which to build new parking facilities. A close spacing of contours indicates a sharp decrease in parking demand, and the desirability of access to off-street parking on certain block faces is indicated by the shape and location of contours.

Evaluating Facility Usage

After existing parking needs have been identified, the next steps are to evaluate future needs and the consequences of future parking actions. Two procedures are involved here:

1. Projected changes in available parking supply and future parking demands should be estimated, and future parking needs

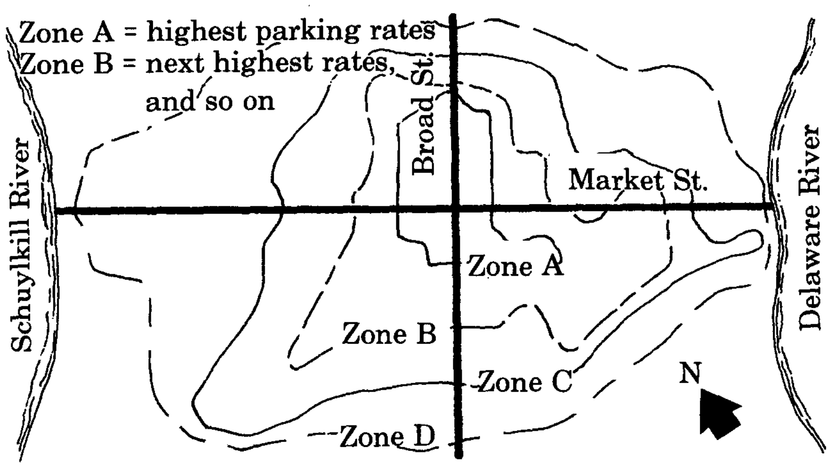


FIGURE 3. Parking rate contours in a typical central business district.

should be established by comparing supply and demand for each individual analysis area.

2. Alternative sites should be identified and analyzed, giving consideration to site acquisition and development costs, ability of site dimensions and shape to accommodate an efficient parking facility design, traffic capacities of adjacent access streets, and land-use compatability. Usage should be projected, and each facility's impact on the environment and energy usage should be assessed, along with related access, parking, and land-use development projects.

Current and future needs can be estimated by manual, semicomputerized, or modeling analysis techniques. Some parking studies have used origin-destination data from previous transportation studies as the basis for a parking needs estimate, using current inventory and occupancy surveys for calibration. Cordon counts around a city center (or study area) are valuable in measuring traffic entering, leaving, and accumulated in the area, and also can be used to identify the number of persons parking outside the study area and walking (or riding via public transit) into the area.

Factors Affecting Future Demands. Future growth in CBD parking demands relates closely to the economic growth of the community and its CBD. Factors influencing parking demand include (1) normal growth in population, motor vehicle registrations, and travel; (2) economic factors relating to the CBD and the community (changes in CBD employment, floor space, or retail sales; new generators and loss of existing generators, competition from outlying areas), public transit development and usage, changes in CBD accessibility, and the general economic level of the community and the nation; (3) economic factors relating to a specific parking project (competitive price changes and subsidies, and development of competitive parking facilities); (4) public policies regarding parking and transit; and (5) general considerations, such as developments in technology or science affecting transportation, new laws and regulations affecting motor travel, and energy or fuel shortages.

Impacts of New Facilities. Parking facilities may attract parkers diverted from other facilities, displaced parkers from facilities taken out of service, parkers induced by additional parking, motorists whose place of parking has shifted due to a change in their trip destinations, persons who are using a parking facility for a change of travel mode, and previous transit riders who park because of additional parking availability or improvement in income levels.

One study[8] found parkers at a new facility, who once used other existing curb and off-street facilities in the area, were *diverted* by more favorable conditions of cost and convenience. The study concluded that diversions of up to 30 percent from existing off-street spaces may take place on the basis of rates, up to 40 percent on the basis of location, up to 10 percent on the basis of accessibility, and up to 10 percent on the basis of improved operations. Where existing curb spaces were metered, diversion of up to 50 or 60 percent was found to be possible if rates were comparable. The study points out, ". . . if rates in the new facility are significantly higher than metered curb spaces, little diversion could be expected since parkers apparently prefer curb space." (Such a condition might suggest that curb rates should be increased.)

Figure 5 illustrates the relation between diversion, distance from major generator, and parking costs as found in a California study;[9] it plots diversion against the product of the cost and distance ratios. In this study, parking cost was found to be more important than distance. Further, the amounts of diversion were found to be in proportion to the square root of distance. Using similar curves to Figure 4, based on field studies in a given area, the effect of a proposed parking facility on other parking facilities within its influence area could be estimated for any assumed combinations of rates and distances.

Daily and Annual Usage. Parking facility usage on a daily and annual basis should be estimated, based on comparisons of existing and anticipated supply and demand, and from usage patterns for other facilities in the area of influence. Estimated parking volumes should be derived for each facility's first year of operation. To this must be added an estimate of future growth. The time period over which future growth or change is estimated is based generally on the assumed life of bonds or other financing methods, that commonly range from 20 to 30 years.

Forecasts of future parking volumes should be conservative, particularly where financing is involved. On the other hand, it may be advisable to make a more liberal supplementary forecast for design purposes.

[8] D. Jackson Faustman, "Estimation of Parking Facility Usage," *Traffic Quarterly*, 27 no. 1 (January 1963):68–78.

[9] Ibid.

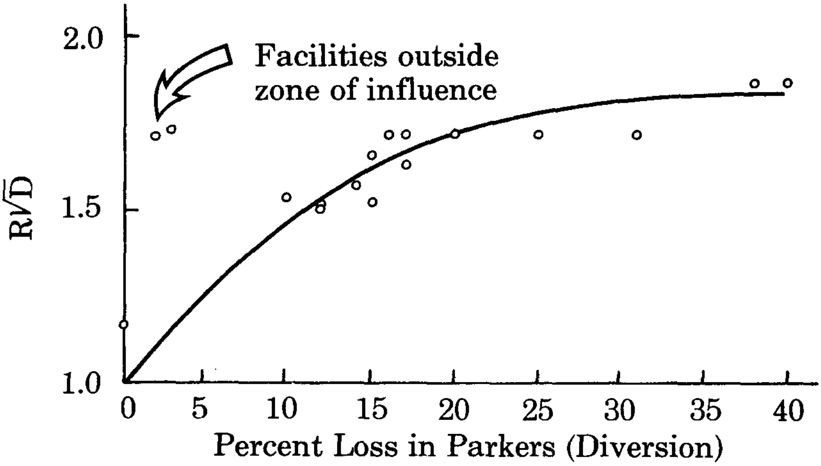


FIGURE 4. Relation between parker diversion, rates, and distance from generator. These percentage ranges for diverted parkers were derived from an analysis of diversion from existing parking facilities when two new parking lots were opened in the same demand-influence area. The diversions from existing facilities were developed from field studies and related to price differential and relative distance from the main shopping and business street. Price differential was calculated as the ratio of the parking fees charged at existing and new parking facilities (ratio termed R), based on a parking duration of 2 hours (the average parking duration for the area). Relative distances from the major generator area to existing and new parking facilities were expressed as a ratio D.

Source: D. Jackson Faustman, "Estimation of Parking Facility Usage," *Traffic Quarterly*, Eno Foundation (January 1963), p. 73.

Reasonableness of Estimate. Estimates of first-year parking volumes and future year volumes should be reviewed for reasonableness. Annual parking volumes should be reduced to daily totals and compared to the proposed facility's capacity to handle such volumes. Computed turnover should be consistent with estimated average parking durations.

It is important to assess the ability of adjacent street systems to accommodate anticipated traffic loads. This is accomplished by determining the traffic capacity of the streets and any scheduled near-term capacity additions, and comparing these with the peak hourly load expected from a proposed parking facility. The peak parking load is obtained by applying the appropriate hourly factor to the estimated daily parking volume, depending on the type of parkers served.

Operating results of existing facilities, such as daily parking volumes and turnover, can serve as indicators of the reasonableness of parking volumes estimated. Estimated volumes that are considerably higher (or lower) than those experienced in existing facilities in the influence area should be reviewed to determine whether special circumstances justify them.

FEASIBILITY ANALYSIS AND PROGRAM IMPLEMENTATION

Cost-revenue projections made in an economic feasibility analysis will be studied carefully by potential investors, and the credibility of the results will depend on the on-site research and the assumptions made. Assumptions of traffic, parking turnover, parking rates, or operating expenses and development costs must be reasonable for credible analysis. For a new parking facility to be competitive, it must provide parking rates that approximate those of the competition.

Most investors will want to know answers to questions such as:

1. In the subject community, what degree of competition is provided by private enterprise in parking? Does the public parking agency own or control most, if not all, of the prime downtown parking sites, or is the municipal ownership of parking facilities in the minority, with strong private ownership interests well represented at "City Hall"?
2. Are the existing or proposed new parking facilities in prime locations adjacent to major vehicular traffic generators such as private office buildings, hospitals, downtown medical clinics, universities or colleges, downtown shopping malls, major hotels or motels, sports coliseums or arenas, theatres, or government buildings? To what degree does a single parking facility depend on a single source of traffic generation, and what type traffic will be generated (long-term, short-term, daytime only, or evenings)?
3. How do the environmental considerations weigh in the economic study? The Clean Air Act Amendments of 1977 prohibit the U.S. Environmental Protection Agency from restricting commercial off-street parking operations. However, states may impose restrictions on off-street parking facilities as indirect-source polluters of the air (not directly polluting but attracting automobiles that do). Potential investors want to know the vulnerability of a proposed parking facility to potential shutdowns or other restrictions that could result in temporary cessation

or reduction of revenues. They may want to know if business interruption insurance is available, which could constitute an offsetting factor.

Economic Feasibility

Most new parking facilities cannot be financed on the basis of annual debt service coverage projected for the new facility alone, without combining this coverage with the demonstrated annual debt service coverage from historical net revenues of existing facilities. Even so, parking as a wholly self-supporting enterprise is becoming more difficult to achieve because of rising construction and operating costs and interest rates relative to parking fees.

Quite often, economic feasibility is compared on a numerical basis represented by an estimated debt coverage ratio (net revenue divided by debt service). However, the same debt coverage ratio found for two different projects may not mean equal economic feasibility. For example, two parking garages might each have a debt coverage ratio of 1.20, which normally would be adequate to support the sale of general obligation bonds or for certain other financing methods, but unacceptable for revenue bond financing. In this case, financial feasibility may hinge on the financial method available for the individual garages rather than the debt service ratio alone.

Comparative Analysis for Break-Even Income. Parking garage cost-revenue relationships vary, depending on type of construction, land cost, and financing arrangements. These factors, in turn, influence the break-even income required for any given facility.

Table VII illustrates required minimum daily break-even incomes on a per-space basis for differing land costs and interest rates. This comparative analysis assumes municipal financing through general obligation bonds. Alternate financing arrangements might result in differing costs. Table VII is based on the following assumptions:

1. construction cost at $3,500 per space ($3,000 for superstructure, $500 for electrical, mechanical, plumbing, and so forth);
2. engineering, architecture, and contingencies at 18 percent of construction cost;
3. floor space per vehicle assumed at 325 square feet;
4. land cost at $5, $10, and $20 per square foot;
5. financing costs at 3 percent of land, construction and contingencies cost;
6. interest during construction (2-year period) at 6 percent is

0.12 times the cost of land, construction and contingencies; at 8 percent is 0.16 times cost of land, construction and contingencies; and at 10 percent is 0.20 times the cost of land, construction and contingencies;

7. thirty-year bond issue, 2-year construction period, and 28-year earning period (at 6 percent interest, debt service factor is 0.0746; at 8 percent interest, debt service factor is 0.0905; and at 10 percent interest, debt service factor is 0.1075);

8. three hundred revenue-producing days per year assumed;

9. operating costs assumed at $0.90 per space per day;

10. general obligation bond financing (1-year debt service reserve is not included).

Table VII also shows the effects of construction type, assuming no construction cost differential for additional parking levels. For example, at 8 percent interest, incomes of $0.63 per space per day are required to meet construction cost for both a three-level and six-level structure; however, for each $10 per square foot in land value, a three-level structure requires an additional $0.16 per space per day, while a six-level structure theoretically cuts this land cost in half, to $0.08 per space per day.

Construction delays and inflationary increases in construction costs can have a substantial impact on required minimum daily break-even incomes. For instance, assuming a 7 percent annual increase in construction costs and a fixed 8 percent interest rate, a 1-year construction delay for a three-level structure would require an additional $0.11 in daily revenues to meet construction costs, and approximately $0.13 additional for each $10 per square foot in land values. Such cost increases emphasize the importance of rapid, meaningful actions and assessments to avoid protracted impact-evaluation periods that would cause building delays.

TABLE VII—REQUIRED MINIMUM BREAK-EVEN PARKING INCOMES (DAILY COST/SPACE)

Land Cost Per Sq. Ft.	*3-Level Garage*[a] *Interest Rate*			*6-Level Garage*[a] *Interest Rate*		
	6	*8*	*10*	*6*	*8*	*10*
$ 0	1.50	1.53	1.56	1.50	1.53	1.56
$ 5	1.58	1.61	1.64	1.54	1.57	1.60
$10	1.66	1.69	1.73	1.58	1.61	1.64
$20	1.82	1.86	1.90	1.66	1.69	1.73

[a]No differential assumed between 3-level and 6-level construction costs.

Financing Methods

Parking facility financing is essentially similar to other enterprises, including the usual differences between private and public ownership and financing. General obligation bonds and revenue bonds have been chief sources of public funds, while insurance companies, banks, local investors, and mortgage companies have been common sources for private borrowing.

Private Financing. Use of private financing for commercial parking traditionally has been based on a relatively short loan repayment period, typically 15 to 20 years, and has required an equity payment equal to the value of the site. This has sometimes resulted in the equity being 30 to 40 percent of project costs.[10] However, developers have used a variety of arrangements to finance parking projects, including public participation. Where a new parking facility would be important to adjacent businesses, an association of the benefited enterprises may be formed to provide the developer with funds for land acquisition or to assist otherwise in securing a loan. In return for rights to operate a facility, potential operating management has in some instances participated in the financing.

Public Financing. Use of public financing for parking facilities is related to local government practices. Project cost is normally met through bond issues or assessment districts. Bond financing feasibility can sometimes be improved and interest costs reduced through provisions for broader-base and diversified bond security.

To maximize the creditworthiness (rating) of parking revenue bonds, it is common practice to include in the pledge of available revenues the income of several parking facilities. Investors consider a single parking facility suspect as to its ability to obtain projected revenues, over a long period of time, equal to the retirement schedule of the bond issue. It is therefore rare to find a high bond rating applied (or any rating at all) to a bond issue supported by the revenues of a single parking facility. This condition seems to hold true regardless of projections made in economic feasibility reports. By including the revenues from all parking facilities under the control of a parking agency, a greater degree of parking diversification and a broader parking revenue base

[10] Alan M. Voorhees and Associates, Inc., and Lev Zetlin Associates, Inc., *Technical Report on Steel Framed Parking Structures*, prepared for the United States Steel Corporation, May, 1971, p. 4. Available through United States Steel Corporation, Pittsburgh, Pennsylvania.

are obtained—and the major detriment to single facility financing is alleviated.

Figure 5 illustrates a typical flow of funds, using parking-revenue bond financing with pledged parking revenues from several off-street facilities, and augmented as needed by on-street parking meter revenues.

Curb-meter revenues are often used to augment off-street parking facilities. In some communities, such revenues are set aside in a special fund used to meet deficiencies from inadequate off-street user revenues. At the end of each fiscal year, surplus curb-meter revenues flow into the community's general fund. Autonomous parking authorities, however, often do not have access to curb-meter revenues—a situation contributing to increasing financial indebtedness of many parking authorities that are unable to support the aggregate of operating and maintenance expenses, plus debt service and reserves, with tolerable user charges.

Issuance of general obligation bonds for parking facilities, or any other purpose, is another way in which bond security is maximized. These full faith and credit tax bonds reflect all the tax sources a public agency has to offer.

Some financing for parking development comes from capital budgets, federal revenue-sharing, capital improvement grants, and urban renewal credits.

Baltimore County, Maryland, has established a benefit assessment district for off-street parking. The city's approach requires developers to provide adequate parking, either privately or through the county, with the county recouping any debt-service deficits through an *ad valorem* tax.

Several western states allow businessmen to form parking districts, with parking facilities supported by *ad valorem* taxes on benefited property within the district, similar to the manner in which sewers and sidewalks are financed. Curb-meter and other parking revenues are also included as parking district revenue.

Cooperative Public-Private Approaches. Advantages of both private and public undertakings can be effectively combined by cooperative public-private approaches, to overcome obstacles that each might face when working alone. This public sector-private enterprise cooperation can assume a variety of methods.

In some instances, cities have purchased land for parking from groups of businessmen over a period of time, while in other cases government agencies have leased land from private individuals or companies for parking purposes. Cooperation also has taken the

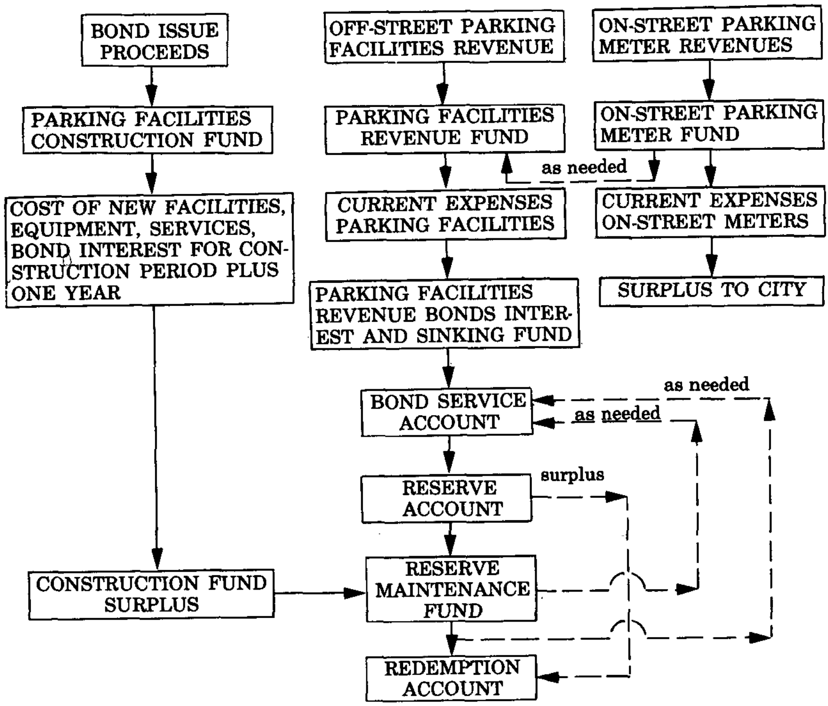


FIGURE 5. Typical flow of funds using parking revenue bonds.
Source: *Municipal Parking System Report*, City of Tampa, Florida (1974).

form of tax relief agreements;[11] urban redevelopment programs under which designated land in a development area is to be developed by private enterprise for parking; and government-provided technical services, advice, and surveys.

Cities can use powers of eminent domain and obtain low rates of interest on bonds. Private groups can provide efficient day-to-day management. Some cities, for instance, have made arrangements with private operators to partially finance parking facilities, permitting the operators to borrow a percentage of project costs from the city at favorable interest rates. Other cities have acquired land by condemnation to assist private enterprise in obtaining suitable parking sites. And many cities actually construct facilities,

[11] Tax exemption or relief may not be constitutional in some states. The two principal grounds for unconstitutionality are: (a) Power to grant exemptions made by a state constitution is confined to public and charitable institutions; and (b) constitutional provisions providing for equality and uniformity of taxation may be violated.

which then are operated by private groups. Short-term management contracts (usually under three years) are generally desirable for private operation of publicly owned facilities (see Chapter VII for discussion of parking management contracts).

Parking As a Public Service. Rising construction and operating costs and interest rates make it increasingly difficult for garages to be financed from user revenues alone. Consequently, parking garages are increasingly viewed as essential public services in which the developers, or public agencies, offset a portion of development costs.

The relative roles of private enterprise and public agencies in providing and financing new facilities will vary among communities. Each community must identify the type of parking program best suited to its particular needs. Regardless of who assumes the primary responsibility for developing, financing, and implementing parking facilities, public agencies should assume a basic role in program formulation and administration.

Implementation Considerations

Following the financial analysis, the parking project or program should be refined and detailed. Related regulations needed to ensure project performance should be identified, including curb parking regulations, enforcement, street improvements, and so forth.

Implementation strategies and priorities then should be developed. The methods of program accomplishment, including public-private sector cooperation, should be defined. Once established, the program should be kept current by continuing review, financial monitoring, and adaptation to changing requirements or community values.

Once the program, or project, is established and a decision is reached to develop a parking garage, the next steps include detailed planning, design, and operation. Guidelines for these steps are set forth in remaining chapters of this monograph.

Chapter III

GENERAL DESIGN GUIDELINES

The planning of parking garages, as well as location and design, involves balancing economic, engineering, environmental, and land-use considerations. With a knowledge of parking needs and parameters, the developer, whether public or private, turns to site selection and parking facility design. While site selection is a planning function, it is so closely related to parking facility design that it is discussed in this chapter.

Site selection for new off-street parking reflects a balance of many competing factors, especially site costs and usefulness in meeting parking needs. Additionally, other factors, relative to demands, influence site selection. These include land availability, land-use compatability, site size and shape, and accessibility. Together with site costs and usefulness, these factors dictate parking facility type, and influence functional design elements.

Parking facility design must also consider alternatives in materials and building systems, appearance objectives, and space-use efficiency. But above all else, parking facility design must reflect consideration for the user through safe, functional operational features.

Site Location and Development

Parking facility location is basic to gaining optimum facility use. Whether new parking is intended to enhance economic viability of a particular area, reduce street congestion, attract new investment, or to serve combinations of these objectives, location is always paramount to their attainment.

Individual parking facility location depends on the nature of parking deficiency, generator types to be served, user characteristics, street system controls, and costs relative to alternatives in location and facility type. An individual parking project must be compatible with overall transportation system plans as well as local parking needs, and land uses in the area of influence.

Subject to the constraint of avoiding land fragmentation, off-street parking facilities should be sited as near as possible to the generators they serve. The usefulness of potential sites is established by parking studies. However, many areas of greatest parking need may be economically impractical parking locations because of site costs or lack of convenient access. A project's economic practicality may be improved, in some instances, through sharing land and development cost with other land uses. Such joint use also provides continuity for pedestrian movements and minimizes land fragmentation.

Parking facility usefulness can be improved by location and design considerations that permit daytime and nighttime use, and provide for differing usage characteristics of these different time demands. For example, daytime parking may be business oriented while nighttime parking is mainly for recreational or cultural purposes.

Accessibility

Accessibility to parking sites for both vehicles and pedestrians is an important aspect of site selection.

Pedestrian Access. Pedestrian considerations are critically important to site selection and parking development. Ideal sites are those within short walking distance of parkers' destinations. Maximum walking distances of 1,000 to 1,500 feet (305 to 457 meters) for work trips, and 500 to 800 feet (152 to 244 meters) for shoppers, represent desirable guidelines for large cities.[12] For smaller cites, maximum desirable walking distances are 600 to 700 feet (183 to 213 meters) for work trips, and 200 to 350 feet (70 to 107 meters) for shoppers.

For pedestrian access to be safe and convenient, it should be restricted to designated points, with informal pathways for random access prevented. Restricting pedestrian access to prescribed points may conflict with convenience considerations, but is necessary for safe operation, minimizing pedestrian-automobile conflicts, and for security reasons stemming from unauthorized and/or undetected access. Designated points of pedestrian access at parking locations further serve to direct unfamiliar users to their intended destination along the safest and most convenient route.

Pedestrian access is improved when sites can allow direct connections to major generators via bridge or tunnel, avoiding vehicular traffic crossings. Enclosed pedestrian overpasses offer weather

[12] Herbert S. Levinson and Edward M. Whitlock, "Economic and Environmental Considerations in Parking and Design" (Paper presented at American Society of Civil Engineers Annual and National Environmental Convention, Kansas City, Missouri, October 25, 1974) p. 7.

protection and—whether covered or not—are generally preferred over tunnels for security reasons. Overlighting and unrestricted sight distances add to actual and perceived security of pedestrian-users.

Walking distances can be psychologically enhanced if they are designed to route pedestrians along commercial frontages having display windows. Cantilivered structure appurtenances over sidewalks, landscape plantings, informational and directional signing, or other amenities such as time and temperature displays, make walking more pleasant.

While hilly terrain may leave few alternatives, steep hillside locations are undesirable from the standpoint of pedestrian convenience. Where such grade differences are unavoidable, parking sites located *uphill* from major trip generators should be favored, since pedestrians are psychologically more influenced by the perceived walking trip *to* the generator than by the return trip. However, hillside locations may offer unique means for vehicular access to different parking garage levels, not requiring interfloor ramp travel.

Pedestrian access points should preferably be located on the parking facility side nearest the major generator(s), providing

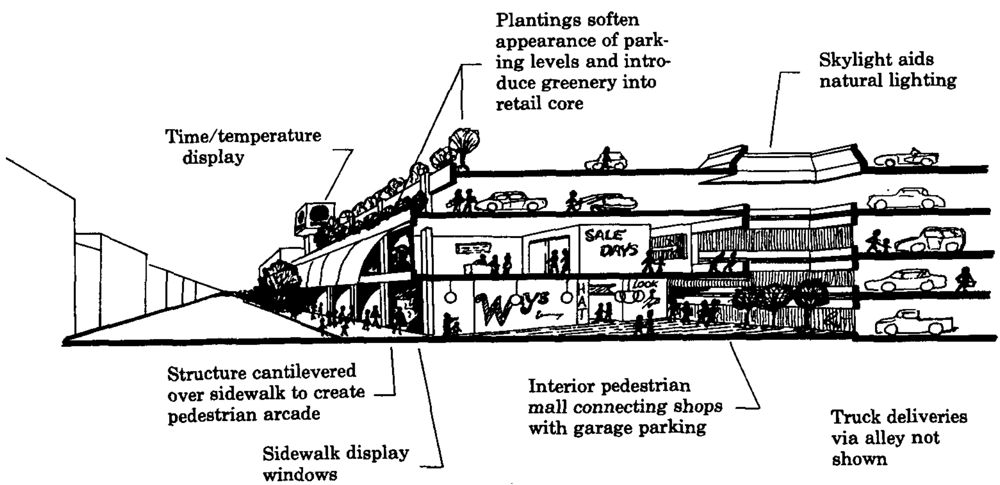


FIGURE 6. A multiple-use design concept for downtown offering efficient foot-traffic patterns in semi-malled and weather-controlled galleries connecting multi-level commercial space with structure parking.

pedestrians visual contact with generators and routing them over the shortest possible distance. Unsafe alternative routes should be discouraged by use of barriers or other disincentives (landscaping, fencing, architectual facades, signing). While barriers may be necessary to direct safe pedestrian travel, they should not be designed in such a way as to provide hiding places, or restrict sight distances and lighting.

Existing at-grade pedestrian street crossing facilities and controls surrounding potential parking sites should be examined, and changes warranted by the addition of a parking operation should be anticipated. Nearby intersections may require traffic signalization, or rephasing of existing signal controls, for increased pedestrian movements. Midblock pedestrian crossings may be justified, or street type and traffic conditions might be such as to preclude at-grade pedestrian crossings altogether. Upgraded street lighting may also be required.

Vehicular Accessibility. Site selection and facility design must recognize vehicular interchange between a parking facility and the street system as of major importance to user, operator, and the community. From these differing perspectives, vehicular access considerations may face conflicting objectives. Parkers will desire convenience and undelayed ingress and egress. Operators will be concerned with the street system's ability to accommodate entering and exiting traffic. The general community will be concerned about traffic routing impacts, back-ups onto city streets, and pedestrian safety. It is important that these objectives be attained, and conflicts minimized as much as possible.

Ideally, sites should be located to minimize cruising by motorists in search of a suitable parking space. A site requiring motorists to travel on side streets to enter a parking facility may be suitable for workers, familar with the location and routing, but is not convenient for transient parkers entering the area. Nor may it be acceptable to residents and property owners along the side streets, because of increased traffic flows.

Design and capacity analysis should view a parking site and its surrounding streets as a *system*. Directional traffic approaches to the influence area, and traffic conditions and controls on adjacent streets, are critical considerations to both site selection and facility design. Precise routing from major arterials and freeways to potential parking sites must be examined in regard to probable traffic impacts of future development. Introduction of a parking facility may complicate traffic patterns, requiring one-way street systems or other means to reduce driving times and improve accessibility.

Sites offering access from different streets, such as corner locations, can be advantageous for parking facilities if entrances and exits can be located without intersection interference. However, corner sites are desirable for retail development and often command a higher land cost.

A site's ability to offer well-located street access points may be determined by answers to such key questions as:

1. Will traffic queues from nearby intersections extend across potential entrance or exit points?
2. Are there already traffic queues on site approaches?
3. Can all access to and from two-way streets be via right turns?
4. Can streets be widened to provide adequate storage space for queued vehicles?

Facility size should be scaled to the ability of adjacent streets to accommodate parking facility traffic. This suggests a range from

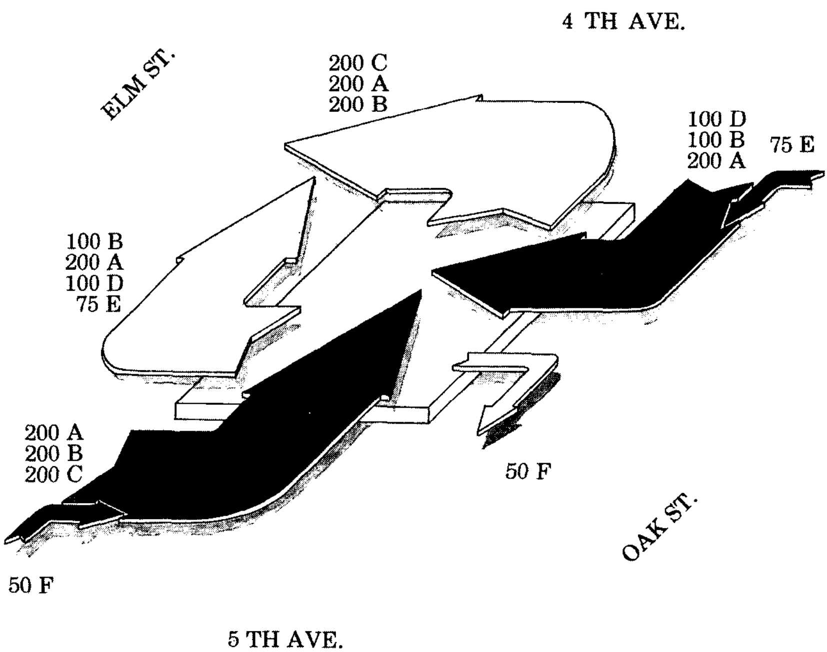


FIGURE 7. Potential traffic movements into and out of a proposed garage can be determined if the destinations of potential parkers are obtained on a relatively accurate location basis (such as a block face) and give some indication of time of arrival and duration of stay.

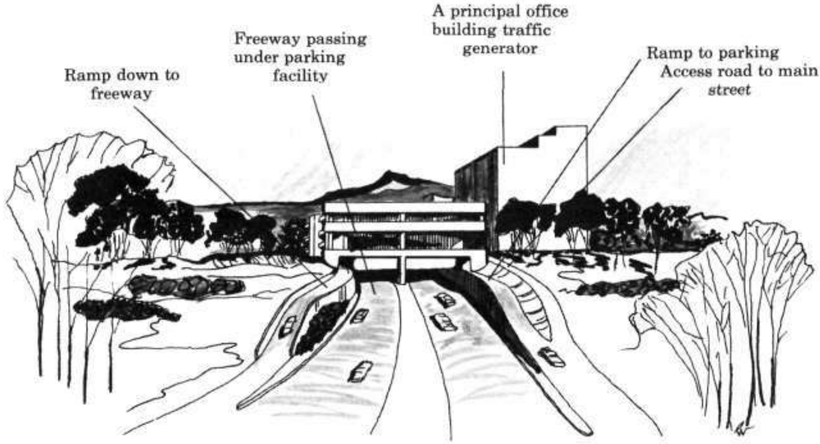


FIGURE 8. Structure parking with direct freeway access.
Note: This parking plan is being developed as a four-level garage to accommodate 1,000 cars in Tulsa, Oklahoma.
Source: Hudgins, Thompson, Ball, and Associates, architects and engineers of Tulsa and Oklahoma City, Oklahoma.

approximately 500 to 2,500 spaces. Parking garages exceeding 1,200 spaces should be located for nearby or direct freeway access.[13]

The ideal movement into an off-street parking facility is a straight approach, requiring no on-street turning movement. A left turn from a one-way street into a parking facility is also desirable, because a driver using the inside lane for a left turn has better visibility and can make more accurate vehicle manuevering judgments.

Site access from high-volume two-way streets may require left-turn restrictions on entering and exiting parking facility traffic, special left-turn lanes at mid-block entrance locations, or access separated from adjacent street traffic. When entrances and exits are separated, entrances should be placed in the upstream traffic portion of the block, and exits should be located in the downstream portion of the block. Side-by-side entry and exit points should preferably be located at mid-block.

Environmental design for minimizing air pollution from traffic congestion requires sufficient entrance and exit capacity. As a general guideline, one inbound lane should be provided for every

[13] Ibid., p. 8.

500 spaces in a garage serving long-term employee parking, and for every 600 spaces in garages serving short-term shopper parking. One outbound exit lane should be provided for every 200 spaces in an employee garage, and for every 250 spaces in a shopper garage.[14]

Parking facility entrances should be clearly visible to drivers along approach streets. Whether the facility itself should be unmistakably visible as a parking facility is subject to considerations discussed later. Sidewalk pedestrian circulation requirements should be recognized where multi-lane access points may be required. In some cases, this may limit width of the access points.

Additional design parameters for vehicular access and pedestrian circulation are discussed in Chapters IV and VI.

Site Efficiency

The size, shape, and often the topography, of a site influence parking layout efficiency. Site efficiency may also depend on a site's ability to accommodate multiple-use development.

Site Size and Shape. Rectangular sites generally provide the best shape, since parking structures usually have rectangular floor plans. Although irregular-shaped sites are generally avoided, they can be suitable for helically-shaped parking ramps, serving circular floor plans. For parking stuctures, odd-shaped sites may offer opportunities to develop either ingress or egress ramps outside the basic structure envelope, or special access to streets.

Site topography may permit direct street access between different parking levels.

Site width is particularly important to parking layout efficiency. Design alternatives and space-use efficiency are seriously impaired with site widths less than 120 feet (37 meters). Site widths between 95 and 120 feet (29 and 37 meters) can be used for parking structures, but require angle parking and severely limit alternative parking layouts and interfloor ramp systems. Site widths between 120 and 200 feet (37 and 61 meters) can accommodate several different floor layouts, parking angles, and interfloor ramp designs, providing alternatives from which to select the most cost-effective and space-efficient design.

Site length is relevant to both space-use efficiency and operational efficiency. Longer sites permit more space-efficient develop-

[14] Highway Research Board, *Parking Principles*; and Levinson and Whitlock, "Economic and Environmental Considerations in Parking and Design," p. 8.

ment of parking stalls along access aisles parallel to the site's long dimensions. This is because there are more stalls on which to prorate unusable floor space located at structure corners.

However, as aisle lengths increase as a result of available site length, inefficiencies may develop in traffic operation caused by excessive travel length and increased potential for conflicting traffic movements. Longer travel lengths require more driving time, reducing user convenience, increasing air pollution, and requiring more extensive traffic control measures within a parking facility. These factors are aggravated by increased chances for disruption to circulating traffic caused by parking-unparking maneuvers.

Maximum site length is related to horizonal circulation require-

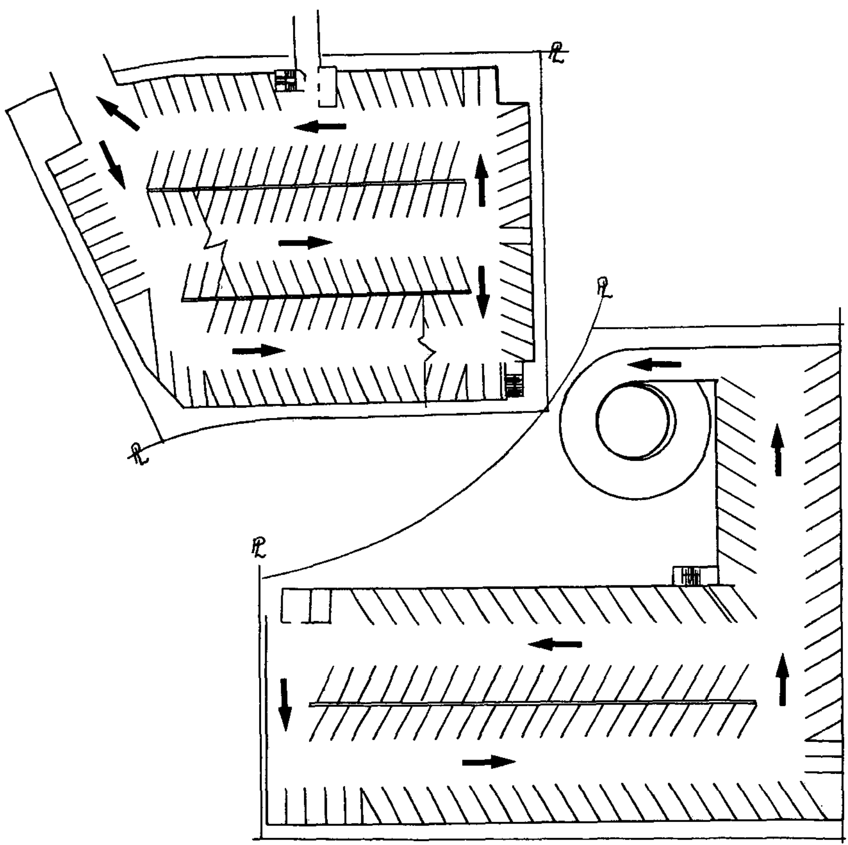


FIGURE 9. Odd-shaped sites may offer opportunities to develop ramps outside the basic structure envelope, or special street access.

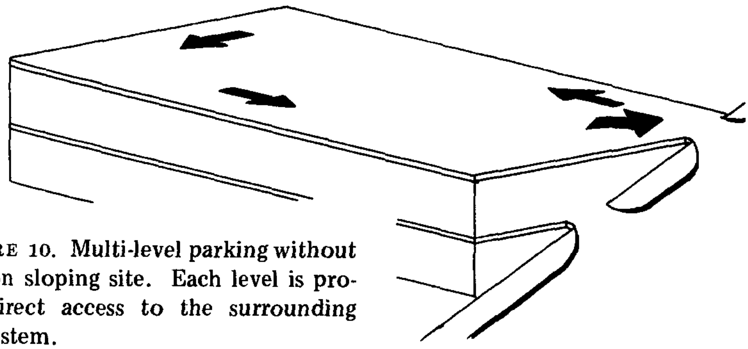


FIGURE 10. Multi-level parking without ramps on sloping site. Each level is provided direct access to the surrounding street system.

ments of particular facility configurations. Generally a 300-foot-long (91 meters) aisle is considered optimum in efficient length.[15] Shortening the length decreases space-use efficiency on a per stall basis. Lengthening increases travel time and traffic conflict potentials, unless auxiliary ramp systems are provided.

Land-Use Compatibility

Local ordinances frequently regulate new development. Height limitations, building setback requirements, visual screening of parked cars, and landscape requirements used to improve land-use compatibility affect parking design and, in some instances, site selection.

Height Limitations. Parking structure height is limited by (1) how many floor levels motorists are willing to traverse to reach a parking space, (2) cost of building vertically compared to cost of horizontal development, and (3) conformity to building heights in the area. The first two aspects represent design and economic controls; the third aspect relates to local ordinances.

In parking structures, clear height between floor and ceiling is commonly a little over 7 feet; 7.5 feet is desirable, (2.13 meters minimum, 2.29 meters desirable), floor-to-floor height being approximately 10 feet (3.05 meters). It has been found that to require drivers to make more than five or six 360-degree turns in traveling between the most distant parking level and the street level invites driver confusion, particularly on downward movements. Depending on ramp-system configuration, this maximum

[15] Parking Standards Design Associates, *A Parking Standards Report, Vol. I*, prepared for Associated Organizations Committee and Other Involved Groups, City of Los Angeles, California, (March 1971), p. 22.

turn parameter will generally limit parking structures to seven stories above ground, resulting in 90 feet (approximately 27 meters) of maximum overall height, including roof-level light standards and stair/elevator towers.

Local regulations sometimes limit the maximum ground space for parking facilities, which may require multi-level development to provide a desired number of parking spaces. On the other hand, local regulations may also establish maximum building heights for reasons of visual amenity and/or fire-fighting accessibility. Table VIII provides typical examples of building code regulations for above-ground open-wall parking structures. Of the 92 cities listed, 30 permit 6 tiers of floors, and 26 permit 9 tiers. Seven cities allow 85-foot structural heights.

Height limitations, whether imposed by accepted design practices or local regulations, can have significant cost impacts on parking structure development. When height limitations prevent development of a desired number of above-ground parking spaces on a particular site, the alternatives are to acquire more land or to extend below ground, which both increase costs. A third alternative is to reduce capacity.

Setback Requirements. Street setback requirements are advantageous, although they can increase development cost by reducing overall size of possible sites. Advantages are generally believed to overshadow incurred costs. Setbacks provide more reservior space to temporarily store entering and exiting traffic between street and parking facility access openings. Sight distances at parking garage entrances and exits are less likely to be obstructed, and turning radii can be more generous, providing faster traffic movement. Setbacks also allow space for landscaping and aesthetic improvements.

Visual Screening. Parking structures can be developed to look like a parking facility or blend with surrounding architectural statements. The choice depends on individual project goals and area objectives. When a parking facility looks like a parking facility, it serves as its own advertisement, conveying evidence of parking availability. However, many developers have felt that maintaining existing neighborhood architectural character, or improving visual aesthetics, is prerequisite for area or generator attraction. As a result, they have provided facades that fit the parking structure into the surrounding area.

Visual screening may have aesthetic as well as economic value. However, screening can conflict with good design and safety practices. Considerations requiring special attention include natural ventilation (or use of mechanical ventilation), maintenance of critical sight distances at access points, user security and orientation to surrounding generators, and natural lighting. Screening can also serve to control pedestrian access.

Multiple-use development is an effective means of blending parking with its environment, and at the same time integrating pedestrain and vehicular systems. Multiple-use development can both unify and beautify downtown areas.

Multiple use is the integration of parking with other land uses on the same site. A parking garage constructed under or above an office building, or as part of a retail complex, are examples—as would be a parking garage driving ramp extended outside a garage structure in airspace over property devoted to nonparking use.

Multiple-use development improves city center environmental quality, provides pedestrian circulation continuity, improves CBD land-use accessibility, and helps offset parking development costs. Advantages can also include convenience afforded by close proximity of parking facility and generator, a higher assurance of parking-space utilization, and lower total land costs through reduction in land requirements. Development cohesiveness and nonduplication of facilities are fostered by multiple-use development.

Principal problems are increased development costs and legal constraints impacting some public agencies. However, increased

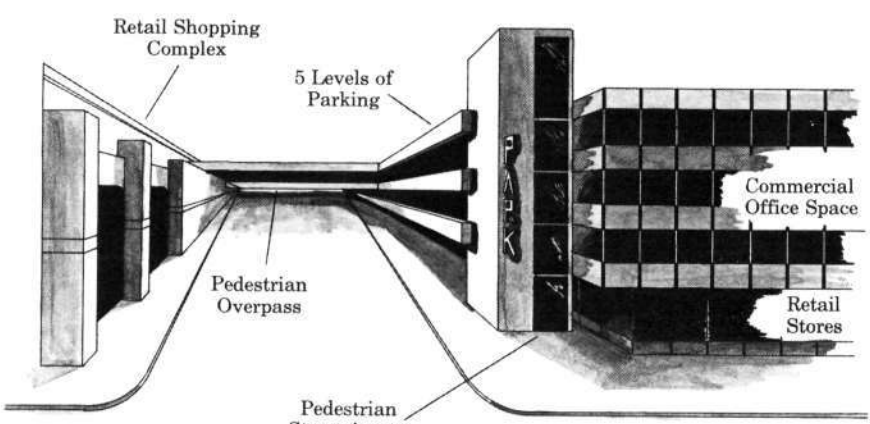


FIGURE 11. A multiple-use development concept integrating parking with other land uses on the same site, as well as a separate site.

TABLE VIII—REPRESENTATIVE ALLOWABLE HEIGHTS AND AREAS FOR RAMP-TYPE OPEN AUTOMOTIVE PARKING STRUCTURES OF UNPROTECTED NONCOMBUSTIBLE CONSTRUCTION

Building Code	*Allowable Height (Tiers or ft)*	*Allowable Area Per Tier (sq. ft)*	*Increases Permitted**	*Design Live Load (psf)*
BOCA-Basic Building Code, 1970 Edition	9	30,000	Area	50
AIA-National Building Code, 1967 Edition	55 ft	30,000		50
SBCC-Southern Standard Building Code 1970 Edition	9	30,000	Area	50
ICBO-Uniform Building Code, 1970 Edition	6	30,000	Area & Height	50
State of Connecticut, 1970 Edition	9	30,000	Area	50
State of Indiana 1968 Edition	8	30,000	Area & Height	50
State of New York, 1964 Edition	5	30,000	Area	50
State of North Carolina, 1967 Edition	9	30,000	Area	50
State of Ohio, 1967 Edition	85 ft	30,000	Area	50
State of Pennsylvania, 1968 Edition	No Limit	30,000	Area	50
Akron, Ohio	85 ft	30,000	Area	50
Allentown, Pennsylvania	9	30,000	Area	50
Amarillo, Texas	6	30,000	Area & Height	50
Anaheim California	6	30,000	Area & Height	50
Atlanta, Georgia	55 ft	30,000		50

Baton Rouge, Louisiana	55 ft	30,000		50
Beaumont, Texas	6	30,000	Area & Height	50
Berkeley, California	6	30,000	Area & Height	50
Birmingham, Alabama	9	30,000	Area	50
Bridgeport, Connecticut	9	30,000	Area	50
Buffalo, New York	5	30,000		50
Canton, Ohio	85 ft	30,000	Area	50
Charlotte, North Carolina	9	30,000	Area	50
Chattanooga, Tennessee	9	30,000	Area	50
Cincinnati, Ohio	85 ft	30,000	Area	50
Columbus, Georgia	9	30,000		50
Columbus, Ohio	85 ft	30,000	Area	50
Corpus Christi, Texas	9	30,000	Area & Height	50
Dallas, Texas	6	30,000	Area & Height	50
Des Moines, Iowa	6	30,000	Area & Height	50
El Paso, Texas	5	30,000		50
Erie, Pennsylvania	5	30,000	Area	75
Evansville, Indiana	8	30,000	Area	50
Flint, Michigan	9	30,000	Area	50
Fort Wayne, Indiana	8	30,000	Area	50
Fresno, California	6	30,000	Area & Height	50
Gary, Indiana	8	30,000	Area	50
Glendale, California	6	30,000	Area & Height	50
Greensboro, North Carolina	9	30,000	Area	50
Hartford, Connecticut	9	30,000	Area	50
Honolulu, Hawaii	6	30,000	Area	50
Houston, Texas	9	30,000	Area	50
Indianapolis, Indiana	8	30,000	Area	50
Jackson, Mississippi	6	30,000	Area & Height	50
Kansas City, Kansas	6	30,000	Area	50
Knoxville, Tennessee	9	30,000		50

(continued)

TABLE VIII—(*continued*)

Building Code	*Allowable Height (Tiers or ft)*	*Allowable Area Per Tier (sq. ft)*	*Increases Permitted**	*Design Live Load (psf)*
Lansing, Michigan	6	30,000	Area & Height	50
Lincoln, Nebraska	6	30,000	Area & Height	50
Little Rock, Arkansas	5	30,000		120
Los Angeles, California	40 ft	30,000		50
Macon, Georgia	9	30,000		50
Memphis, Tennessee	9	30,000	Area	50
Minneapolis, Minnesota	60 ft	40,000	Area	50
Mobile, Alabama	6	30,000		50
Montgomery, Alabama	6	30,000		50
Nashville, Tennessee	6	30,000	Area	50
Newark, New Jersey	9	30,000	Area	50
Newport News, Virginia	9	30,000	Area	50
New York, New York	75 ft	30,000	Area	50
Niagara Falls, New York	5	30,000	Area	50
Oakland, California	6	30,000	Area & Height	50
Pasadena, California	6	30,000	Area & Height	50
Peoria, Illinois	55 ft	30,000		50
Philadelphia, Pennsylvania	9	30,000		50
Pittsburgh, Pennsylvania	9	30,000		50
Portland, Oregon	6	30,000	Area & Height	50
Portsmouth, Virginia	9	30,000	Area	50
Richmond, Virginia	9	30,000	Area	50
Rochester, New York	5	30,000	Area	75
Rockford, Illinois	55 ft	30,000		50
St. Louis, Missouri	5	30,000	Area	75
St. Petersburg, Florida	6	30,000	Area	50

Salt Lake City, Utah	6	30,000	Area & Height	50
San Antonio, Texas	6	30,000	Area & Height	50
San Diego, California	6	30,000	Area & Height	50
San Jose, California	6	30,000	Area & Height	50
Savannah, Georgia	6	30,000	Area	50
Scranton, Pennsylvania	5	30,000	Area	50
Shreveport, Louisiana	6	30,000		50
South Bend, Indiana	5	30,000	Area	75
Spokane, Washington	4	30,000	Area & Height	50
Syracuse, New York	5	30,000	Area	50
Tacoma, Washington	6	30,000	Area & Height	50
Tampa, Florida	9	30,000	Area	50
Toledo, Ohio	85 ft	30,000	Area	50
Topeka, Kansas	6	30,000	Area	50
Utica, New York	5	30,000	Area	50
Washington, D. C.	6	30,000		75
Waterbury, Connecticut	9	30,000	Area	50
Wichita Falls, Texas	4	30,000	Area & Height	50
Yonkers, New York	5	30,000	Area	50
Youngstown, Ohio	85 ft	30,000	Area	50

*Indicates increases in either height or area or both are permitted for access in excess of that required by code.

Source: United States Steel, *Technical Report on Steel Framed Parking Structures*, prepared by Alan M. Voorhees and Associates, Inc., and Lev Zetlin Associates, Inc. (May 1971), Table 3, p. 17-18.

development costs usually can be offset by land cost savings. Other potential problem areas concern water drainage and waterproofing, pedestrian circulation and security, truck loading-unloading provisions, and parking layout and operating efficiency. Practical column spacing for parking may not be suitable for other building uses above or below parking levels.

Careful planning is necessary to develop designs that consider structural needs and that do not present problems in operation. Design must ensure that nonparking development will not place undue safety hazards on the parking operation.

Landscaping. Whether a local requirement or simply the desire of the developer, landscaping can add to parking facility attractiveness and is good public relations. Disadvantages are initial cost and maintenance of appearance.

Landscaping in the context of parking facilities is generally restricted to trees, shrubs, and grasses. The latter two are minimized in actual use because of their relatively high maintenance requirements.

Landscape plantings should be selected on the basis of their disease resistance, future height, shape, color, maintenance needs, and ability to grow in the particular microclimate of the planting spot. Each planting location will have a set of conditions that will determine future satisfaction and ease of maintenance. Trees, especially, require detailed consideration of their intended surroundings. Is it hot, dry, wet, windy? Is the proposed tree location under wires, in the sidewalk, or near a traffic signal or sign?

Columnar trees, appropriate for narrow areas, include columnar maple, sentry gingko, crabapple, or any species ending in the word "fastigata" or "columnaris." Overhead restrictions such as wires or structures may favor shorter trees (hedge, tartarian and Japanese maples, crabapples, flowering cherries, dogwood, mountain ash, golden rain, Russian olive).

Fastest growing trees, which are suitable for street plantings, include green ash, London plane, American elm, honeylocust, and little leaf linden. The willow oak is also a good urban tree.

In snow climates, plants can be damaged by deicing salts. Calcium chloride is less damaging than sodium chloride. Trees more resistant to salt include the red and white oak, American elm, willow, sycamore maple, Australian pine, ailanthus, Japanese and Austrian pine, black gum, hawthorne, white poplar, and Russian olive.

Tree location decisions should take into account their effect after maturity on sight distances and structures. Trees that are highly subject to splitting in storms (willow, poplars, cottonwood, silver maple) should be avoided in close proximity with structures, open parking, and sidewalks.

In selecting landscape plantings, it is always best to consult with local agricultural extension services or landscape architects, particularly before planting a tree or shrub that is not native to the area.

Surface Lot Versus Structure Parking

Limited availability of land in central business district areas, coupled with many competing demands for space, results in relatively high land costs. This has placed increasing pressure on developers to make optimum use of land by building multi-level and/or multi-use parking facilities. "The nearer one goes toward the heart of a city, the greater is the value of the land, and the greater is the demand for parking space."[16]

Under conditions of high land costs or limited availability of land, structure parking often becomes more economically feasible than surface lot parking.

In core areas of larger cities, site costs alone may range to several thousand dollars per parking space. Construction cost may range upward from $3,000 per space, depending on type of structure—simple two-level deck construction at the lower end of construction cost while underground structures frequently exceed $7,000 per space (1976 price levels).

Where land is abundant and comparatively inexpensive, surface parking may be more economical than multi-level parking structures. The effects of land and construction costs (exclusive of interest and finance costs) on the unit costs for surface parking lots and multi-level parking structures are illustrated in Figure 12. This figure denotes the economic range for each facility type in relation to land costs for 1976 conditions.[17]

For land values below $14 per square foot, surface parking lots are generally more economical per space than structures. Above $14 per square foot, multi-level garages cost less per space than sur-

[16] John Brierley, *Parking of Motor Vehicles* (London: C. R. Books, 1962), p. 133.

[17] The following assumptions were used in deriving cost calculations. Approximately 325 square feet per parking stall; parking lot construction costs of $2.75 per square foot for demolition, grading, paving, lighting, fencing, landscaping, traffic appurtenances, and equipment; total construction costs of $2,600 per parking space for simple deck construction, and $3,500 for parking garage construction; 18 percent was added to construction costs for engineering, architecture, and contingencies, but no finance charges and costs were included.

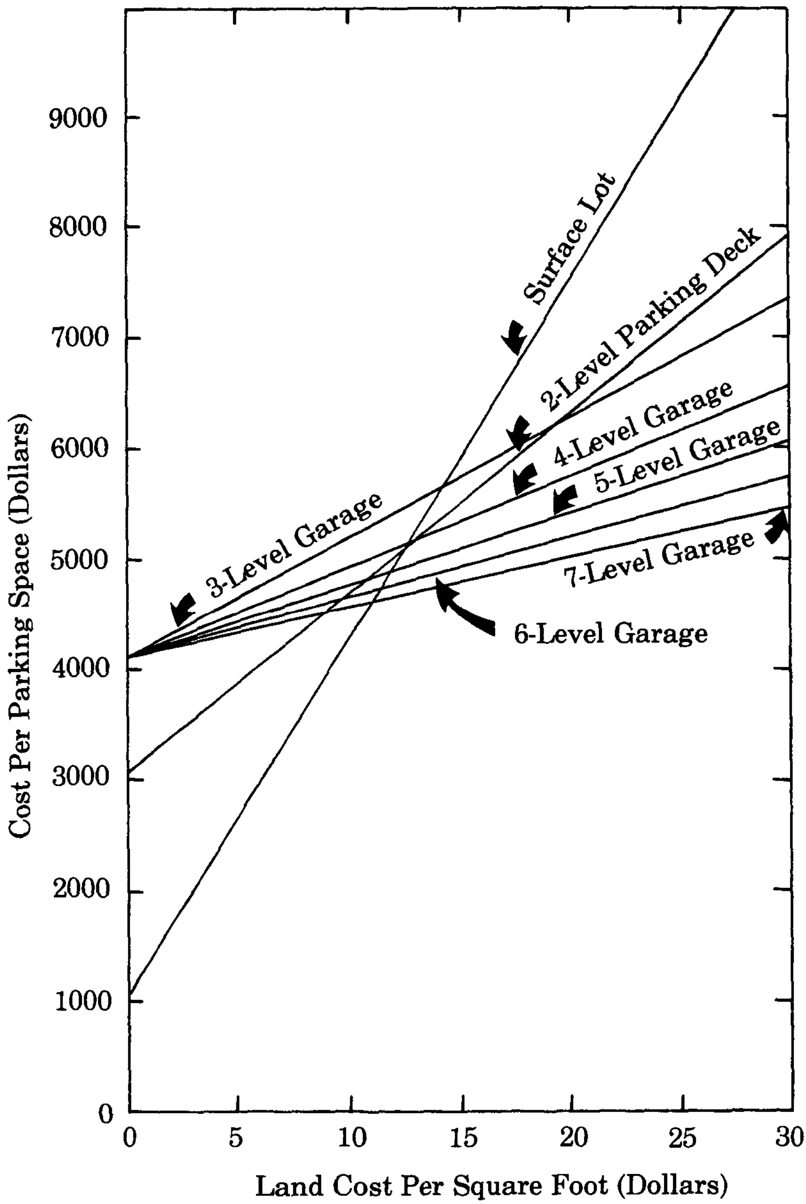


FIGURE 12. The effect of land value on parking space costs, 1976.

face lots. Combination facilities with vertically-mixed land uses may be more feasible where land costs are unusually high.

Trade-offs shown in Figure 12 reflect one point in time (1976). They will change, depending on relative increases (or decreases) in land values and construction costs. They will also vary when a portion of the land costs can be assumed by other developers (for example, urban renewal).

PARKING STRUCTURE DESIGN CONCEPTS

Parking garages may be free-standing (designed only for parking) or multiple-use structures. Either type may be above-ground open-air structures, underground structures, or combinations. They may be further classified by their means of interfloor vehicular travel—elevator (mechanical), or ramp types; or by their method of operation—self park or attendant-park.

Building Systems

All parking garages have structural systems that are either poured-in-place steel-reinforced concrete, precast concrete, post-tensioned concrete, structural steel, or combinations of two or more of these material systems.

The relative economy and adaptibility of various structural and material systems reflect:

1. local building code requirements, placing restrictions on kinds of structural systems allowed;
2. availability of materials, fabricators, and experienced contractors;
3. costs and shipping distances;
4. future maintenance requirements;
5. erection time and future facility expansion plans; and
6. atmospheric and environmental conditions.

One structural or material system cannot be better than another, or more economical, in all locations and under all conditions. Choice of the most correct structural and material system(s) can only be made after a comparative economic analysis, considering all influencing factors.

In addition to structural material systems, consideration must be given to alternative building systems. Choices can involve some form of modular or demountable design concept. Alternatives also exist in structural span lengths between supporting columns.

Modular Systems. The modular building system concept is based on maximum off-site fabrication of components prior to actual on-site erection. Components are prefabricated in units as large as possible, with each component being complete in structural integrity.

Modular systems can have advantages as compared to the historically more conventional concept of building-in-place. Faster on-site erection through factory fabrication serves to reduce costs. Modular structures also can have a high degree of demountability and reusability.

Modular component transportation to the erection site is the major disadvantage. State and federal laws specify maximum weights and dimensions for over-the-highway movements. The large size usually associated with modular components can make handling during transport and field erection more difficult, sometimes requiring heavier equipment than might be needed for building-in-place.

The modular concept is well suited to parking structures since parking geometrics are generally uniform and repetitive. However, many architects have considered modular construction aesthetically undesirable because of design monotony and the limits imposed on design by rigidized systems.

Demountable Systems. Demountable (portable) structures are designed and constructed to allow future disconnection of components and removal from the original erection site. This building concept uses structural systems that have the design and construction capability for its components to be portable, with reusability incorporated.

Theoretically, the concept of demountable parking structures is ideal for interim land use or air-space use, where future higher use is anticipated but where current parking demand is in excess of available spaces.

Demountable parking structures have been suggested for use where land is leased, with the landowner anticipating a different use of the land; and where the leasee will not have sufficient time under the life of the lease to amortize the structure, and therefore wants reuse capability for a future date at another site.

The demountable concept can be applied for temporary parking where construction or other temporary activity has reduced the available parking supply, or where temporary parking is needed to facilitate a temporary demand for parking space.

A large West Coast city, for example, acquired land in anticipation of developing it for a public office building at a later date, which would also include provisions for underground parking. The land became available for purchase several years before the office building need was expected. The city was able to lease a demountable parking structure and have it erected on the newly acquired site. This action resulted in several benefits to the city. First it permitted land acquisition when the land was first available, and probably at a lower cost than at a future date. Second, by providing a temporary parking facility, the city was in a position to begin recovering expenses from parking revenues while supplying needed parking. Finally, judicious use of the land prior to permanent development helped avoid blighting effects and social problems that associate with vacated or undeveloped land in urban areas.

Demountable structures have been built in numerous cities since the mid 1960s. However, most are still in use as garage structures on their original site. There are inherent problems in reusing a demountable structure. It is difficult to locate a site with similar conditions, and many garage components are not economically salvagable—such as electrical wiring, plumbing, and to a large extent, floor slabs, which are subject to a high mortality rate due to damage when moved.

Structurally, demountable structures are as strong as permanent structures; although if left in place, some garage designers believe maintenance problems may become more pronounced than those of a permanent structure. However, no evidence has been accumulated to support this view. Another commonly expressed disadvantage is that demountable structures lack certain aesthetic values. Appearance can be improved or made to blend with desired tastes by enclosing the structure in decorative masonry or anodized metal facades.

There are structural devices designed to increase storage capacity of surface parking by providing a partial decking above surface parking stalls. This second level can be accessible from a moveable ramp positioned at the ends of individual stalls—or vehicles can be parked bumper-to-bumper above and perpendicular to surface stalls, with access from a fixed ramp at one or both ends of the elevated decking.

These garage-like parking devices generally share a high degree of demountability and reusability. They can be advantageous for expanding surface parking lots or for providing parking space on very limited land area. However, they usually require attendant-parking.

Clear-Span Construction. Improved materials and construction techniques have reduced the cost of longer clear-span beams be-

FIGURE 13. Parking devices such as this can increase parking for very limited land areas.

tween supporting columns. Clear-span designs between 48 and 63 feet (14.6 and 19.2 meters) can eliminate columns within parking areas, thereby providing advantages to both functional design and parking operations.

Obvious advantages of longer spans include column-free space for parking, more parking spaces per given structure parking level, greater parker acceptance, less obstruction to sight distance, and fewer obstacles to impede vehicular movement. Probably the most important advantage is the flexibility enabled by clear-span designs, allowing parking stall sizes and parking angles to be changed without wasting valuable floor space.

Disadvantages include possibly higher construction costs. Because of deeper beam construction, clear-spans necessarily have greater floor-to-floor height.

Figure 14 illustrates two similar-size parking garage layouts (exclusive of express down ramps), one using clear-span design and the other using short-span column spacing. The clear-span design accommodates 111 parking spaces, a 13 percent increase over the 98 spaces provided in the short-span design.

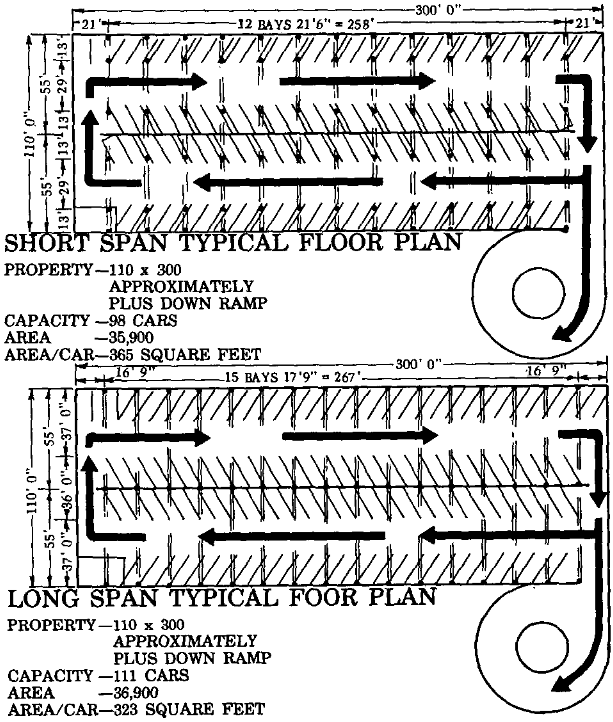


Figure 14. Efficiency comparison of short versus long span design.
Source: Adapted from "Methods of Construction Construction Costs," by Richard C. Rich and Associates, for National Parking Association, 1966.

In recent years, clear-span parking garage construction has become more cost-competitive with shorter spans, but clear spans are still generally considered more expensive—with some comparative estimates placing costs at 5 to 10 percent more.[18] Operational advantages permitted by the flexibility of clear-span designs must be weighed against the probability of higher construction costs.

Short-Span Construction. Functional parking design favors clear-span construction. However, other structural considerations, such as supporting appurtenants for a structure housing non-parking uses above the parking floors, may require closer column spacing to economically support the additional loading. Short-span

[18] James M. Hunnicutt, "Parking, Loading, and Terminal Facilities," *Transportation and Traffic Engineering Handbook.*

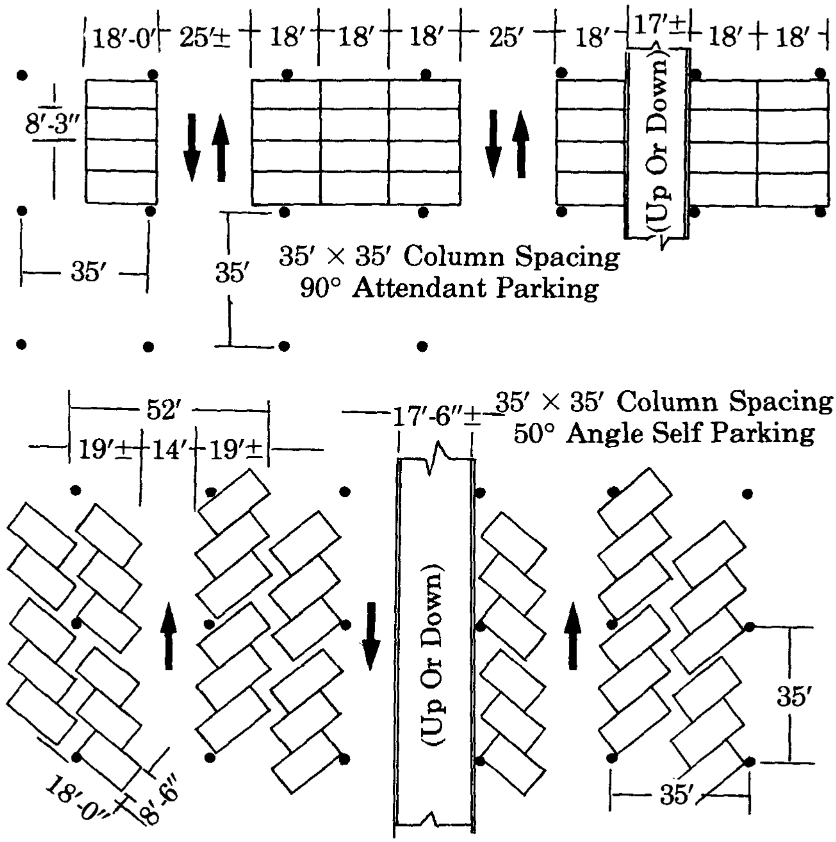


FIGURE 15. Contrasting architecural concepts.

construction permits shallower beam depth, thereby reducing floor-to-floor heights, and this may be a critical consideration under severe zoning code restrictions.

If clear spans cannot be achieved, a 30 to 35 foot (9.1 to 10.7 meter) grid of column spacing can be a feasible alternative. For example, a 35-foot-square column grid in accordance with Figure 15 allows use of straight ramps for interfloor vehicular circulation, and facilitates three-angled parking stalls between columns for self-park operations. The 35-foot-square grid will afford additional flexibility for developing a successful attendant-park operation with 90-degree parking, using four parking stalls between each column, three vehicles deep. Dimensions of column grids allowing efficient parking operation are dependent on factors that include type of operation, characteristics of the parking demand, and possible circulation patterns between the street and parking spaces.

Underground Parking Structures. Conserving above-ground space and the visual amenities afforded by underground parking

FIGURE 16. Arena Underground Garage in Detroit's Civic Center.

are obvious; however, special construction problems, including excavation and public utility relocation, make underground garages generally more expensive than above-ground parking structures. Cost-contributing factors, usually not associated with above-ground garages, include special waterproofing, daytime illumination, heavier load-bearing roof, and ventilation and fire-sprinkling systems. The latter two factors alone can typically add 20 to 30 percent to basic construction costs.[19]

Water runoff from upper levels, and seepage from hydrostatic pressure, are common problems with underground garages. The fear of some parkers in using underground parking is another problem; however, security in underground structures may actually be better since access is more easily controlled.

Underground garages may be more suited to extremely high-cost land, or where open space is needed to complement densely-developed land. Applications commonly include use under downtown parks and office buildings. Underground garages have been built with a variety of ramp systems.

DESIGN VEHICLE

Changing automobile dimensions were a major reason for early obsolescence of some parking structures built before the 1940s. Between 1930 and 1942, domestic passenger car widths increased from 10 to 12 inches (25.4 to 30.5 centimeters) and length increased over 37 inches (94.0 centimeters).[20] Increases in vehicle size caused staggering reductions in parking garage capacity, since early garages used short structural spans with supporting columns located on parking floors. The distance between columns was often designed to accommodate the width of four parking stalls. Thus, when vehicles became wider, there was virtually no flexibility to increase stall widths without decreasing the number of parking stalls, leaving a large percentage of floor space between columns wasted.

Contemporary parking structures have solved this problem with the use of longer clear spans that allow column supports to be located at the perimeter of parking areas.

[19] Highway Research Board, *Parking Principles*, p. 95.

[20] Richard F. Roti, *The Coming Change in Passenger Cars—Its Effects on Parking Design and Investment* (Washington, D. C.: National Parking Association, October, 1972).

Vehicle Trends

Currently, there appears to be a reversing of the long-term trend in American consumer tastes for longer and wider automobiles. Consumer tastes are being modified by concerns over inflation, energy shortages, and environmental protection.

The demand between small and large automobiles has been rapidly fluctuating in recent years. For example, the consumer responded to the fuel crisis of late 1973 by buying smaller, lighter, more fuel-frugal cars. The automobile industry evaluated the trend and made a rapid transition from large to small car production. But as the energy crisis eased, consumer preference turned back to larger cars. However, pressure to improve fuel economy is forcing manufacturers to reduce vehicle weight, and the principal means of accomplishing this is by size reduction. Many of the 1977 car models, comprising the largest models manufactured, became nearly a foot shorter (approximately 30 centimeters) than their 1976 counterparts. Widths also decreased by 6 to 9 inches (15 to 23 centimeters).

Even though smaller automobiles appear to be the trend, it is impractical to reflect smaller vehicle size and operating characteristics in garage design in proportion to their sales popularity. Older, larger automobiles will continue to be a significant portion of the vehicles stored in parking facilities, and larger vehicles determine minimum parking dimension values. The average age of automobiles on the road today is nearly 6 years. Cars less than 3 years old comprise 30 percent while those 3 years old or older represent 70 percent. There are almost 2 million automobiles on the road 16 years old or older.[21]

Design Vehicle Dimensions and Operating Characteristics

Parking dimensions should reflect automobile dimensions and operating characteristics. Design standards are formulated by expanding minimum parking dimensions to take into consideration average driving ability and user convenience.

An automobile's overall length in conjunction with overhang and turning radius affects parking stall length and driving aisle widths. Automobile width affects parking stall length and width; in conjunction with vehicle tracking characteristics, it affects aisle

[21] Motor Vehicle Manufacturers Association, *1975 Automobile Facts and Figures* (Detroit, Michigan: Motor Vehicle Manufacturers Association, 1976), p. 29.

widths; in conjunction with vehicle turning radius and wheelbase, it affects the clearance required for curbside objects at corners.

Vehicle height affects overhead structure location, including lighting fixtures and signs. Although relatively high vans and certain types of recreational or "special purpose" vehicles are increasing in routine travel usage, it is usually not practical to provide clear floor-to-ceiling heights to accommodate "extreme" vehicles. A clear height of 7.5 feet (2.29 meters) will allow access by most vans and light trucks; however, additional clear height might be considered for parking structures in areas with high recreational vehicle or van registrations. A parking garage recently designed for Denver, Colorado, for example, provides 8-foot (2.44 meters) floor-to-ceiling clear height in anticipation of concentrated recreational vehicle usage.

Passenger vehicle weight is not considered a critical characteristic in functional parking design, nor are vehicle characteristics such as hood profile, seating height, and roof designs that limit upward, downward, and horizontal fields of vision for the driver.

Vehicle turning radius influences corner radii. Transition for straight line to minimum radius will be affected by speed, driver steering performance, and vehicle steering ratio. Minimum obtainable turning radius will be achieved at a very low speed condition—the assumed condition for vehicle operation in parking facilities.

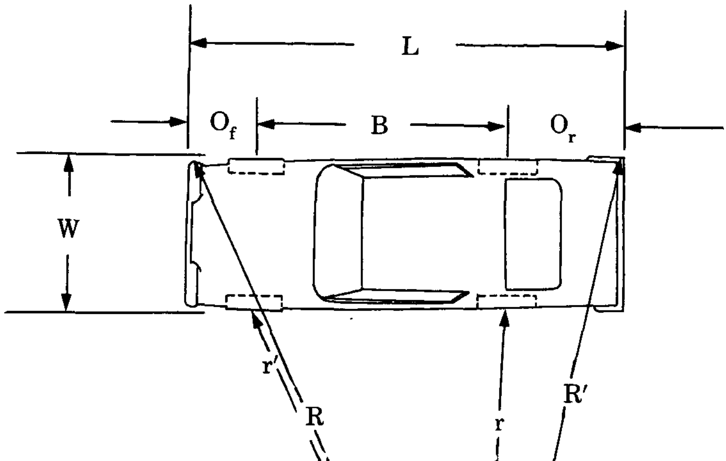
Vehicle underclearance and end clearance can be critical for ramp design and entrance and exits, to prevent local rates of slope (grade) change from causing vehicle ends or center to contact the pavement.

Critical vehicle dimensions affecting parking design are shown in Figure 17, based on 1970 model-year vehicles.

The principal difference between contemporary car dimensions and those of 1970 is that most models are becoming smaller. For 1970 cars, maximum width was 80 inches (203 centimeters), minimum width 69 inches (175 centimeters), and the weighted average width 77 inches (196 centimeters). As nearly half of the 1970 production fell within the 79 to 80 inch (200 to 203 centimeters) range, a design vehicle width of 80 inches (203 centimeters) was selected, which remains reasonable for today's needs.

Design vehicle length, based on weighted 1970 averages, is 225 inches (572 centimeters). This length is exceeded by several pre-1977 luxury sedan models, and a few 1977 models.

Standardized design vehicles are developed to represent a common standard size, reflecting space requirements for a majority of



Symbol	*Dimension*	*Value* inches	*Value* centimeters
L	Overall length	225.0	572
W	Overall width	80.0	203
B	Wheel base	127.0	323
O_f	Front overhang	41.5	105
O_r	Rear overhang	61.0	155
Minimum Turning Radius:			
r	Inside rear wheel	174.0	442
r′	Inside front wheel	218.0[a]	554
R	Outside point, front bumper	294.0	747
R′	Outside point, rear bumper	255.0[a]	572

FIGURE 17. Design vehicle dimensions.
[a]Computed values.
Source: George E. Kanaan and David K. Witheford, "Parking Lot Design Standards," *Traffic Quarterly*, Eno Foundation for Transportation, (Saugatuck, Connecticut: July 1973).

vehicle models. The design vehicle will not have dimensions of the average size car, but rather dimensions equal to or greater than the largest common models likely to frequent a parking facility.

While automobile dimensions are important as a basis for geometric parking design, the great variety of vehicle sizes, operating characteristics, and driver responses, require dimensions that exceed minimums calculated from design vehicle dimensions, characteristics, and average driver ability. Field observations and experimentation have been the contemporary basis for establishing adequate parking geometrics.

The design vehicle no longer exists in one size. The generally shrinking size of standard (full size) cars, and the growing percentage of compacts and subcompact cars, suggests consideration of two design vehicles, one representative of full-size cars, and the second representative of compacts and subcompact models.

Chapter IV includes discussions on parking stall dimensions and other geometric layout features based on these design vehicles and user characteristics.

Chapter IV

FUNCTIONAL DESIGN AND PARKING GARAGE LAYOUT

This chapter concentrates on parking floor layout and design practice, and includes other functional design details. Detailed discussions of vehicular and pedestrian interfloor travel systems are covered in following chapters.

Parking facility design must provide for traffic movement and storage operations in a safe, expedient manner, with minimum opportunity for delay and conflicting movements. The basic operational steps are similar for both surface parking lots and parking structures, as are stall/aisle dimensions, horizontal circulation, and street-access needs. Parking structures, however, require consideration of additional design elements that include vertical circulation patterns and interfloor travel facilities, daytime lighting, ventilation, fire-fighting systems, and column support locations.

Functional parking garage design is concerned principally with parking area arrangement and layout, and vehicular pedestrian circulation in relation to garage operations. Each of these design elements must be considered as it is affected by associated operational elements. These include:

1. *entrance*, involving an intersectional movement for vehicular access from the street system (affects entrance lane design);
2. *acceptance*, which may only involve driving through the entrance area—as in facilities controlled by parking meters—or momentarily stopping to receive a time-stamped ticket, or turning the vehicle over to a parking attendant (affects design of entrance reservoir for temporary storage of entering vehicles);
3. *storage*, involving driver search for a vacant parking stall, and a maneuvering into stall (affects design of access aisles and parking stall);
4. *pedestrian access* to and from the parking facility boundaries (affects design of pedestrian circulation facilities);
5. *delivery*, consisting of unparking maneuvers and travel to the exit area (affects design of parking stalls, access aisles, and exit reservoir); and
6. *exit*, departing from the exit area, including intersectional movement to enter street traffic stream (affects design of exit lanes).

When parking fees are charged, placement of revenue control facilities and equipment will affect these basic operational features.

ACCESS DESIGN

Parking garages have a main floor and storage floors. The main floor's principal function is accepting and delivering vehicles to and from the street system. This usually makes it the primary traffic control area where customers enter and leave by car and on foot. Vehicle storage may also be a main-floor function.

Main Floor Facilities

Areas for cashiering, ticket dispensing, manager's office, and employee facilities are usually provided on the main floor. Public restrooms and other customer convenience facilities, such as package checkrooms, telephones, vending machines, and waiting areas, when provided, are located typically on the main floor.

For commercial multiple-use developments incorporating structure parking, the street level or main floor is usually most desirable for retail development. Street-level retail development in multiple-use parking garages helps also to maintain block-face continuity in commercial areas.

While located generally at street level, the main floor can be one level above or below street level to accommodate multiple-use development. The most important main-floor design consideration involves location and capacity of entrance and exit points on surrounding streets.

Access and Reservoir Requirements

Access points should be provided in conformance with local regulations. They should present a recognizable and attractive appearance to prospective customers, while simultaneously providing for safe crossing of pedestrian and vehicular traffic. Requirements for reservoir storage space and control of entering and departing movements depend on whether parking fees are charged and method of revenue collection, type of operation (self-park or attendant-park), magnitude of peak parking-unparking activity, and reservoir opportunities on surrounding streets.

Functions of Reservoir Spaces. The purpose of reservoir spaces is to temporarily store queued vehicles entering or leaving a parking facility. Exit reservoir space should be adequate to prevent queued traffic, stopped to pay the parking fee and/or stopped by street traffic, from congesting the garage circulation system and blocking stall access.

Entrance reservoir problems exist principally in attendant-park garages, where customers drive into the garage entrance reservoir,

TABLE IX—TYPICAL INBOUND RESERVOIR NEEDS

Use	*Reservoir Requirement*
Free flow entry	1 space per entry lane
Ticket dispenser entry	2 spaces per entry lane
Manual ticket dispensing	8 spaces per entry lane
Attendant parking	10 percent of that portion of parking capacity served by the entry lane

Source: Paul C. Box & Associates, generally unpublished field studies.

leaving vehicles to be parked by garage attendants. In self-parking garages, customers drive directly to storage levels, pausing briefly at the entrance, if at all, to receive a parking ticket or to activate an automatic revenue control mechanism.

Most parking garages are operated as self-parking facilities because customers prefer to park their own vehicles and because operators prefer to avoid high labor costs associated with attendant-park operation. Self-park facilities usually require an inbound traffic reservoir for one to eight cars per entry lane, depending on revenue control and operational type (see Table IX). This space provides for driver orientation and prevents blocking of the street system by vehicle queues.

Anticipation of the amount of queuing at entrance and exit control points, or queuing by exiting vehicles that might be blocked by street traffic, requires an analysis of average arrival rates of parking-unparking vehicles and the capacity of revenue-control points and the recipient street lanes.

Desirable Intake/Discharge Capacities. Generally, garages should be able to fill or completely discharge within a maximum of 1 hour.[22] When generated parking demand is of a surge type, such as demand generated by sporting events, rapid parking garage filling and emptying becomes a critical consideration. Ideally, special-event, surge-type demand facilities should be capable of emptying within 30 minutes.[23]

With well-designed stall/aisle and interfloor ramp systems, traffic-flow capacity limitations most often occur at entrance and exit points, and at junction points where departing vehicles enter the street system. Traffic flow breakdowns happen when the parking

[22] Highway Research Board, *Parking Principles*, p. 115.
[23] Hunnicutt, "Parking, Loading, and Terminal Facilities," p. 687.

garage system is constrained by traffic restrictions at entrance points or is congested by the lack of capacity at exits. These conditions usually happen in morning and afternoon peak periods, but could occur at other times if the turnover rate is high.

Entrance/Exit Capacity. Entrance/exit capacity should prevent vehicles from queuing onto approach streets, and minimize vehicle queuing before they enter the street flow. Too many lanes at entrance or exit points may cause driver confusion through duplication, and are a costly misuse of space, inviting inefficient labor use when garage personnel issue tickets or collect fees. The important consideration is that an adequate number of lanes be provided, not necessarily the maximum number possible.

Automatic Gate Controls. Lifting barrier-arm gate types are often used at entrances or exits to ensure parking ticket issuance or parking fee payment (and/or to count or ensure one-way traffic flow). Capacity varies according to barrier purpose, angle of approach, curvature radius of the vehicle travel path, and approach lane gradient.

Entrance gates are usually in conjunction with automatic ticket dispensers or magnetic-coded card readers. Lane capacity with automatic ticket dispenser and gate control is generally between 350 vehicles per hour (when tight turning movements are required) and 500 vehicles per hour when the approach is straight or in-line with structure openings.[24] Under conditions of constant waiting lines, 660 vehicles per hour per lane with automatic ticket dispensers have been counted.[25] Maximum design capacity is typically 400 vehicles per hour per controlled entrance lane.

Contemporary parking garage design favors large, unrestricted entrance openings, well delineated for easy driver recognition. In some instances, entrances have been made three lanes wide to avoid impressions of a "hole-in-the-wall." However, two-lane entrances are more common.

The discharge capacity of gate-controlled exit lanes has been found to range between 150 and 225 vehicles per hour per lane.[26] Full discharge capacity may not be achieved if there is insufficient

[24] P. B. Ellson, *Parking: Dynamic Capacities of Car Parks, RRL Report LR221*, (Crowthorne, England: Road Research Laboratory, Ministry of Transport, 1969), pp. 14-15.

[25] Highway Research Board, *Parking Principles*, p. 115.

[26] Ellson, *Parking: Dynamic Capacities of Car Parks*, pp. 14-15; and Highway Research Board, *Parking Principles*, p. 115.

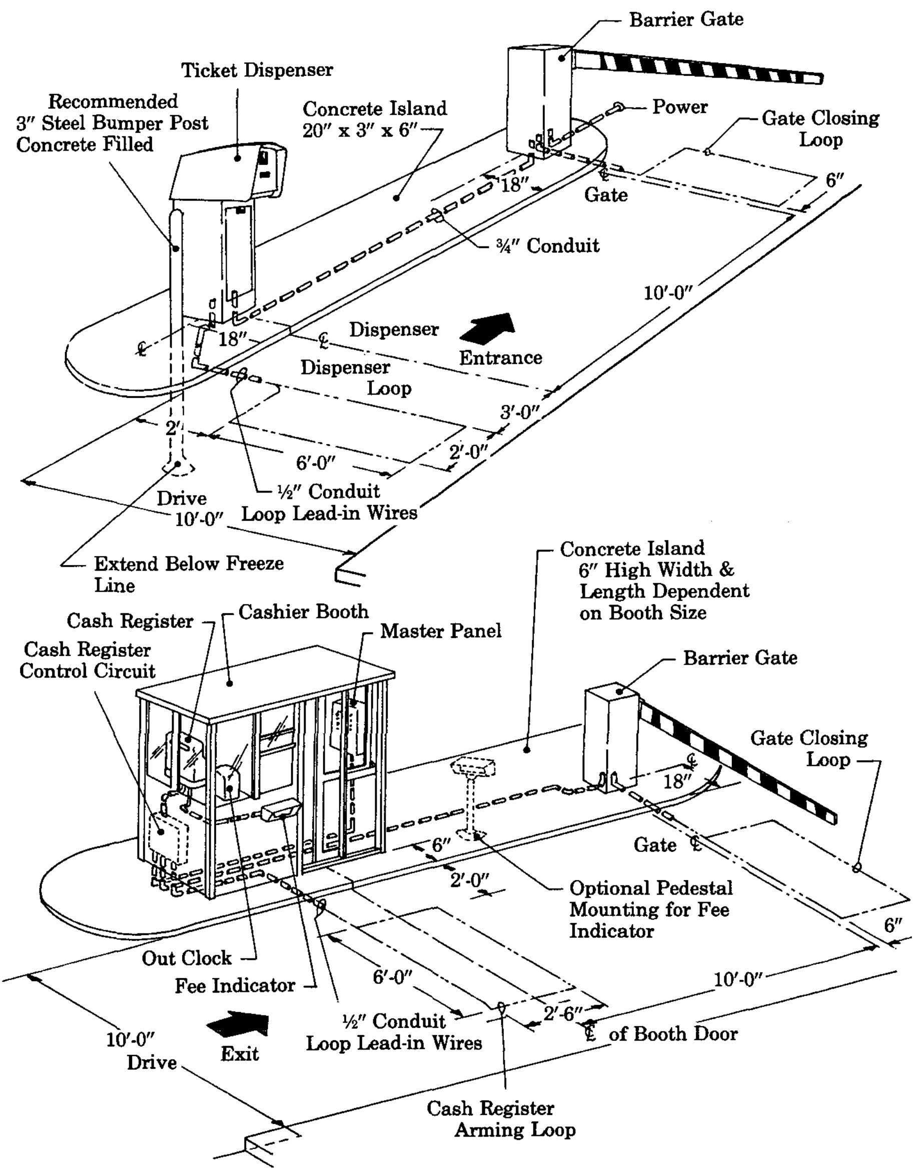


FIGURE 18. Typical ticket dispenser with barrier gate installation, and typical exit lane control equipment.
Source: Stanley Parking Systems, Madison Heights, Michigan.

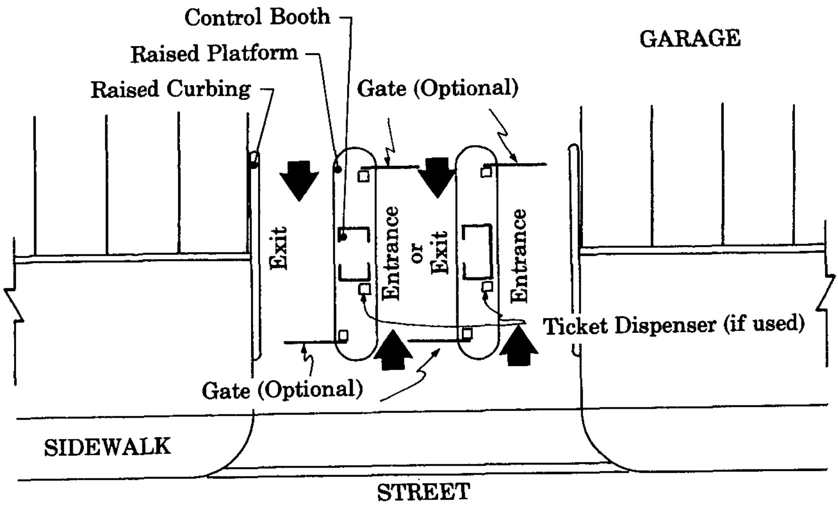


FIGURE 19. Plan for reversible lane operation.

reservoir space beyond the gate or garage exit for vehicles to queue while waiting for acceptable gaps in street traffic flow.

Parking garages generally need two exit lanes for each entry lane. Reversible lane operation is desirable to accommodate peak outbound and inbound traffic flow. Directional traffic flow is commonly facilitated with red and green traffic signal lights over each lane.

Entrance/Exit Dimension Guidelines. Driveway entrance and exit design should consider driveway width, turning radii, angle of approach and departure in relation to the street, directional traffic flow, and spacing from intersections, other driveways and property lines. Table X gives suggested driveway design values for urban area locations with both high and low pedestrian activity. Ideally, pedestrian-vehicular crossing separations should be used where driveways cross sidewalks with very high pedestrian traffic.

When driveway widths and radii (on the entering side) are made larger, more rapid traffic flow generally can be expected. While generous widths and radii are usually desirable, driveways with high pedestrian volume crossings may be designed with less generous dimensions to encourage lower vehicular entry and exit speed.

Entrance/Exit Safety. Sidewalk pedestrian circulation requirements should be recognized in developing multi-lane garage access points. Ideally, several car-lengths should be provided between the sidewalk and the control point.

TABLE X—TYPICAL ENTRANCE AND EXIT DRIVEWAY DIMENSION GUIDELINES

Dimension	*Urban*		*Rural*
	High Pedestrian Activity[a]	*All Other*[b]	
Width[c] (in feet)			
Minimum (one-way)	15	15	15
Minimum (two-way)	25	25	30
Maximum	30	35	40
Right turn radius[d] (in feet)			
Minimum	5	10	15
Maximum	10	30	50
Spacing[e] (in feet)			
From property line	0	0	0
From street corner	10	10	15
Between driveways	10	0	0
Angle[f] (in degrees)	75	45	45

[a]As in central business areas or in same block with auditoriums, schools, and libraries.
[b]The remaining city streets including neighborhood business, residential, and industrial.
[c]Measured along right-of-way line at inner point of curbed radius sweep or between radius and near edge of curbed island at least 50 square feet in area. The minimum width applies principally to one-way driveways.
[d]On side of driveways exposed to entry or exit by right turning vehicles.
[e]Measured along curb or edge of pavement from roadway end of radius.
[f]Minimum acute angle measured from edge of pavement.
Source: *Parking Principles*, Highway Research Board, Special Report No. 125, (1971), p. 121.

Special consideration should be given to entrance lighting, since drivers entering a parking garage from bright sunlight may experience some temporary visual impairment if light levels are low immediately inside the entrance. While landscaping of border areas between structure and street often improves aesthetics, care should be taken to assure that decorative landscape features, after maturity, do not obstruct lateral sight distance at garage access points.

Parking garage exits should be designed to permit unobstructed sight distance for drivers and pedestrians. Wherever possible, however, signs and pavement markings should be used to alert both drivers and pedestrians to potential crossing conflicts. Some garages use vehicle-activated signals or audio alarms in conjunction with signing. Mirrors have been used also to afford drivers and pedestrians a means of observing entrance/exit point conditions otherwise obscured from straight-line vision.

PARKING LAYOUT DESIGN

Efficient use of space calls for balancing generous dimensions for customer convenience with restrictive dimensions for maximum economy. Stall, aisle, and ramp dimensions should be based on vehicle size and operating characteristics, parker characteristics, and type of parking operation (self-park or attendant-park).

Parker characteristics influence stall and aisle widths and other parking dimensions. Downtown public parking, suburban parking, employee parking, and shopper parking require different convenience or comfort considerations. Conditions of high parking turnover (stall-use frequency) and customer package loading, commonly found at suburban shopping centers, will usually call for parking stalls considerably wider than minimum requirements. All-day or long-term employee parking in downtown areas may justify narrower stalls, closer to minimum requirements.

Type of parking operation also influences parking dimensions. While experienced parking attendants can park in areas with tight or restricted geometrics, typical self-park patrons should not. This is particularly true for parkers with short-term trip purposes (high-turnover parking).

From an operational viewpoint, restricted dimensions can materially impair efficient traffic movement, increasing the amount of time necessary to enter, park-unpark, and exit a parking facility. They are extremely detrimental to parking operations, especially in high-turnover parking facilities.

Design Elements

Parking stalls along an access aisle are commonly referred to in combination, as a parking module (or parking bay). This fundamental unit is used to denote combined distance of aisle width and stall depth, measured perpendicular to the access aisle. Parking modules may be composed of one- or two-way aisles, with parking stalls on one or both sides. Aisles having parking stalls on both sides are defined as double-loaded access aisles, and with stalls only on one side as single-loaded aisles. Single-loaded aisles are less efficient and generally avoided where possible.

Figure 20 illustrates parking layout elements. Boundary conditions W are used to describe parking module types. Basic boundary conditions are: (1) walls on each side (W_1 and W_2); (2) a wall on one side and a different parking module on the other side (W_3); and (3) different parking modules on each side (W_4).

Parking Stall Dimensions. Minimum practical stall widths for attendant-park facilities typically range between 8.0 and 8.5 feet (2.44 and 2.59 meters), while stall widths in self-park facilities range between 8.5 and 9.0 feet (2.59 and 2.74 meters). Stall widths from 8.3 to 8.5 (2.53 to 2.59 meters) are most desirable in attendant-park facilities with high parking turnover. Self-park stall widths of 8.5 feet for long-term employee parking to 9.0 feet for short-term parking or residential users (2.59 to 2.74 meters) are

θ Parking angle
W_1 Parking module width (wall to wall), single loaded aisle
W_2 Parking module width (wall to wall), double loaded aisle
W_3 Parking module width (wall to interlock), double loaded
W_4 Parking module width (interlock to interlock), double loaded aisle
AW Aisle width
WP Stall width parallel to aisle
DI Stall depth to interlock
D Stall depth to wall measured perpendicular to aisle
S_L Stall length
S_W Stall width

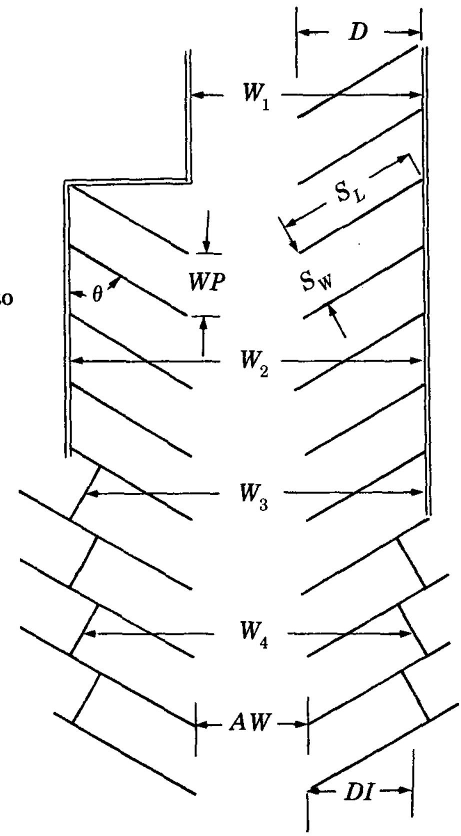


FIGURE 20. Dimensional elements of possible parking layouts.

customary design dimensions in parking lots serving shopping customers; however, stall widths of 9.5 feet to 10.0 feet (2.90 to 3.05 meters) have been used occasionally to facilitate customer package loading. In parking structures, stalls wider than 9.0 feet (2.74 meters) are rarely used, except for special types of parking—such as for the physically handicapped.

Parking stall widths (S_w) are measured perpendicular to stall markings. At angles of less than 90 degrees, stall widths parallel to the aisle (*WP*) are proportionately greater.

Adequate clearance for door opening between vehicles parked adjacent is a high visibility convenience factor. A Los Angeles study[27] found that with a minimum stall width of 8.3 feet (2.53 meters), 20 inches (51 centimeters) of clearance is provided between standard-size automobiles with a 80-inch (203 centimeter) vehicle width when vehicles are centered in stalls. This width permits door opening to the first stop position without touching adjacent vehicles, and without creating too great an inconvenience for in-and-out passenger movements. The study also found that a 16-inch (41 centimeter) clearance between vehicles permits in-and-out movements, although with greater difficulty; therefore a 8.3 foot (2.53 meter) parking stall would provide a 4-inch (10 centimeter) safety factor for misalignment of a vehicle in the parking stall.

Ricker found in his 1957 study[28] that the "natural spacing"—the average parking stall width used by customers parking in commercial parking lots without stall markings or other restrictions—indicated a minimum of 24 inches (61 centimeters) between vehicles was necessary to permit driver/passenger movements in and out of parked vehicles without restrictions. Automobiles grew wider, with longer, thicker doors during the ensuing period, and this factor caused Kanaan and Witheford to conclude in a 1973 study[29] that acceptable clearance was 27 inches (69 centimeters) between vehicles that parked adjacent to one another. Their study found the "natural" stall width selected by all-day parkers was on the order of 8.75 feet (2.67 meters).

For most self-park applications, a stall width of 9.0 feet (2.59 meters) is optimum, since this provides sufficient space for door opening and convenient driver/passenger access, plus enough margin for misaligned vehicles.

[27] Parking Standards Design Associates, *A Parking Standards Report.*

[28] Ricker, *Traffic Design of Parking Garages*, pp. 62–67.

[29] George E. Kanaan and David K. Witheford, "Parking Lot Design Standards," *Traffic Quarterly*, 27 no. 3 (July 1973): 451–473.

Substandard self-parking stall widths can be false economy. It takes only one vehicle misaligned in a row of parking stalls to cause subsequent parkers to encroach on other stalls. Substandard stall widths also increase opportunity for delay, customer irritation, and accidents.

Parking stall length (S_L) is measured parallel to stall markings. Stall length should accommodate the overall length of nearly all cars expected to use the space. Lengths of 18, 18.5, and 19 feet (5.49, 5.64 and 5.79 meters) have been suggested as minimum standards for stalls.

Kanaan and Witheford[30] found parkers did not, on average, pull all the way into parking stalls, but instead stationed their vehicles an average of 9 inches (23 centimeters) short of end-of-stall markings. Bumper-to-wall clearances for vehicles parked adjacent to walls and bumper-high obstacles were found to average approximately 8 inches (20 centimeters). Thus, the Kanaan-Witheford study suggested 19 feet (5.79 meters) as a minimum desirable parking stall length.

Stall lengths of 18 feet (5.49 meters) were most commonly used in parking garages surveyed. However, 18.5 to 19 feet (5.64 to 5.79 meters) are more desirable stall lengths.

Access Aisle Dimensions. Aisle width is defined in two ways: (1) the measured width between the furthest projection of parking stalls, or (2) the measured distance between furthest projection of parked vehicles. In cases where the parking angle is relatively flat (less than 45 degrees), the second definition is more logical since parked vehicles would normally not extend to the furthest projection of a delineated parking stall. For these flatter parking angles, designers generally prefer to express dimensions in terms of parking module width (W) rather than stating aisle width and stall depth separately.

Figure 21 illustrates graphically the difference in aisle width, given the same module width (W_2), when different methods are used to measure—stall projection versus vehicle protection.

Typically, two-way aisles are used with 90-degree parking, and one-way aisles are used with angle parking. However, two-way aisles can serve angle parking if parking stalls on either side of the aisle are parallel (see Figure 24b and c). Generally, in self-park operation, two-way traffic configurations complicate traffic circulation and can increase conflict points. They are also less efficient when drivers are searching for a parking space.

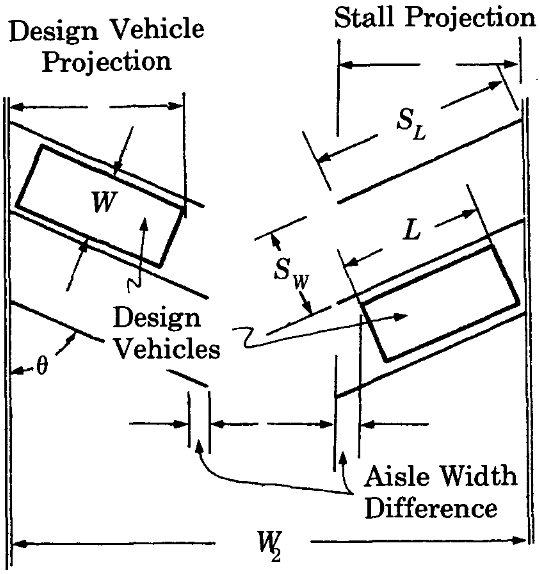
[30] Ibid., p. 456.

Design Vehicle
L = 18.75 feet
W = 6.67 feet

Stall Dimensions
S_W = 9 feet
S_L = 19 feet

Stall Projection =
$S_L \sin\theta + S_W \cos\theta$

Vehicle Projection =
$L \sin\theta + W \cos\theta$



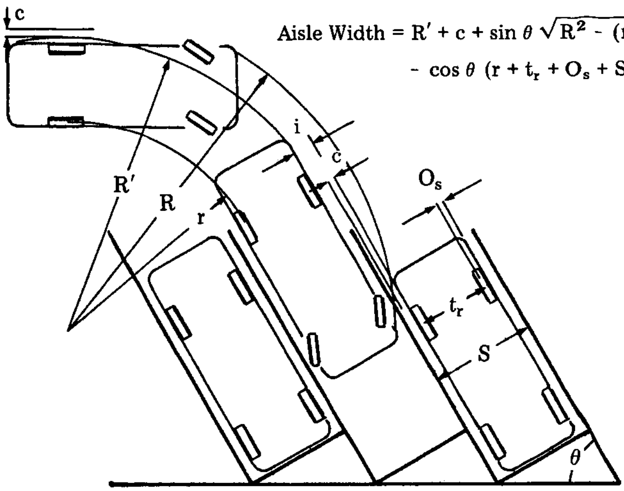
Parking Angle	Stall Projection	Design Vehicle Projection[a]	Module Width Difference
(Degrees)	*(feet)*	*(feet)*	*(feet)*
30	17.29	15.16	4.26
45	19.80	17.98	3.64
60	20.95	19.58	2.74
75	20.68	20.44	0.48
90	19.00	18.75	0.50

FIGURE 21. **Stall projection versus vehicle projection.**
[a]**Assuming vehicle is pulled all the way into the stall.**

Aisle systems should function to minimize turns. Longer aisles can be advantageous in this respect, but may require one or more cross-over aisles for dispersion of parking activity and assurance of minimum travel.

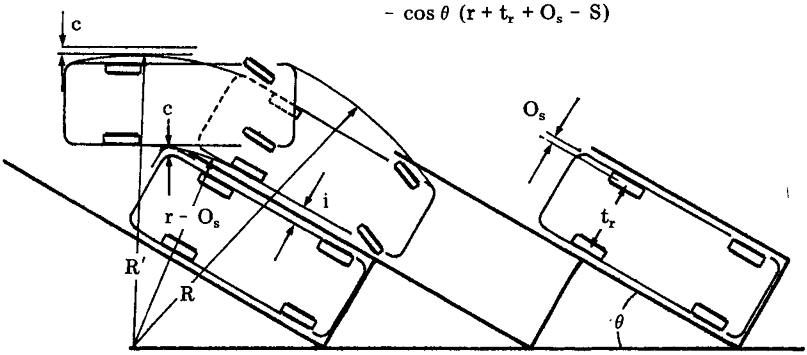
Both theoretical and empirical analysis can show that aisle widths may be reduced by using back-in instead of head-in vehicle parking. However, since the vehicle back-in parking method seldom receives voluntary compliance, it is rarely considered in self-park facilities.

$$\text{Aisle Width} = R' + c + \sin\theta\sqrt{R^2 - (r + t_r + O_s + i - c)^2} - \cos\theta\,(r + t_r + O_s + S)$$



(a) Drive-in stall at angle greater than critical parking angle. *
Movement is limited by car in stall to left.

$$\text{Aisle Width} = R' + c - \sin\theta\sqrt{(r - O_s)^2 - (r - O_s - i + c)^2} - \cos\theta\,(r + t_r + O_s - S)$$



(b) Drive-in stall at angle less than critical parking angle. *
Movement is limited by car in stall to right.

*Critical parking angle is the angle at which the aisle width required for parking-unparking car to clear the car in the stall on the left is equal to aisle width required to clear car in stall on right. This angle is given by the expression:

$$\theta' = \cot^{-1}\frac{\sqrt{R^2 - (r + t_r + O_s + i - c)^2} + \sqrt{(r - O_s)^2 - (r - O_s - i + c)^2}}{2S}$$

FIGURE 22. Formulas derived for the aisle width required to maneuver into or out of a parking stall in one pass.

Theoretical equations have derived aisle widths for parking as a function of stall width and parking angle. Ricker, however, pointed out in the 1957 edition of *Traffic Design of Parking Garages*[31] that certain assumptions made in the use of theoretical derivations do not always hold for actual parking manuevers; hence, numerical values computed from formulas (see Figure 22) could not be taken as absolute measurements, but can be used to compare aisle dimensions and area required for different types of parking.

Maneuvering space required to park-unpark in one continuous movement determines aisle width. It is difficult for formulas to take into account the varying spiral turning movement of different drivers, using differing degrees of steering effort and speed to enter a parking stall.

Aisles must have adequate width to accommodate parking-unparking maneuvers and to provide efficient circulation. It is obvious that as the parking angle becomes flatter and the parking stall width increases, parking maneuvers require less aisle width. Aisle widths derived from design formulas based on minimum clearances may indicate adequate width for parking maneuvers, but less than acceptable aisle width for efficient traffic circulation.

Minimum suggested aisle widths vary slightly, depending on the source. Suggested absolute minimums, regardless of parking angle and stall width, range from 11 to 12.5 feet (3.35 to 3.81 meters) for one-way traffic aisles, and from 20 to 22 feet (6.10 to 6.71 meters) for two-way traffic aisles. The wider aisle widths in these ranges are desirable.

The design of aisles at their intersections is determined by the turning radii of vehicles and average driver ability. At parking module ends, sufficient radius must be provided to accommodate turning movements on the aisle system. The typical passenger car driver requires an inside turning radius of about 18 feet (5.49 meters), creating a turning path approximately 11 feet (3.35 meters) wide at its extreme.[32]

Figure 23 illustrates parking module end treatments for 90-degree and 60-degree parking layouts. The end areas or islands may be striped or treated as a curbed island. These otherwise unusable areas can be used for shopping cart storage, planting, or for storing limited quantities of snow on floors open to the weather.

[31] Ricker, *Traffic Design of Parking Garages.*

[32] Highway Research Board, *Parking Principles*, p. 106.

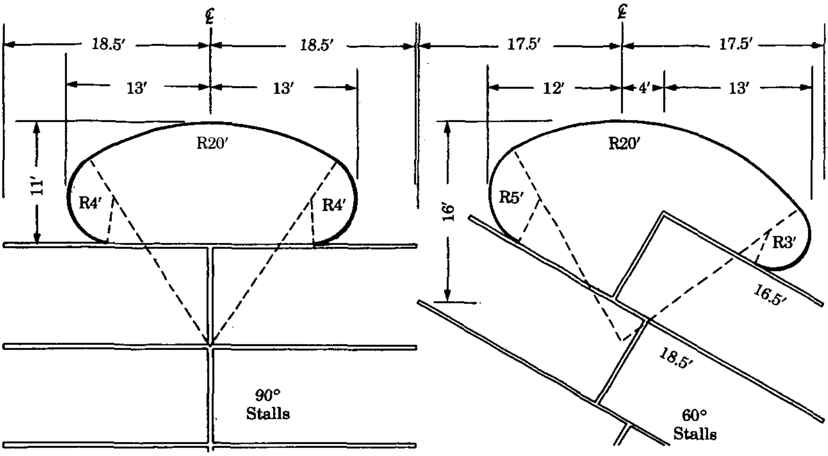


FIGURE 23. Examples of parking module end treatments for 9-foot parking stalls.

Source: Adapted from *Parking Principles*, Highway Research Board, Special Report 125, (1971), p. 106.

Desirable Parking Dimensions. Table XI lists suggested design dimensions for typical parking angles, stall widths, and parking modules. Increased dimensions can provide more rapid parking operation for high-turnover facilities. Slight decreases in dimensions may be suitable for low-turnover parking.

Parking Layout Efficiency

Parking layout efficiency depends on selection of stall widths and parking modules that will provide a desired degree of service and economy while using a given site to its best advantage. The objective should be to maximize the number of vehicles that can be parked within a given area, subject to operational viability.

Efficiency Comparisons. Comparing the space-use efficiency of different layouts is accomplished by prorating storage floor area on a per-stall basis. Table XII compares area efficiency for typical stall and aisle dimensions.

When considering a complete storage floor level, the area to be prorated per stall consists of the parking stall area plus a prorated portion of area required by aisles and ramps—including unusable spaces at ends of parking stall rows. Areas required for pedestrian elevator shafts, stairwells, separated walkways, and certain ancil-

TABLE XI—TYPICAL PARKING LAYOUT DIMENSIONS

					Parking Module Width			
Stall Width Parking Angle (Θ) *(feet)*	*Stall Width Parallel to Aisle* (*WP*) *(feet)*	*Stall Depth to Wall* (*D*) *(feet)*	*Stall Depth to Interlock* (*DI*) *(feet)*	*Aisle*[a] *Width* (*AW*) *(feet)*	*Wall to Wall* (W_1) *(feet)*	*Wall to Wall* (W_2) *(feet)*	*Wall to Interlock* (W_3) *(feet)*	*Interlock to Interlock* (W_4) *(feet)*
8.5	12.0	17.5	15.3	13	30.5	48.0	45.8	43.6
9.0	12.7	17.5	15.3	12	29.5	47.0	44.8	42.6
9.5	13.4	17.5	15.3	11	28.5	46.0	43.8	41.6
8.5	9.8	19.0	17.5	18	37.0	56.0	54.5	53.0
9.0	10.4	19.0	17.5	16	35.0	54.0	52.5	51.0
9.5	11.0	19.0	17.5	15	34.0	53.0	51.5	50.0
8.5	8.8	19.5	18.8	25	44.5	64.0	63.3	62.6
9.0	9.3	19.5	18.8	23	42.5	62.0	61.3	60.6
9.5	9.8	19.5	18.8	22	41.5	61.0	60.3	59.6
8.5	8.5	18.5	—	28	46.5	65.0	—	—
9.0	9.0	18.5	—	26	44.5	63.0	—	—
9.5	9.5	18.5	—	25	43.5	62.0	—	—

[a]Measure between ends of stall lines.

Note: See Figure 20 for dimensional identification. These dimensions are for stall lengths of 18.5 feet measured parallel to the stall markings and are based on results of a special study to evaluate the effects of varied aisle and stall widths for the different parking angles shown. The study was conducted in December 1970 by the Federal Highway Administration and Paul C. Box and Associates.

Source: Adapted from *Parking Principles*, Highway Research Board, Special Report no. 125, 1971, p. 101.

lary uses, are generally not included as part of the area prorated to parking stalls.

Ninety-degree parking stalls with aisles parallel to the long dimensions of the site, and 60-degree interlocking parking stalls with one-way aisles, usually require the least amount of space per stall.

Angled parking stalls are generally believed to provide greater ease in parking than 90-degree stalls, and may derive additional advantage in the fact that drivers are able to see and anticipate empty parking stalls more easily. Angle parking is often used where site dimensions do not allow an integral number of 90-degree stalls.

TABLE XII—RELATIVE AREA EFFICIENCY OF TYPICAL PARKING LAYOUTS[a]

Parking Angle	*Stall Width*	*Stall Width Parallel to Aisle*	*Module Width*[b]	*Number of Stalls per 100 Feet of Aisle Length*	*Prorated Area per Stall in Square Feet*
45	8.5	12.0	48	16.67	288
	9.0	12.7	47	15.74	299
	9.5	13.4	46	14.92	309
60	8.5	9.8	56	20.40	275
	9.0	10.4	54	19.24	281
	9.5	11.0	53	18.18	291
75	8.5	8.8	64	24.10	282
	9.0	9.3	62	21.50	289
	9.5	9.8	61	20.40	300
90	8.5	8.5	65	23.52	276
	9.0	9.0	63	22.22	284
	9.5	9.5	62	21.06	295

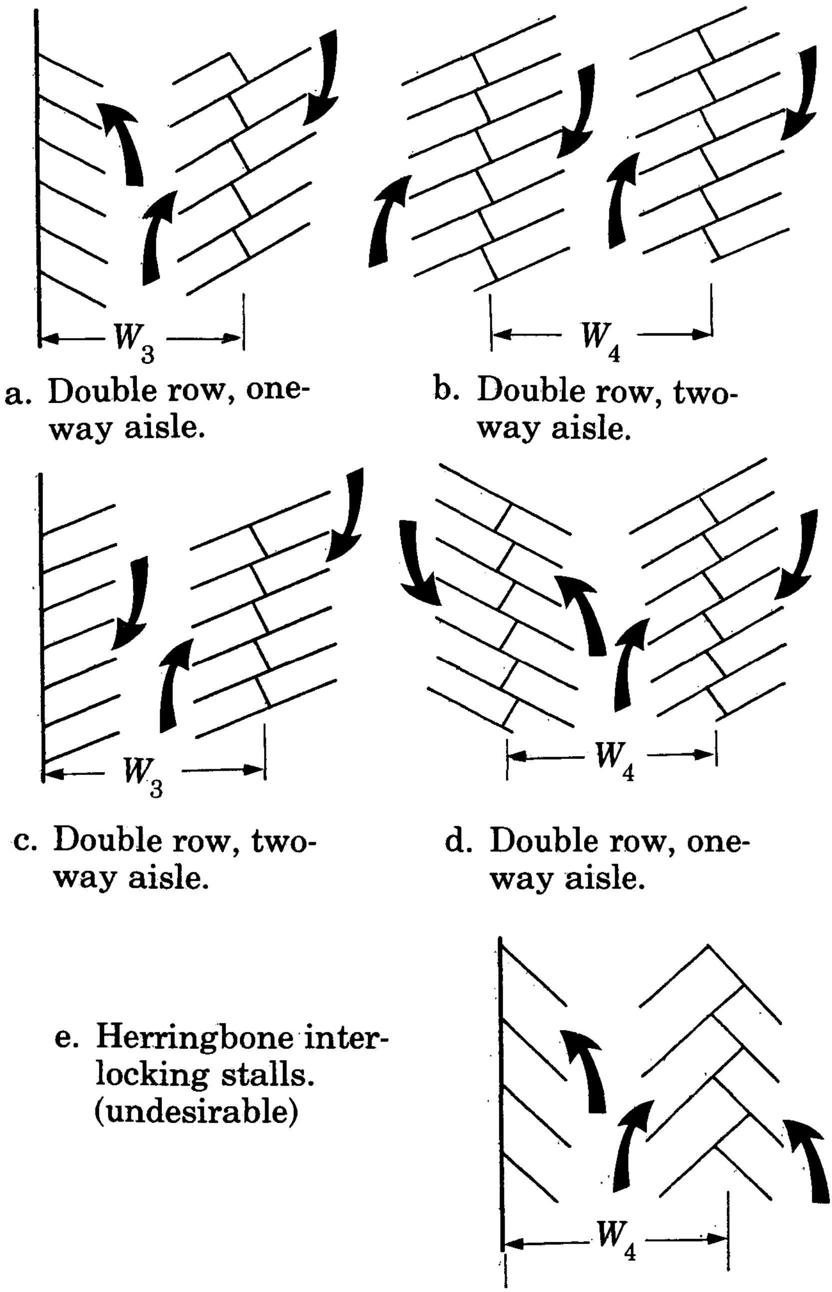
[a]Prorated areas per stall do not include allowance for end aisle space or unusable spaces as would be found at ends of parallel parking rows, which could increase prorated per stall areas by 10 to 15 percent.

[b]Comparisons based on wall to wall module dimensions with double loaded aisle.

Parking Layouts. Typical angle parking module configurations are illustrated in Figure 24. The preferred interlocking stall arrangement places the front bumpers of vehicles in opposing parking stalls next to one another, as illustrated in layouts *a*, *b*, *c*, and *d*. Layout *e* is a herringbone pattern, suitable only for 45-degree parking. Although the herringbone layout requires the least area per vehicle, it usually is avoided because of potential for vehicle damage from necessary bumper-to-fender alignment of adjacent vehicles.

The most prevalent aisle circulation pattern used in conjunction with angle parking is a continuous system of alternating-direction one-way aisles. One-way aisles are desirable because they require less gross floor area per stall, and they eliminate or greatly reduce head-on as well as crossing vehicular conflicts.

The principal advantage of two-way aisle systems is reduction in travel distance. Two-way aisles can be dead-ended, requiring parkers to return over the same aisle that was used to enter. In this type of design, 90-degree parking is a prerequisite. With 90-



a. Double row, one-way aisle.

b. Double row, two-way aisle.

c. Double row, two-way aisle.

d. Double row, one-way aisle.

e. Herringbone interlocking stalls. (undesirable)

FIGURE 24. Possible parking module layouts with interlocking stalls.

degree parking, vehicles may use either direction of travel on an aisle.

Compact and Special-Purpose Parking Stalls

The substantial mix of both long- and short-term parkers found in many facilities compounds the problem of selecting the most efficient parking layout. With a growing segment of the driving public using vehicles substantially smaller than the standard design vehicle, many garage facilities are attempting to increase storage capacity by providing a number of smaller parking stalls, commonly referred to as "compact stalls."

The parking industry generally defines a compact stall as 7.5 feet wide and 15 feet long (2.29 by 4.57 meters). This stall size will accommodate many imported cars and most domestic models classified as compacts and sub-compacts.

In practice, smaller size compact stalls do not always discourage use by drivers of larger cars. Signing and special markings, although probably helpful in distinguishing special size or purpose stalls, are not entirely effective in assuring use by small cars only, since many drivers are apparently unable to place a size classification on vehicles they drive.

Compact Stall Design Techniques. Several design techniques have been developed to segregate large and small vehicles in appropriately sized stalls, although enforcement remains a problem in self-park facilities.

One example[33] describes a system in which a series of relatively large parking stalls are laid out in one parking region (area) and smaller stalls in another. Larger vehicles are directed to the region having larger parking stalls and smaller vehicles to the parking region having smaller stalls. In parking facilities having no attendant on duty, such as those (1) metered, (2) without parking charge, or (3) operated on a permit or automated basis, signing and natural selection appear to be the only alternatives to attendant-controlled usage.

The Drachman System[34] employs full-size parking stalls at 45 to 60 degrees on one side of an aisle and 90-degree compact stalls

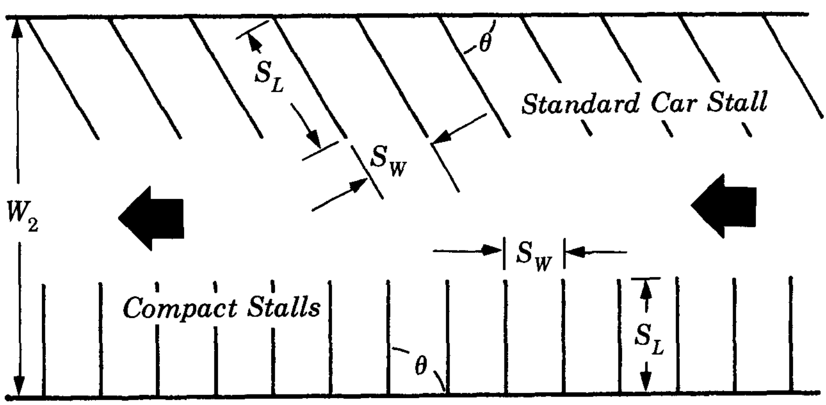
[33] One such system is "The Vehicle-Parking System," U.S. patent number 3,641727 (February 15, 1972) by Charles D. Hill.

[34] The "Drachman System of Parking," Roy P. Drachman, 810 Lawyers Title Building, Tucson, Arizona 85701. Although this system is not patented, Mr. Drachman has initiated an honor system requesting users of the Drachman System to contribute to the University of Arizona Medical School.

on the opposite side (see Figure 25). With a unit depth (width of parking module) of 50 to 55 feet (15 to 17 meters), the most persuasive claim for this system is that large vehicles cannot turn into the 90-degree compact parking stalls without backing at least once to complete the parking maneuver. Thus fewer standard-size automobiles would find the smaller 90-degree stalls convenient. With one-way aisles necessary to this system, there is a possibility of drivers unparking from the 90-degree stalls and inadvertently leaving in the direction opposite to the intended traffic movement.

Another design solution for stall-size segregation in parking garages involves using end bays for compact parking, thereby allowing center parking rows to be offset to gain additional parking stalls (see Figure 26).

Parking for the Handicapped and Bicyclists. Several states now require that all new parking facilities provide special extra-wide



Module Width (W_2)	Parking Angle (θ)	Compact Car Stall Width (S_W)	Standard Car Stall Width (S_W)	Stall Length (S_L)
54	60		9.0	18.0
54	90	7.5		15.0
50	60		9.0	18.0
50	90	7.5		15.0
48	45		9.0	18.0
48	90	7.5		15.0

FIGURE 25. Drachman System of Parking.

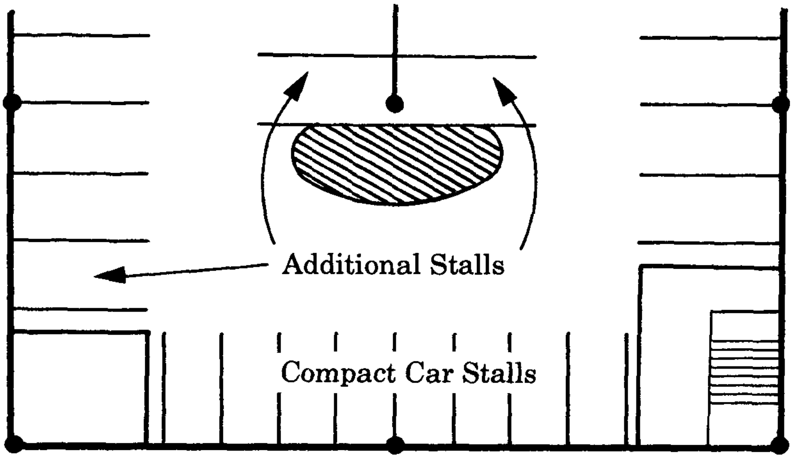


FIGURE 26. End bay arrangement of compact stalls.

stalls for the physically handicapped. The number required is usually based on a percentage of total stalls provided in the facility. Widths range from 10 to 12 feet (3 to 3.7 meters). Parking stalls for the handicapped are generally located near elevators or on ground-level floors.

Bicycle parking in garage facilities has not been widespread, possibly because there has not been the demand. However, numerous bicycle storage rack designs are available, and some garage facilities have found demand for bicycle parking. Most often, bicycle storage is fitted to otherwise unusable spaces on ground floors. For security reasons, bicycle storage areas should be located in areas where cashiers or other stationed garage personnel can see them.

PLANNING AND DESIGN DETAILS

Remaining sections of this chapter deal with current design practices for parking structure elements such as ceiling heights, drainage and plumbing provisions, ventilation and heating, lighting, floor and stall markings, internal directional and informational signing, and safety and security measures.

Ceiling Height

Ceiling heights have been reduced in past years as a result of lower automobile heights and recognition that parking garage storage levels seldom are converted to other uses. Consideration should be given, however, to increased ceiling heights on the

Low ceilings require careful placement of lighting fixtures and overhead signs so that these garage components can function adequately without high risk of damage from vehicles. Building components such as water lines, drainage lines, and air ducts, should not encroach on overhead or lateral clearances. This appears to be a frequent problem in garages built beneath non-parking uses such as offices.

Drainage and Plumbing

Storage floors should be sloped 2 percent (approximately ¼ inch per foot or 2 centimeters per meter) for cast-in-place floors, and 1 percent (approximately ⅛ inch per foot or 1 centimeter per meter) for precast floors, at right angles to aisles to drain water or melting snow that drips from parked vehicles. Drainage should be away from aisles to provide a reasonably dry and puddle-free surface for vehicular and pedestrian movements.

Damage to automobile finishes from oil and chemical-saturated water drippings leaching through structure floors onto vehicles parked below is a common customer complaint. Many water-proofing products, techniques and construction methods are available to eliminate this condition, and every effort should be made in preliminary design and construction stages to assure waterproof construction. Proper drainage and waterproofing can be particularly important in structures providing integrated commercial nonparking uses.

Floor drains should be located at frequent intervals and in such a manner that water pooling caused by trash-clogged drains or unusually heavy runoff will not impede or endanger pedestrian traffic movements, or damage equipment controls housed in the structure.

If future expansion is envisioned, underground drainage pipes should be sized and constructed initially for the maximum runoff surface area of the expanded structure. Vertical expansion does not increase the roof area; however, horizontal expansion increases roof area and drainage requirements.

Frequently omitted, either as an oversight or as a cost factor, is the provision of water supply outlets on each parking level to permit convenient washing of floor and ramp surfaces. This relatively small cost item should always be provided.

Lighting

Lighting varies greatly among different parking garages. Accounting for these variances are obvious differences in designer interpretations of minimum acceptable light levels, and fixture placement and type. Less obvious reasons for variance include dirty fixtures, low ambient air temperature, and fixture age—factors significantly reducing lighting effectiveness.

Fluorescent lighting tubes, for instance, can lose 20 percent of their light output during an 8,000-hour cycle, with over half of this loss occuring during the first 2,000 hours of operation.[35] Output of fluorescent tubes, normally measured at 25 degrees Centigrade, will be reduced by approximately 30 percent when operating at the freezing point.

Adequate lighting is necessary not only for safe movement of vehicles and pedestrians but also for the security of patrons and parked vehicles. The amount of illumination that should be provided depends on the interaction among such factors as visibility, visual comfort, light distribution, and lighting system geometry. Basically, the quality of lighting is determined by four characteristics: (1) lighting level; (2) lighting level uniformity; (3) restriction of glare; and (4) the degree to which lighting delineates garage pavement and wall surfaces.

Desirable Light Levels. Entrance and exit areas should be provided with 50 horizontal footcandles of illumination for the first 10 seconds of driving time inside the structure. Aisles should have an illumination range of 2 to 5 horizontal footcandles.

Higher light levels are needed at entrance and exit points to minimize effects of sudden changes in light levels between the structure and outside. Higher levels of illumination (minimum of 15 footcandles) are also suggested for areas where drivers are expected to follow a turning path, or where aisles intersect. Remote areas that may be subject to security problems including stairways and passenger elevators, should also have higher illumination levels (20 to 50 footcandles).

Common practice in parking garage lighting design concentrates light on aisles and ramps, with spillover lighting often being adequate to illuminate parking stalls.

Incandescent vaportight fixtures, mercury vapor, and pressurized sodium lights all have application in parking garage lighting; however, fluorescent tubes were predominant in facilities surveyed. Popular arrangements for fluorescent fixtures involve mounting tubes parallel and across from each other along sides of aisles or

[35] John Glanville, "Car Park Lighting," *Traffic Engineering and Control* (March 1969): 571.

above the center-line of aisles. The latter arrangement may be more susceptible to damage from vehicular traffic, but generally requires fewer fixtures.

Lighting fixture placement requires consideration of economy, and protection against vehicular damage, vandalism, and weather. Fixtures must be located to minimize glare and obstruction of driver vision while maximizing servicing convenience.

Good design practice is to install lighting and other electrical controls in a central panel located conveniently to garage personnel and secure from unauthorized use or tampering. It is desirable to have independently controlled lighting on each parking level, to allow lights to be turned off on parking levels not used in slack periods.

Roof-level placement of lights and supports is recommended at ends of parking modules and along boundaries of adjoining modules, so as not to impede traffic movements. Light-standard locations must avoid spillover lighting and glare that could adversely affect adjacent properties.

Ventilation

Mechanical ventilation to remove harmful automobile exhaust gases is essential in developing *underground* parking garages. Except for very special circumstances, most above-ground parking garages are ventilated naturally, since they generally use open-wall designs.

Carbon Monoxide Hazard. Carbon monoxide, the most voluminous of detrimental elements in automobile exhaust gases, is odorless, colorless, and tasteless. It can cause unconsciousness and death, although the more likely danger in parking garages is associated with impaired reaction time and visual acuity affecting driving coordination and ability to operate a vehicle.

Carbon monoxide, contrary to many opinions, is the same weight as air and usually concentrates about 2 feet (0.61 meters) above the floor—the approximate elevation of vehicular exhaust systems. It tends to collect heavily in parking garage corners that are not adequately ventilated, and near curb lines at street levels.

Air Exhaust-Intake Requirements. Building codes frequently specify how much inside air over a specific time must be exhausted by mechanical means and replaced with outside air in underground and enclosed parking structures. In addition, codes often specify where air changes must be made, such as near the floor and/or ceiling. However, different operating characteristics of individual buildings prevent development of a rigid standard on how many air changes per hour are needed.

Generally, three changes of air per hour are minimal requirements, with seven or eight air changes per hour often needed for peak operating periods. However, in some facilities, even 14 changes have proved to be insufficient. In practice, the quantity of noxious foul-smelling exhaust gases usually reaches an intolerable stage long before harmful amounts of carbon monoxide are present.

Ventilation should be sufficient to prevent accumulation of carbon monoxide levels in excess of 100 parts per million. A simplified flow system of air through the garage has proved most successful by introducing new air at a point approximately two feet (0.61 meters) above the garage floor.

Carbon Monoxide Detection. Ventilation equipment operating and maintenance costs can be comparatively expensive. Recognizing economies involved in operating ventilation equipment at partial capacity during slack periods of parking activity (in lieu of full capacity), many building codes now allow partial capacity operation if monitored by an approved type of carbon monoxide detection system.

Three commonly used types of systems are employed to detect and measure carbon monoxide concentrations.[36]

1. The "heat of reaction" method passes an air sample through a heated chamber containing a catalyst that promotes oxidation of carbon monoxide to form carbon dioxide. Generated heat from this reaction is in proportion to carbon monoxide concentrations in the sample. Temperature change is measured by thermocouples and amplified to provide a signal to actuate alarm circuits if the reading is beyond prescribed limits.

2. A second method, the "infra-red absorption" method works on the principle of carbon monoxide absorbing infra-red radiation in proportion to amounts of carbon monoxide in an air sample. Air sample comparisons are made against a reference cell containing a known standard gas to determine carbon monoxide amounts contained in the sample.

3. The "colormetric" analyzer is a third system. A sensing material responds to the presence of carbon monoxide by changing color. Color change is measured by instrumentation and relayed to activate a signal alarm circuit.

[36] Donald F. Roos, "Ventilation System Control for Underground Parking Garages," *Parking*, (Fall 1968): 21.

The economic feasibility of carbon monoxide detection systems depends on costs, including operation and maintenance, as compared to costs of operating the ventilation system at full capacity during operating hours. It is generally less costly to integrate a carbon monoxide detection system with initial construction rather than to add it later. Consequently, ventilation needs and controls should be determined in preconstruction planning and design stages.

Parking Garage Heating

Once widely practiced, parking garage heating is now seldom considered necessary in vehicle storage areas. The manager's office, cashier booths, and enclosed areas for the exclusive use of pedestrians are the only places generally heated in parking garages.

In regions of heavy snowfall and low temperature extremes, pavement heating has been used to free exposed driving surfaces of ice accumulations. It is usually limited to entrances, exits and exposed ramp surfaces.

Floor Markings and Stall Delineation

Floor pavement markings should delineate parking stalls and give warning and directional messages.

It is nearly universal practice to delineate stalls in public parking facilities. Marking stall side boundaries aids drivers in positioning their vehicles, assuring efficient floor space usage. Single paint lines 4 to 6 inches (10 to 15 centimeters) wide are most commonly used to mark parking stalls. Double lines between stalls further aid drivers in correctly positioning vehicles. Parking stall delineations can be extended up walls, giving drivers highly visible reference guides, but this is not commonly done.

General consensus of garage operators is that yellow paint lines remain visible longer than white, but no conclusions have been developed as to which color is actually best.

Shortening parking stall length delineations to 14 or 15 feet (4.2 to 4.5 meters) is one technique that encourages drivers to pull as far as possible into parking stalls. Vehicle restraining devices should be used at backs of stalls. These devices may be bumper stops or wheel stops. Suggested wheel stop locations are illustrated in Figure 28.

Alternative Marking Methods. Maintaining markings is important, since they become worn quickly and lose effectiveness. While painted stall markings are by far the most common form of

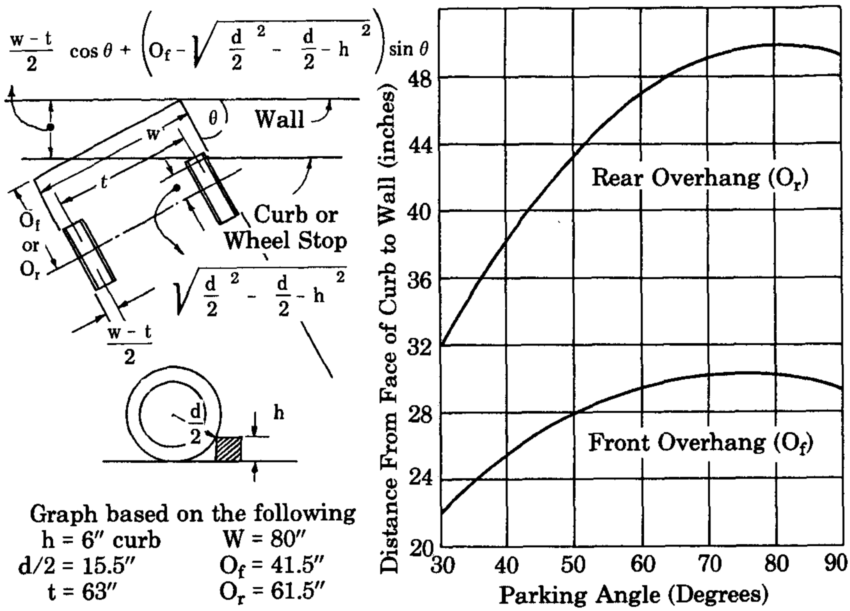


FIGURE 28. Suggested wheel stop locations and curb-to-wall clearances for various parking angles.

stall delineation, other materials and methods have been used successfully. Striping tape and raised surface markers are used in some parking facilities. Low concrete islands were common in earlier garages to reduce labor costs of periodic restriping, but were found to hamper snow removal and floor cleaning, not to mention inflexibilities of modifying parking geometrics at later dates.

The use of curbing inside parking garages is declining because of inflexibility, cost, and maintenance. However, pedestrian safety islands are still used in very sensitive areas where pedestrian-automobile crossings are unavoidable or vehicular channelization is critical. Protection of stationary objects, such as cashier booths, requires barrier-type delineation.

Signing

All vehicle and pedestrian paths should be clearly marked by legible, well-lighted signs. It may not be necessary to provide special illuminated signs if sign placement can take advantage of garage lighting. Both directional and informational signs should conform to graphic style standards applicable to street signing.

ground level to accommodate night parking of trucks, or to provide a potential for later conversion to commercial (nonparking) uses.

Functional design reasons underlying minimum ceiling heights are reductions in ramp grades and lengths. However, low ceiling heights have been a cause for objection because they prohibit entrance by certain types of emergency vehicles. Many types of recreational vehicles—particularly light trucks with camper bodies or mounts that are increasing in usage as dual-purpose transportation vehicles—are also excluded by low ceilings. Other common objections arise from damage to automobile radio antennas and damage caused to garage fixtures. (Overhead clearance signing should be provided outside garage entrances.)

Complaints are likely to increase, since citizen-band radios and their relatively expensive antenna installations are in rapid proliferation. Sufficient ceiling height to provide antenna clearance is not practical. A completely satisfactory solution to this problem has not been devised.

Minimum clear ceiling height should be 7.0 feet (2.13 meters). However, 7.5 feet (2.29 meters) is desirable.

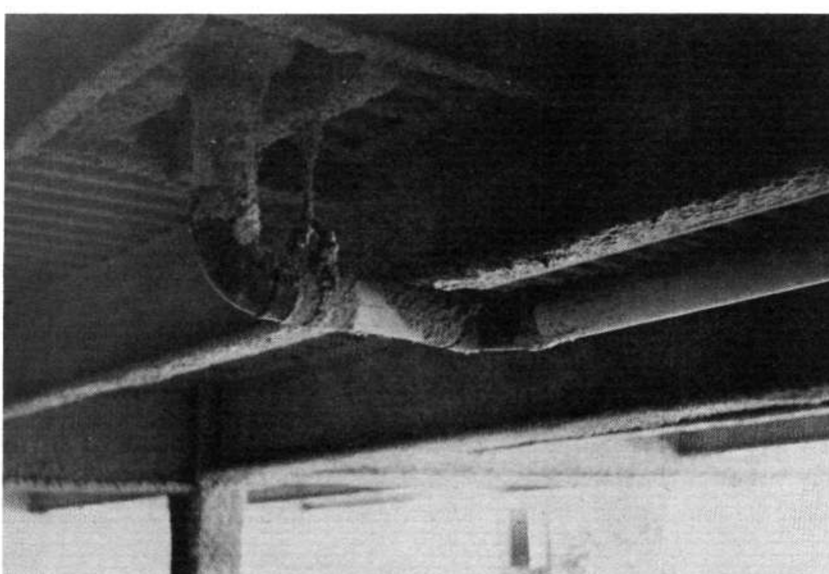


FIGURE 27. Water drain encroaching on already restricted 6.9-foot (2.1 meters) ceiling over driving aisle.

Directional signs should be placed strategically to direct drivers in prescribed patterns to reach parking spaces and exits. Once drivers leave parked vehicles and become pedestrians, it is imperative for safety and good public relations that pedestrian access points, stairways, and elevators be visible from any parking stall location.

Open-wall design is a natural aid to pedestrian orientation, placing adjacent streets and buildings in view. Large parking garages with multiple parking modules, or underground garages, may require signing to orient properly both drivers and pedestrians.

In self-park facilities, parking stalls, sections and/or floors are usually identified by numbers and/or letters to facilitate easy retrieval of parked vehicles.

Use of Color Coding. Color coding, often in conjunction with numbers or letters, is used in some facilities to help customers find their parked cars. Color coding can be used in several ways, including color strips around columns, colored doors and elevator buttons, floor strips, and actually spelling out the color by name in conspicuous locations. An important consideration in color coding, or number/letter systems, is that the patron be made aware of the existence and purpose of the identification system.

Changeable-Message Signs. Internally illuminated "blank out" type signs that provide changeable messages are increasing in parking garage use. This type of sign, coupled with automatic vehicle sensing and counting systems, can signal drivers when certain parking sections become full. Changeable message signs can save travel time within parking facilities, improving operations as well as public relations.

Timing of Decisions on Sign Plans. Difficulties are often experienced in determining an effective signing plan from parking

FIGURE 29. An example of specific signing to remind patrons to note where they have parked.

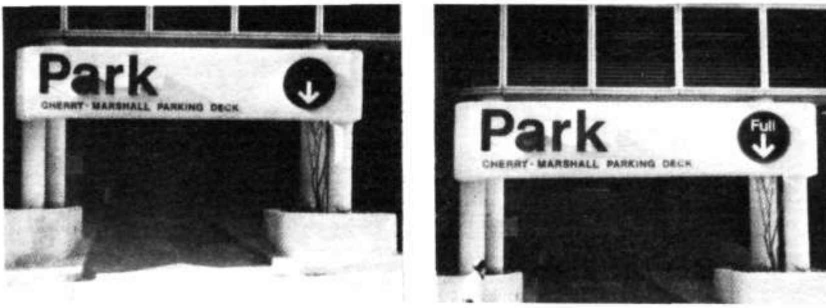


FIGURE 30. Garage entrance utilizing a "blank out" type full sign.

garage construction plans. Some designers make it a practice to postpone sign plans until garage construction is nearly complete. This enables field investigation to determine and assess sign locations and needs on the basis of actual conditions encountered in a parking structure. The delayed timing helps to assure that sign locations will not be obstructed by parked vehicles or building components. Field investigations also afford the opportunity to evaluate required size and lighting for sign graphics.

Safety and Security

Safety and security of persons and property is sometimes a problem in self-park garage facilities. Accordingly, some garages have made post-construction modifications to limit pedestrian entry to specific access points in order to monitor movements (Figure 31). Electronic audio and/or visual equipment are other security devices typically added after construction.

Active and Passive Security. Security techniques are classified as either active or passive. Active security is defined as any technique requiring a human response, such as security patrols, guards, or audio-visual surveillance. Any device or technique not requiring a human response, such as fencing, lighting, and locks, is defined as passive security.[37]

Security begins with measures designed into a structure. Lighting, for example, is basic to safety and security and is a valuable deterrent to criminal acts and loitering. Overlighting of remote areas in a garage can be justified on a security basis. Architectual design should eliminate possible hiding places, and openings that

[37] Charles J. Sharitz, "Patron Parking Security—A Must Today," *Parking* (July 1975): 21.

FIGURE 31. Chain-link fencing added to the ground-level of this garage prevents random pedestrian entry.

could allow random pedestrian access. Open-wall garage design, used in most above-ground parking garages, is particularly vulnerable to security problems if the design does not provide fencing or small-opening screening that prevents random entry.

All fixtures and equipment should be reasonably secure from tampering and acts of vandalism. Painting garage interiors in light colors improves lighting effects while contributing to improved aesthetics and security.

Fake or dummy television monitoring cameras, both fixed and revolving, are sometimes used as a psychological deterrence. Specific signing to the effect that electronic surveillance is used, or that security guards are on duty to patrol, are other popular psychological approaches. How much deterrence value these types of passive techniques have would be difficult to establish, although most garage patrons appreciate the assurances offered.

Stairwell and Elevator Security. Most local building codes require smokeproof and fireproof stairwells. As a result, most stairwells are enclosed with masonry walls. These stairwells, and most elevator cabs, are virtually soundproof and visually obscure from other garage areas, representing potential security problems.

Where building codes permit, stairwells have been constructed by use of safety glass or transparent plastic as an enclosure, or

FIGURE 32. Where building codes permit, transparent stairwell enclosures can improve security.

as open stairwells, thus reducing security problems. Elevators can have one or more walls of transparent material, but it may be more practical to monitor elevators with electronic surveillance techniques.

Nighttime Security. During periods when parking activity is substantially less than the garage capacity, as during night operation, there should be a means of securing unused parking levels from use, including stairwells and elevators. If the garage is not operated on a 24-hour basis, the entire facility should be secured from vehicular and pedestrian access when not in operation. However, over half of the surveyed garage facilities that closed in the evening either did not have the means to lock the facility, or did not believe it was necessary.

Security Patrols and Surveillance. Most parking garages use some form of active security to supplement passive techniques. Publicly-owned parking garages often rely on city police patrols. Some garages with pronounced security problems use the services of professional security guards or off-duty policemen. Uniformed garage personnel can provide effective security by reassuring parking patrons and serving as a deterrent to unauthorized entry or loitering.

Use of electronic visual surveillance systems depends on adequate and uniform lighting. It usually requires the full attention of at least one employee if not used in conjunction with an electronic audio monitoring system. Electronic visual monitoring in parking garages generally is confined to elevator cabs and passenger waiting areas. In some instances, electronic visual surveillance systems can also monitor traffic movements.

Audio Surveillance Systems. Electronic audio surveillance systems consist of two different types: (1) sound amplification throughout the entire parking garage, or (2) sound transmission to a specific monitoring station, usually the manager's office or cashier's booth. To be most effective, an audio system should allow two-way communication.

Fireproofing and Control. Fires in parking structures have not been a significant problem. The combustible material per square foot of floor area in parking structures is considerably less than that of nonparking structures. Parking garage designers and operators believe that many building codes require an inordinate amount of fire protection in garage facilities.

A full-scale fire test was conducted in a modern, open-air, exposed steel parking structure in Scranton, Pennsylvania on October 15, 1972. This test, sponsored by the American Iron and Steel Institute, determined the effect such a fire would have on parked cars and on the steel parking structure.

The test was staged by using cars parked approximately 2 feet apart in the test area. The burn car was positioned 2 feet 8 inches (81 centimeters) from a steel support column and 2 feet 6¼ inches (77 centimeters) below an overhead steel girder. Cars were parked on the deck above the test area to provide typical deck loading. The fuel tank of the test car was filled with 10 gallons (37.8 liters) of gasoline and the cap tightened.

Crumpled newspapers and oil-soaked rags were placed in the front and rear seats of the test car, and the windows were partially rolled down because cars in previous tests would not burn with the windows up. The outside air temperature in Scranton was 41 degrees F. (9 degrees C.) with a 15-to 20-mile-per-hour (24-to 32-kilometers-per-hour) wind. Figure 33 is a photo sequence of the Scranton Fire Test.

The test confirmed results of previous tests conducted in Japan, England, and Switzerland, demonstrating that (1) an automobile has a low combustible content; (2) most of the combustibles are in the interior of the car or in the gas tank, reducing the chance of fire spreading; (3) there is no spread of flammable liquid spill to other parts of the structure; (4) fill pipe and fuel line provided sufficient pressure relief during the car fire to prevent explosion of the gas tank; and (5) exposed steel structural members were undamaged by the generated flame and heat. The parking garage test area was open for business as usual the following morning.

Results from the Scranton Fire Test and other tests conducted in England, Japan, and Switzerland are being used as a basis for reducing fire code restrictions and lowering fire insurance rates for open-wall parking structures.

FIGURE 33. The Scranton Fire Test, Municipal Parking Structure, Scranton, Pennsylvania, October 15, 1972.

A. Zero minutes—Newspaper and oil-soaked rags are ignited in the burn car. Previous tests showed that the same burning pattern occurred when the fire was ignited under the engine or inside the car.

B. $5^3/_4$-minutes—The rear window of the burn car gives way.

C. 11 minutes—All the windows of the burn car are broken by the flames. Flames are impinging on the exposed steel girder. Air temperature above the windshield reaches a maximum of 810 degrees F. Temperature of the steel girder is 260 degrees F.

D. 17 minutes—Right and left rear tires of burn car catch fire. Steel girder temperature is 420 degrees F.

E. 20 minutes—Interior of the car is consumed by fire. Right rear tire blows.

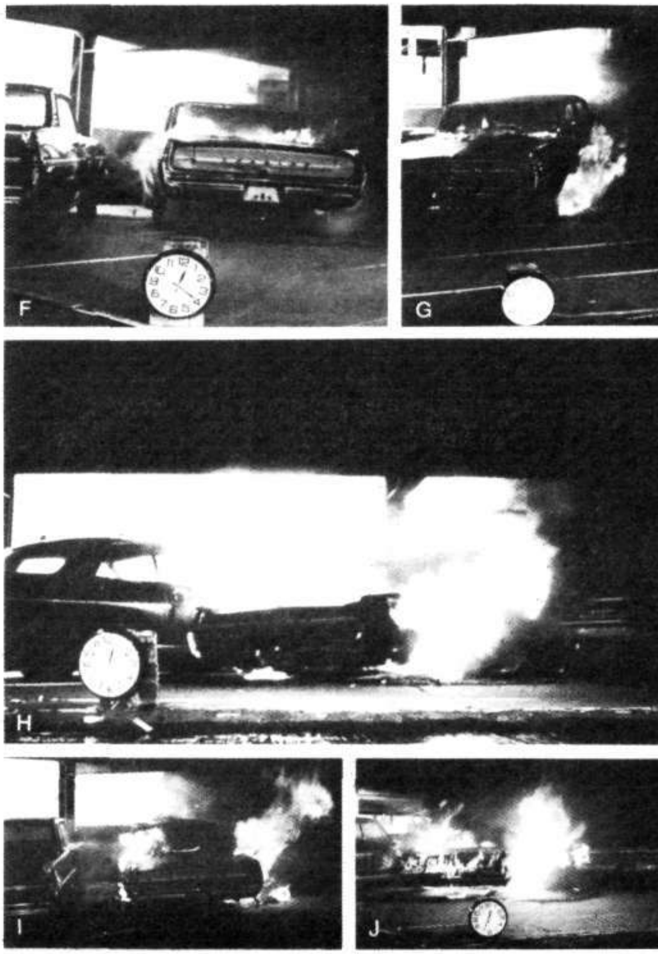


FIGURE 33 (*continued*)

F. 21 minutes–Left rear tire blows. Steel girder temperature decreases to 415 degrees F.

G. 24 minutes–Left front tire of burn car blows. Flames impinge on the adjacent car.

H. 26 minutes–Right front tire blows. Gasoline vapors from gas tank catch fire.

I. 31 minutes–Gas tank of burn car is engulfed in flames. Heated gasoline in the tank boils over and burns. There is no spread of burning gasoline to adjacent cars. It is all consumed under the burn car.

J. 37 minutes–Plastic reflector on the tail light of adjacent car ignites. It burns itself out in 5 minutes with no further fire spread.

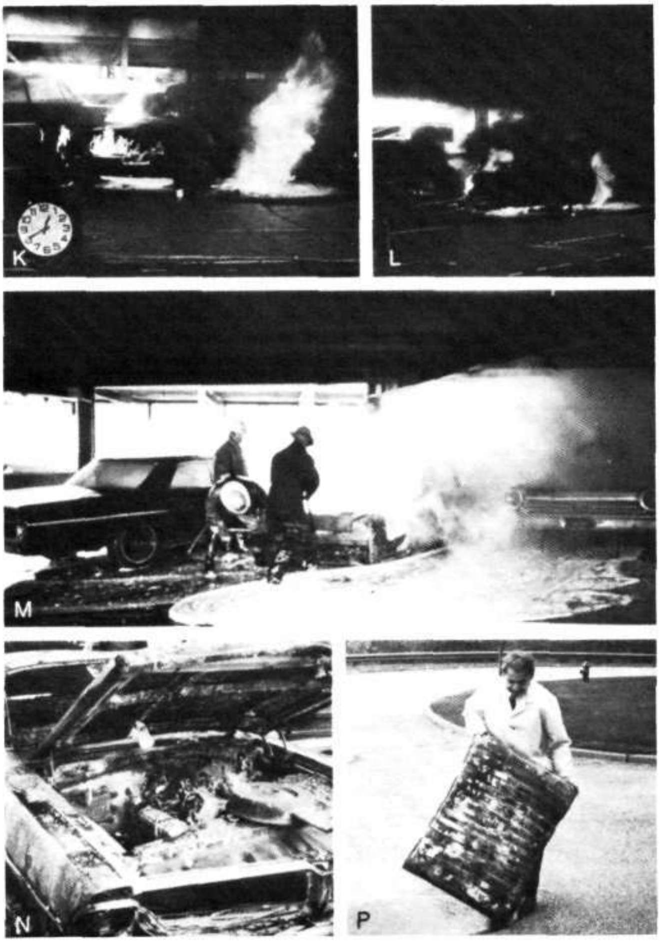


FIGURE 33 (*continued*)

K. 41 minutes—The steel girder reaches a maximum temperature of 440 degrees F. Exposed steel girder reaches its maximum deflection of 1-$^{5}/_{8}$ inches. Maximum elongation is $^{1}/_{8}$ inch. Deflection and elongation return to zero, or pre-test condition, when steel cools.

L. 48 minutes—Fire has settled down, temperature and deflection readings are decreasing. Nothing more can be accomplished by letting fire continue.

M. 50 minutes—Scranton Fire Bureau personnel extinguish the fire.

N. Engine compartment of burned-out car.

P. Gas tank remained intact. All but two quarts of the original 10 gallons gasoline were consumed during test.

Source: American Iron and Steel Institute, 150 East 42nd Street, New York, N.Y. 10017. A 16-mm color sound film is available for viewing on request from this source.

Because of past experience with parking garages and the likely nature of any occurring fires, some cities have granted variances to eliminate sprinkler-system requirements in parking structures. Automobile fires usually consist of smoldering upholstery and electrical fires, both of which are contained or enclosed within the vehicle. Sprinkling of water or foam on the vehicle is therefore of questionable help.

The practice of locating fire extinguishers throughout a parking garage is generally not recommended, since they are frequently stolen or damaged by vandals. An acceptable practice is to use larger extinguisher systems, mounted on handcarts and situated at central locations in the garage. The larger size discourages theft and provides more fire-fighting potential. Locations that allow monitoring of equipment discourages vandalism.

Many newer parking garages have water or foam fire-fighting systems constructed integrally, with firehose connections located at strategic points on walls throughout the structure. Consideration should be given also to rooftop standpipes for firehose connections that can be used for fighting fires in adjacent buildings as well as in the parking structure.

Heat detection systems are available that sound an alarm when temperatures rise beyond prescribed limits within a specified time limit. However, heat- and smoke-detection systems were not commonly used in the parking structures surveyed.

Chapter V

VEHICULAR INTERFLOOR TRAVEL SYSTEMS

Vehicular travel between different levels in a parking structure can be provided by a sloping surface (ramp) that permits vehicles to be driven between parking levels, or by mechanical conveyances. This chapter is concerned principally with ramp-type parking garages. However, the advantages, disadvantages, and operating characteristics of mechanical parking garages also are briefly described.

Ramp Systems

A number of different interfloor ramp systems can be used to enable vehicles to traverse the approximate 10-foot (3 meter) elevation between parking levels. Some of these systems provide separate and exclusive ramps, while others make use of continuous sloping floors that accommodate both parked vehicles and interfloor travel.

Ramps may be straight, curved, or a combination. No single ramp system is best for all applications. The choice should be based on site shape and dimensions, and parking demand characteristics. Ramps may be designed for one-way or two-way traffic movement. However, one-lane-wide ramps should not be operated on a reversible two-way basis.

In some instances, site topography will allow direct access to several parking levels from the street system. This is a desirable arrangement, since it leaves more space for parking and provides more flexibility for traffic distribution between the street system and parking facility.

Time and convenience are important to ramp travel and should be considered in any comparison of ramp types. Actual travel time on ramps varies little among different ramp system types; however, some ramp systems have more potential for delay caused by conflicting traffic movements that limit ramp capacity. Other factors influencing ramp design include accident hazards, construction cost, and ability to accommodate vehicles and drivers conveniently.

Analysis of Ramp Movements

A ramp system includes any portion of storage floors used by vehicles moving between levels. Nearly every successful ramp system requires vehicles to follow an approximate circular path when traveling between parking levels. The number of 360-degree rotations required to circulate through the garage and parking structure height are major concerns, particularly in self-park designs.

It is generally desirable to limit the maximum number of complete rotations to five or six. Depending on ramp system type, this will control the maximum desirable number of parking levels, and limit the number of parking spaces a driver must pass during garage travel. (Although no consensus of opinion was found, one interviewed garage designer suggested that 400 parking spaces is an absolute maximum to expect a driver to pass between entering a garage and reaching a parking space.)

Drivers are sometimes distracted or disturbed by the awareness of height when traveling on upper parking levels—a condition that can be accentuated if parking levels extend higher than adjacent buildings. To reduce driver distraction, parapet walls along driving ramps should be designed to limit the driver's view of surroundings outside the parking structure.

Clearway and Adjacent Ramp Types. Ramp systems may be divided into two types, based on the amount of interference between ramp traffic and parking-unparking operations. Ramp systems designed on the "clearway principle"[38] provide interfloor travel paths completely separated from potentially conflicting parking-unparking movements. Ramp systems in which part or all of the ramp travel is performed on access aisles may be called the "adjacent parking" type. The number of parking stalls adjacent to the ramp may vary from a small number to the total capacity of the facility.

Clearway ramp systems provide the safest movement with least delay and, except for sloping floor designs, are preferred for self-park designs. However, the clearway ramp system is seldom feasible for small garage sites.

An adjacent-parking layout requires less area per parking stall because of the twofold use of travel paths, and consequently can be used to advantage on smaller land parcels. However, adjacent-

[38] The "Clearway Ramp" was invented and patented by the late H. L. Woolfenden. In this text the term "clearway" is used in a general sense.

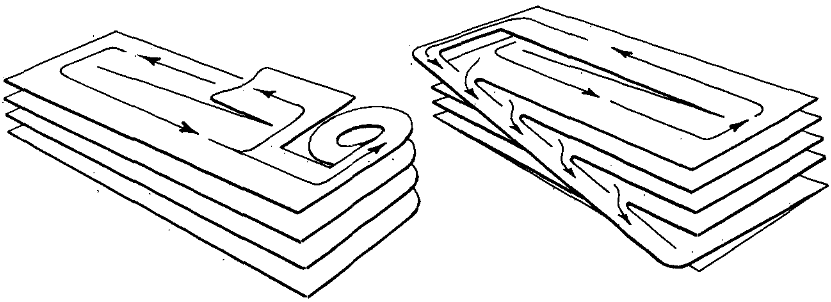


FIGURE 34. Parking garage examples that incorporate adjacent-parking ramp systems for traffic entering, and clearway ramp systems for traffic exiting the facilities.

parking ramp designs are more susceptible to traffic movement delays and potential accident-causing situations.

The actual travel speeds for free-moving vehicles on the two types of ramps do not vary greatly. Delays on the adjacent-parking type ramp system caused by parking-unparking maneuvers are difficult to measure but must be recognized as a sizeable quantity. Delays will be greater on parking levels nearest the street level, since these levels always have larger numbers of vehicles in the circulation system.

Concentric Versus Tandem Ramp Design. Ramp systems also can be classified as concentric or tandem, depending on whether the travel paths of vehicles moving up and down between parking levels revolve about the same or separate centers. Helically-curved (spiral) ramps are usually built concentrically to save space and to provide flatter grades. Straight ramp systems are designed in either concentric or tandem configurations.

Vehicles traveling on a ramp system may move either clockwise or counterclockwise. Counterclockwise rotation is generally preferred in the United States and other countries where drivers customarily sit on the left side in vehicles since it places drivers on the inside of turns, enabling better vehicle handling.

Parallel Versus Opposed Ramp Design. For vehicles to rotate in the same direction on a ramp system, up and down ramps must slope in opposite directions, requiring ramp surfaces to be opposed. If up and down ramps slope in the same direction, ramp surfaces are parallel and vehicles must rotate in opposite directions.

While no significant difference has been observed in operational ease, it is obvious that opposed ramp types are safer, since all vehicles must travel in the same direction. Parallel ramp systems are considerably cheaper to construct, however.

Geometric Ramp Types

For safety, convenience, and traffic operating efficiency, the path followed by the ramp through traffic on any floor of a parking garage should be short, with minimum turns and traffic crossings. Ramp arrangements within a garage should be consistent, in order to be as simple and comprehensible as possible.

Ramp design and arrangement is influenced by (1) orientation of ramp traffic flow to main floor street entrance and exit points and to other ramp systems that might exist in larger garages, (2) conformance of ramps with access aisles throughout each floor area, and (3) site dimensions.

Straight-Ramp Systems. Ramps within a straight-ramp system usually should be "stacked" one over another for construction economy and traffic circulation uniformity. The stacking of ramps creates a "ramp-well." From a plan view, the sum of the system's ramp-well areas and the floor area containing aisles used by ramp portal-to-portal traffic is the ramp system's area, or envelope. This extends vertically through the parking structure (with the possible exception of roof and/or basement levels).

For straight-ramp garages, the ramp system is usually rectangularly shaped (ignoring curved ramp ends), with the ramp well(s) along the structure's longer-side dimension. This is because more horizontal distance is required to satisfy ramp grade criteria than to accommodate vehicular movement between ramp ends.

Figure 35 illustrates a basic straight-ramp system having a ramp-well on one side only. In this system, vehicles follow an elliptical path, most of which is on flat surfaces. Figure 36 is a parallel straight-ramp system, with ramp-wells on two sides of the structure. Turning movements for the up and down ramps are performed in different areas, while the floor travel is performed in a two-way movement along the same aisle. Depending on structure width, the floor travel could be directionally separated. The systems represented in Figures 35 and 36 are both very adaptable to entrance and exit points on the same street.

Figure 37 is an adjacent-parking type opposed straight-ramp system. Travel paths for through up and down movements fall in the same aisle, eliminating traffic crossing points. Figure 38 illustrates a clearway type opposed straight-ramp system. Ends of opposed ramps on the main floor are pointed in opposite directions,

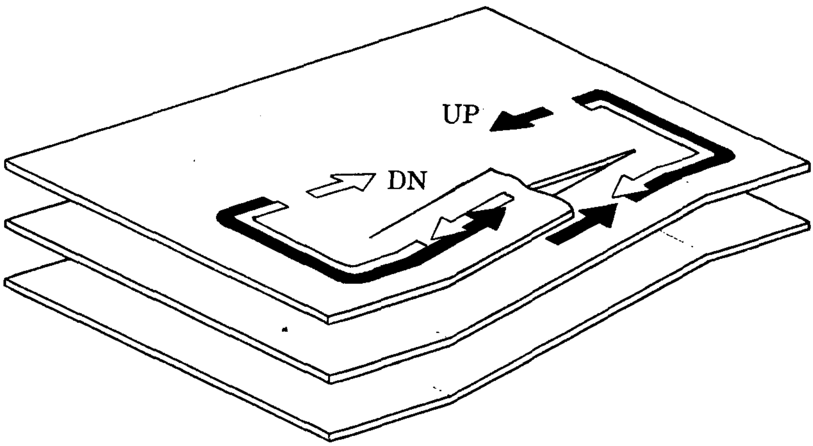


FIGURE 35. Straight ramp system with one ramp-well.

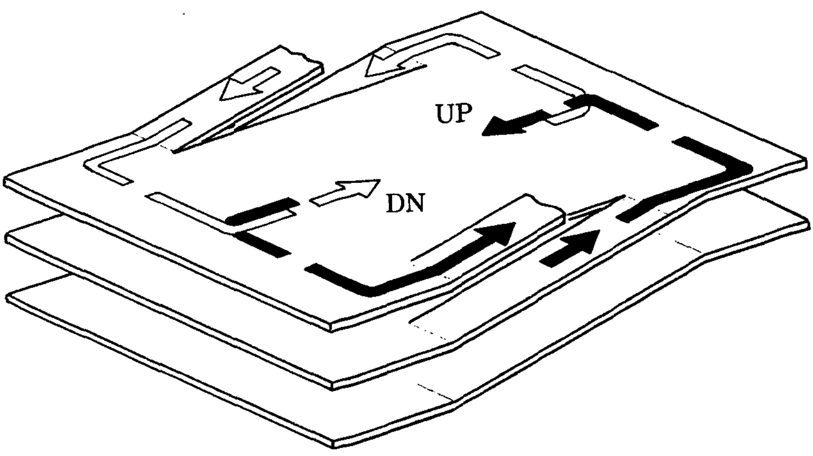


FIGURE 36. Parallel straight ramp system with ramp-wells on two structure sides.

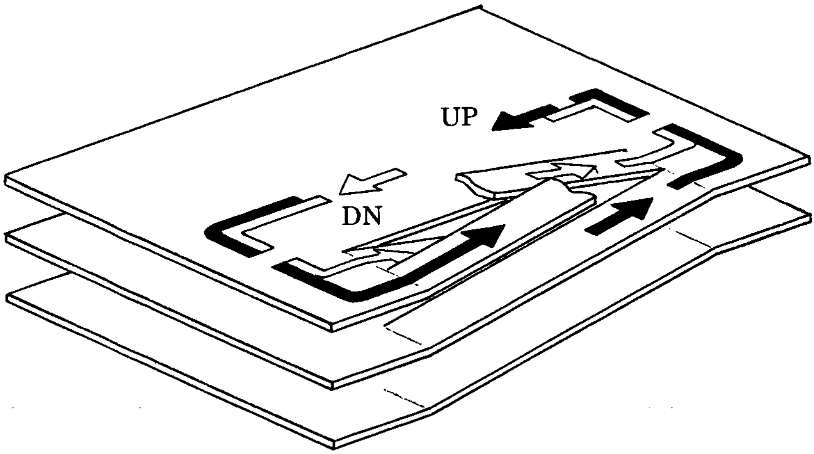


FIGURE 37. Adjacent-parking type opposed straight ramp system.

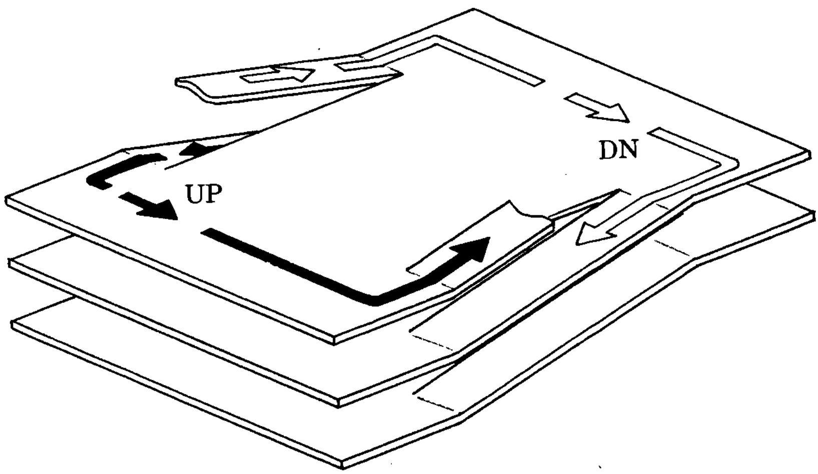


FIGURE 38. Clearway type opposed straight ramp system.

making this type suited to structures with entrance and exit points on separate streets. This design can be adapted to entrance and exit points on the same street, but requires a 180-degree turn on the main floor—necessitating additional space.

Straight-ramp systems are advantageous in relatively narrow buildings. They require less floor area than helically-curved ramps and are simple to construct, particularly in existing structures being converted to parking garages. However, sharp turns, necessary to get on and off straight ramps, are disadvantages.

Split-Level or Staggered-Floor Systems. The staggered-floor parking garage, invented by Fernand E. d'Humy, is now generally referred to as a split-level garage. It is constructed in two sections, with floor levels in one section staggered vertically by one-half story from those in adjacent sections. Short straight ramps, sloped in alternate directions and separated by the distance required to make easily a 180-degree turn between ramps, connect the half-stories.

Any combination of straight ramps can be applied to the split-level floor systems. Traffic rotation direction may be the same, in which case the aisles are one-way, thereby reducing conflicts. Turning paths may overlap, requiring less space for the ramp system. Rotation can be provided also in opposite directions, which simplifies ramp construction by having up and down ramps on the same plane.

The division between split-level structure halves may be perpendicular to the street or parallel. In the latter case, either the front or back half may be elevated. Split-level floors can overlap as much as 5 to 6 feet (1.5 to 1.8 meters) to increase space efficiency and make narrow sites workable.

Figures 39 through 42 illustrate various types of split-level configurations. Figure 41 is the most common type.

Split-level designs are particularly applicable to small, high-cost sites where maximum use of space must be achieved. Construction is relatively simple, and the design fits well on rectangular sites. This system is efficient in terms of floor space per vehicle parking stall but, like all ramp systems employing adjacent parking, frequent conflicts may arise between circulating traffic and parking-unparking vehicles.

One variation in the split-level system uses three separate sections, with the two end sections at equal elevations and staggered one-half story with respect to the center section (see Figure 42). Fifty percent fewer turns are required, thereby reducing travel time.

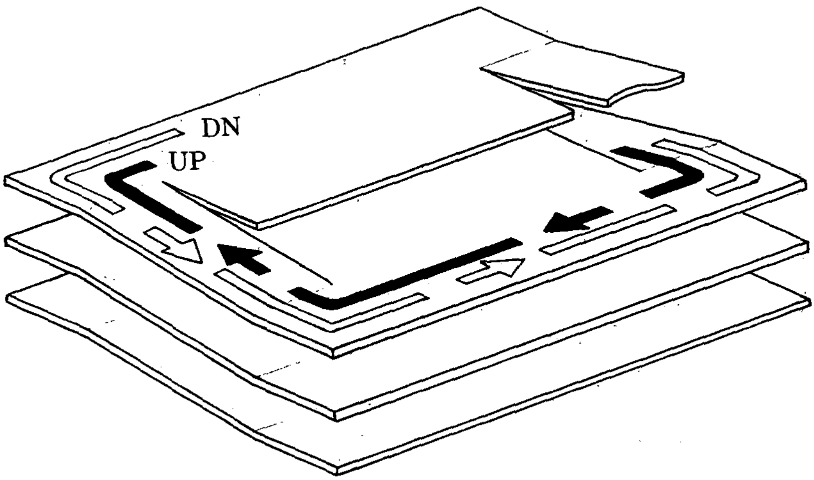


FIGURE 39. Two-way staggered floor ramp system.

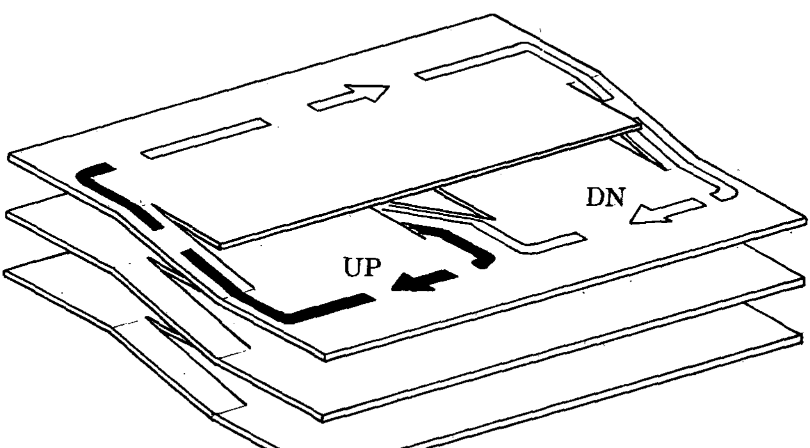


FIGURE 40. Tandem staggered floor ramp system.

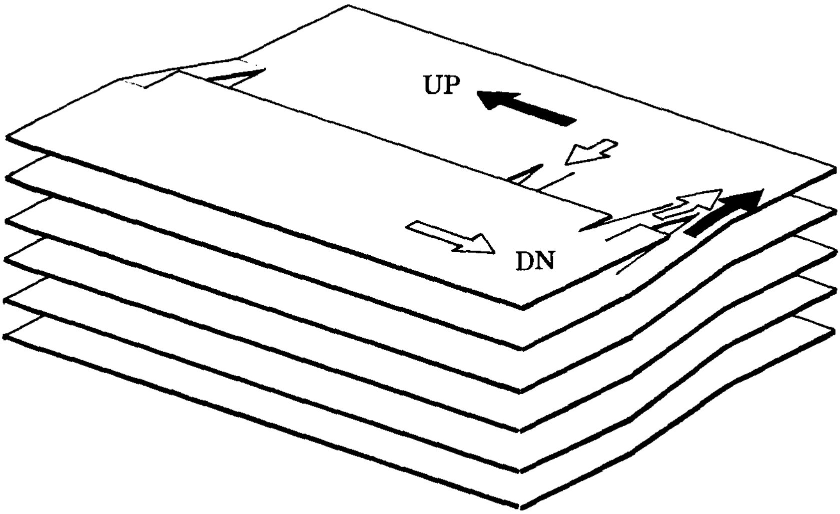


FIGURE 41. This staggered floor system provides parking on level floors and desirable one-way traffic flow.

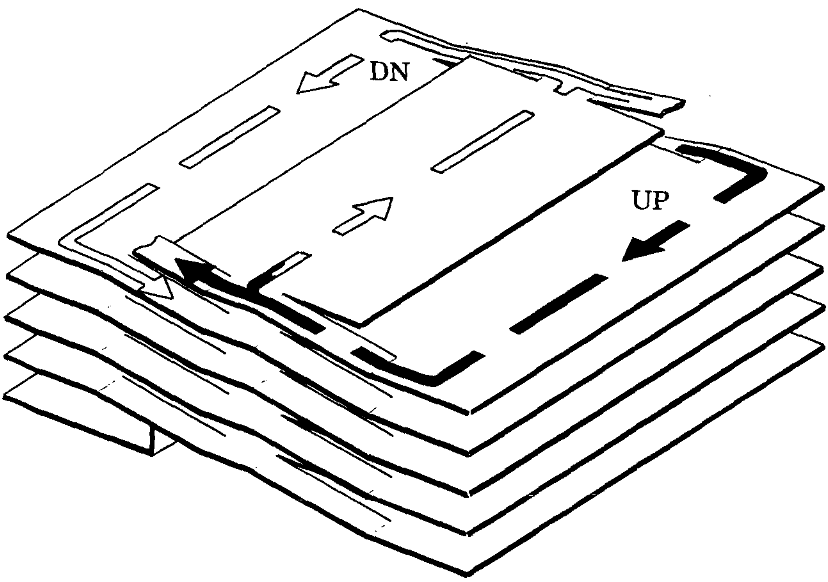


FIGURE 42. Three-level staggered floor ramp system.

However, vehicles parked on the end sections must be driven an extra half-floor when entering or leaving. "Wrong way" ramp travel is also a greater possibility with this type of design.

Sloping Floor Systems. The sloping floor parking garage, in its simplest form, contains two adjacent parking modules tilted in opposite directions, with cross-aisles at each end so that vehicles traveling the length of both aisles make a 360-degree turn to move up or down one complete parking level (Figure 43). Thus, there is no area set aside for ramps in the ordinary sense. The cross-aisles may be sloped or level.

Parking industry experience indicates that the sloping floor design is well-suited to self-park operations. The relatively flat floor slope (customarily ranging between 3 and 5 percent) permits comfortable parking and pedestrian walking. Because parking is adjacent to the interfloor circulation system, each entering customer has an opportunity to park in the first available space. However, the operational problems in adjacent parking can cause congestion during peak out-bound movements if clearway-type express ramps are not used.

Floor-to-floor travel distance is greater in sloping-floor garages than in other types of ramp garages. However, this is offset somewhat by the opportunity for greater travel speeds due to flat slopes and longer tangents.

For large structures it is desirable to have only part of the floor area sloped, with level floor sections at ends to form cross-aisles. Ramp connections at midpoints of opposite sloping floors permit one-way traffic circulation (Figure 44). It is possible to achieve one-way traffic circulation in sloping-floor layouts, with parking along aisles on every level, by using two sloping-floor garage units placed end-to-end. In the level center section where the two units meet, traffic flow can change from up to down and vice versa. This permits flexibility for angled parking, limited only by available site width (Figure 45).

Helically-Curved Ramp Systems. The helix (spiral) ramp can be a single surface that permits vehicles to travel on a continuous helical path between parking levels. When two-way traffic is handled on a single helix, the outer lane is used for up movements, since it has a larger radius of curvature and lower grade. Up movements are usually counterclockwise and down movements clockwise.

Helical ramp entrance and exit points can be located on the same side or opposite sides of the ramp coil. In either case, ramp

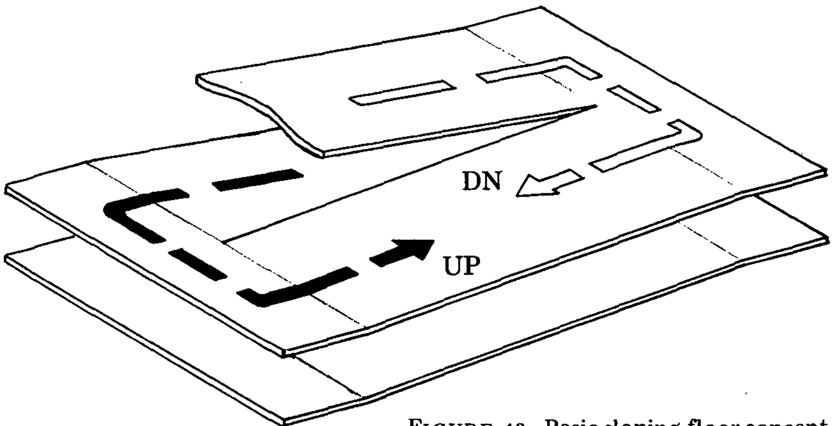


FIGURE 43. Basic sloping-floor concept.

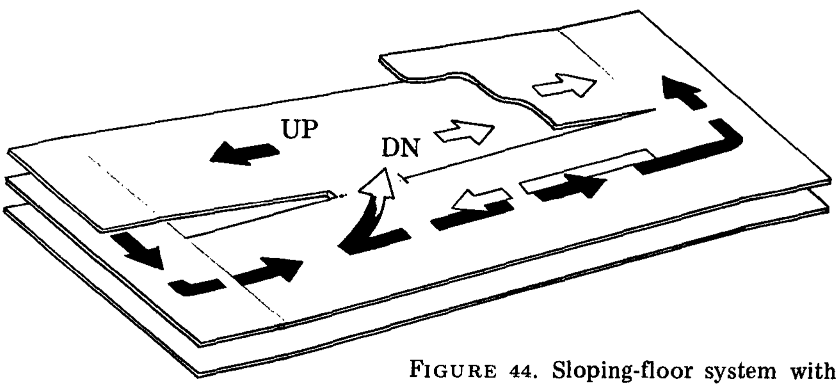


FIGURE 44. Sloping-floor system with cross over ramp at mid-point.

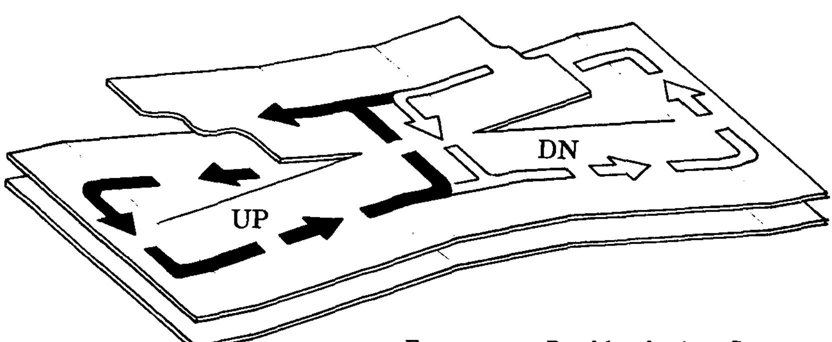


FIGURE 45. Double sloping floor system with mid-point cross over.

access points are located directly above each other on each succeeding floor. Helically-curved ramps should be of the clearway type. Examples are illustrated in Figures 46 and 47.

The double helix system (Figure 47) uses two helical-path surfaces that are sloped in opposite directions. One surface can be used for up movements, the other for down movements. The two sloping helical surfaces may be separated or they may be interwoven. Vehicle movements for both up and down travel directions are made in the same direction of rotation. In the United States and other countries using left-side drive vehicles, counterclockwise rotation is preferred.

Interwoven double helix systems are popular in tall structures (10 to 12 parking levels) because the number of 360-degree turns can be reduced by using two separated helical surfaces to serve alternate parking levels.

Traditionally, curving ramps are said to be continuous where they provide 360 degrees of rotation between two parking levels.

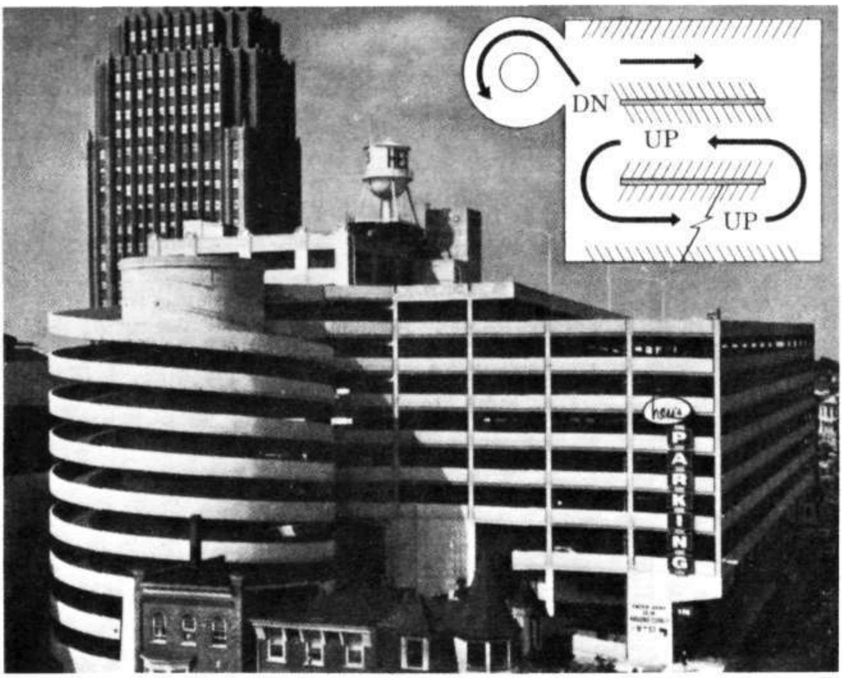


FIGURE 46. Helical ramps such as this one serving an 8-story, 750-car structure, can be used effectively for express exiting.

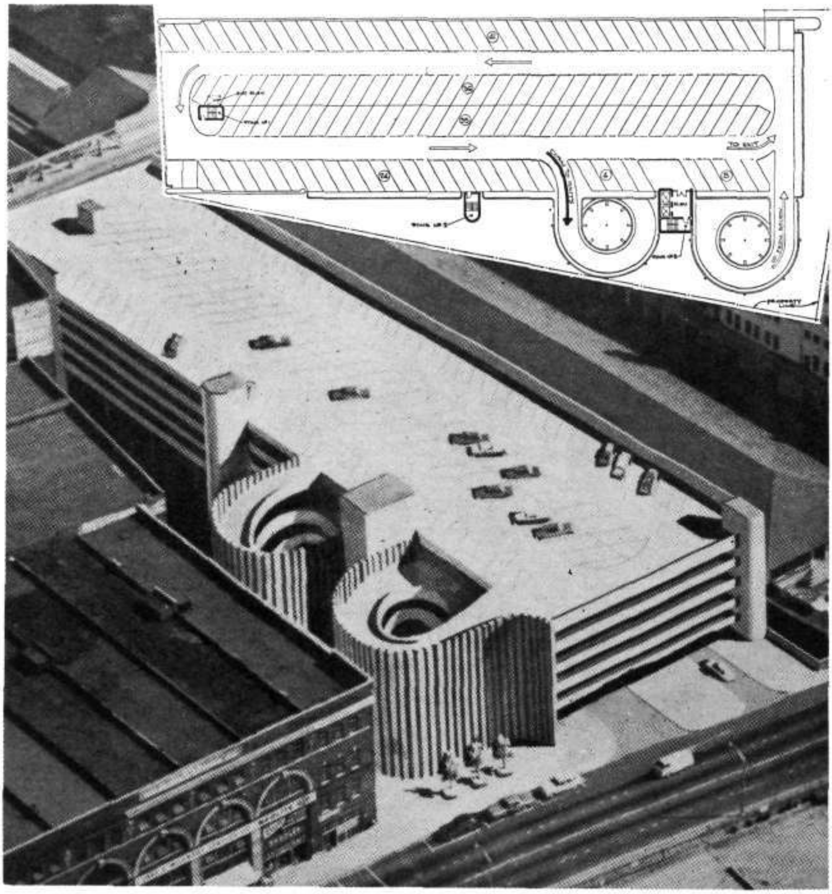


FIGURE 47. Helical ramp systems can often be advantageous for structures situated on odd-shaped sites.

The noncontinuous helically-curved ramps that provide rotation through 180 degrees are commonly referred to as semicircular—although this definition is not quite correct, since the curved section is helical in shape.

Helically-curved ramps are most often located in corners of rectangular structures to minimize floor space loss, or they are located outside the structure when additional site area is available. Helically-curved ramps require more space than straight ramps, but they can offer better traffic operation by providing gradual turning as compared to sharp turning movements usually required

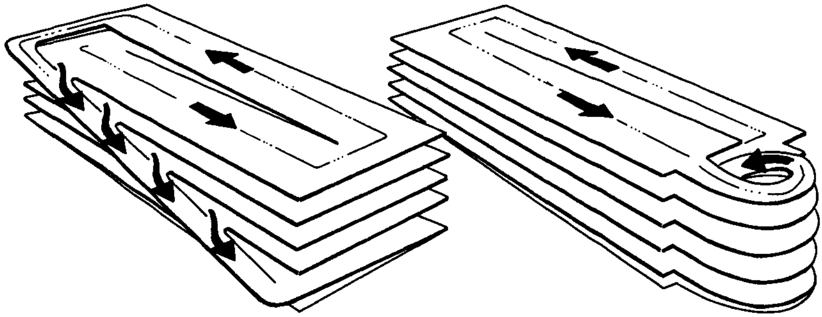


FIGURE 48. Examples of straight and helical shaped express exit ramps.

at ends of straight ramps. In addition, superelevation at ends of straight ramps may require undesirable warping of floor areas.

Express Exit Ramps. Large parking structures with frequent high-turnover conditions may be served best with an express ramp for one direction of travel—usually for exiting traffic. Express exits can be curved or straight, and are designed always on the clearway principle, providing one-way traffic movement (Figure 48). They are generally desirable to serve high-turnover transient patronage. They improve operating efficiency by reducing travel time and conflicts—but may add significantly to structure costs, since they increase the area prorated to each parking space in determinations of space-use efficiency.

Ramp Standards

Ramp design parameters governing the acceptability of such ramp features as maximum gradient and minimum radius of curvature have evolved from garage operating experience. The following discussion presents standards generally used by the parking industry.

Ramp Grades. Ramp grade (slope) is computed by multiplying floor-to-floor height by 100 and dividing by the ramp length. The difference between ramp length measured along the slope or horizontally is negligible. Grades on curving ramps are measured along the outer ramp pavement edge.

Maximum practical ramp grades are principally limited by safety considerations and the psychological effect on drivers, with hill-climbing and braking abilities of automobiles being a secondary factor. Steep ramps slow traffic movement and can be particularly hazardous when wet, requiring drivers to be excessively cautious.

For self-park designs, maximum ramp grades should not exceed

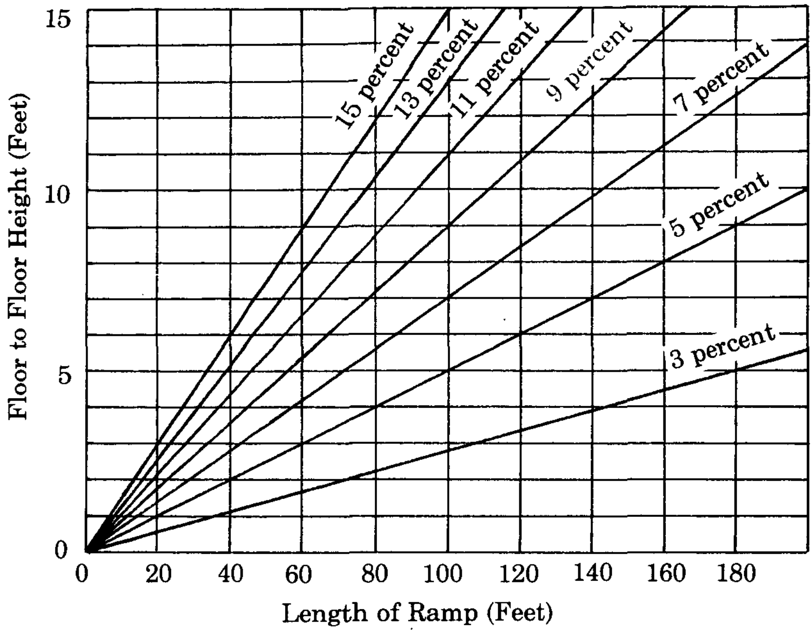


FIGURE 49. Relationship between floor-to-floor height, ramp grade, and length.

Source: Edmund R. Ricker, *Traffic Design of Parking Garages*, The Eno Foundation for Highway Traffic Control, 1957, p. 115.

15 percent; however, 20 percent maximum ramp grades for attendant-parking garages are acceptable.[39] In parking structures where pedestrians are expected to walk on vehicle ramps, grades preferably should be no more than 10 percent.[40]

Figure 49 graphically relates ramp grade and length with floor-to-floor heights. For instance, this graph shows that for a slope of 13 percent and a rise of 9 feet or 2.7 meters (floor-to-floor height), a ramp of 70 feet (21.3 meters) long is required. Similarly, a floor-to-floor height of 11 feet (3.4 meters) and a ramp length of 90 feet (27 meters) results in a slope (ramp grade) of 12 percent.

[39] J. M. Hunicutt, "Parking, Loading, and Terminal Facilities," *Transportation and Traffic Engineering Handbook*; Parking Standards Design Associates, *A Parking Standards Report*; Highway Research Board *Parking Principles*.

[40] American Association of State Highway and Transportation Officials, *A Policy on Design of Urban Highways and Arterial Streets* (Washington, D.C.: American Association of State Highway and Transportation Officials, 1973), p. 426.

The maximum preferable grade for sloping-floor self-park garages is 4 percent, and in attendant-park garages, 10 percent.[41] Angle parking in sloping-floor garages should be 60 degrees or greater, to minimize gravity roll-back of vehicles.

Ramp Grade Transition Design. Critical vehicle clearances, driver comfort, and safety considerations influence the design of ramp ends where they meet flatter floor surfaces. Ramp breakover angle, and the angles of approach (affecting front overhang of vehicles) and departure (affecting rear overhang) are critical vehicle clearance points. These angles are established for stationary vehicles with normal equipment and load, including passengers and fuel.

Ramp breakover angle is limited by wheelbase and vehicle ground clearance, and is a measure of an automobile's ability to be driven over the crest formed by two converging surfaces without scraping its underside. Ramp breakover angle varies inversely to wheelbase.

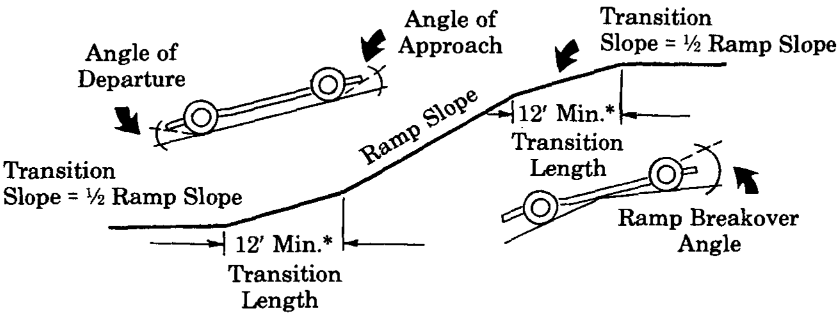
Angles of approach and departure are limited by vehicle front and rear overhang and ground clearance. These vehicle clearance angles determine an automobile's ability to roll over the sag point (lower end of ramp) formed by different grades without scraping or touching the pavement surface. The angle of departure is more critical because the rear overhang of vehicles is generally longer than the front overhang.

Standards established by the Society of Automotive Engineers limit the ramp breakover angle to no less than 10 degrees; angle of departure, no less than 10 degrees; and angle of approach, no less than 15 degrees. Vehicles designed to these minimum standards theoretically are able to traverse sag and crest sections at the bottom and top of a 17.6 percent ramp grade, and to move to flat floor grades without need for a grade transitioning (blending) area.

However, centrifugal force, causing vehicle suspension to compress when crossing a sag point, even at low speed, can result in vehicles scraping pavement surfaces. Without grade transitioning at the ramp crest, driver sight-distance can be limited momentarily, and crossing abrupt grade changes can be uncomfortable for drivers and passengers. Therefore, ramp grades should be blended gradually or transitioned to flatter floor surfaces.

A practical method of blending ramp grades to relatively flat floor levels involves using a minimum 12-foot-long (3.7 meter) transition slope equal to one-half of the ramp grade. Figure 50 illustrates this ramp grade transitioning method. Ramp grades of

[41] Highway Research Board, *Parking Principles*, p. 112.



*Ramp slopes (grades) less than 10 percent can be blended satisfactorily with an 8-foot transition length.

FIGURE 50. Method of blending ramp and floor grades.
Note: Vertical scale is exagerated to show detail.
Source: Adapted from Edmund R. Ricker, *Traffic Design of Parking Garages*, The Eno Foundation for Highway Traffic Control, (1957), p. 117.

less than 10 percent can be blended satisfactorily with a transitioning slope shorter than 12 feet (3.7 meters).[42]

Ramp Width and Radii. For one-way straight ramps, minimum acceptable width is 12 feet (3.66 meters); and for two-way straight ramps, where opposing traffic flows are not separated, 22 feet (6.71 meters) is the recommended minimum width. Where a barrier is used between lanes to separate traffic flows, each lane should be at least of 12 feet (3.66 meters) wide for tangent lengths. Circular ramp lanes generally should be 14 to 18 feet (4.3 to 5.5 meters) wide.

The repeated turning movements of vehicles traveling between parking levels is a primary design consideration. The spiraling path radius must be kept minimal to conserve space and reduce travel distance. However, very sharp and unrelieved turning will produce a dizzying effect on drivers. To minimize this effect, ramp systems can be laid out with sharp curves separated by short tangents or less sharply curved sections (Figure 51).

Lateral clearance for a vehicle traveling a curved path is determined by a vehicle's outermost corner point radius (usually the front bumper) when it is turning on a minimum radius. The inside edge of travel lane radius must be less than the minimum inside

[42] Ricker, *Traffic Design of Parking Garages*, recommended a 12-foot (3.7-meter) minimum transition length. The 1971 study by Parking Design Associates recommended an 8-foot (2.4 meter) length.

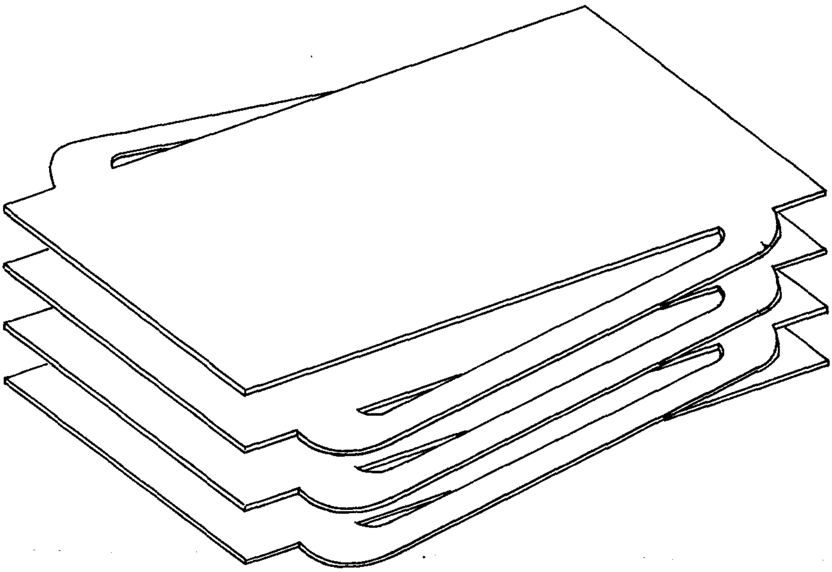


FIGURE 51. Curved ramp system with tangent sections.

rear wheel radius—but not much smaller, or drivers will attempt to enter the ramp at too sharp an angle. The relationship between these radii depends on relative vehicle position, which is determined by maximum steering angle and driver steering input, extreme corner dimensions, and speed. Clearance is usually provided for the vehicle with the largest outermost corner point radius.

Minimum outside radius for a single-lane helical ramp is 32 feet (9.75 meters); however, an outer radius of 35 to 37 feet (10.67 to 11.28 meters) is desirable.[43] With helically-curved two-lane ramp surfaces, the outer lane need not be as wide as the lane used on the inside path. The outer lane radius is less restrictive, allowing drivers to turn at a flatter angle that requires less effective width for a travel path (Figure 52).

Ramp Turn Superelevation. Vehicles traveling on curved paths are acted on by centrifugal force proportional to the square of the velocity and inversely proportional to the radius of curvature. This centrifugal force must be balanced by other forces that are developed by side-friction of the tires on pavement, and superelevation (banking) of the ramp surface. Although speeds in parking garages

[43] Highway Research Board, *Parking Principles*, p. 114.

Minimum radius is 32 feet to outer pavement edge for helical ramp or other turning path. A 35- to 37-foot radius is most desirable.

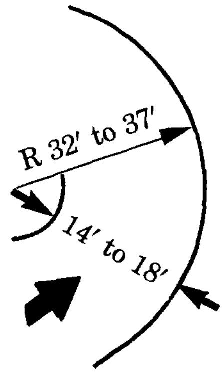


FIGURE 52. Helical ramp dimension standards.
Source: *Parking Principles*, Special Report 125 Highway Research Board (1971).

are low, turning radii are much smaller than those required for street or highways, thus resulting in rather large centrifugal forces.

The equation relating these forces is:

$$e + f = \frac{0.067\ V^2}{R}$$

where

e = superelevation in feet per foot of horizontal width
f = transverse coefficient of friction
V = speed in miles per hour
R = radius of curvature in feet

The value of e on flat surfaces is zero, which means that all centrifugal force must be taken up by tire friction on the pavement. As superelevation is provided, centrifugal force is partially balanced, resulting in less driver turning effort. This may cause drivers to feel free to travel faster, in which case a larger friction will again be developed. Measurements in attendant-park garages have shown values of f as high as 0.53.[44]

Ramp curves should not be superelevated too steeply, because very slow drivers may have difficulty in keeping away from the inside edge of the ramp pavement, and fast drivers may be encouraged to drive at speeds greater than conditions of grade and sight distance safely permit.

[44] Ricker, *Traffic Design of Parking Garages*. Computed on the basis of 15 miles (24 kilometers per hour) speed, a 24-foot (7.3-meter) travel path radius, and superelevation of 0.1 foot per foot (10 centimeters per meter).

Garage ramp superelevation should be approximately ½-inch per foot (approximately 4 centimeters per meter) of ramp width at the point of sharpest turning, with lesser amounts adjacent to straight sections or storage floors.

Ramp Appearance. Some motorists are reluctant to use ramp garages because travel paths in parking garages may combine narrow lanes, steep grades, and sharp turns. Even drivers accustomed to garage parking depend on appearance and "feel" in manuevering their vehicles.

Consequently it is desirable to use architectural and optical effects that will give drivers confidence and reduce possible adverse psychological effects of driving in restricted spaces. An obvious means is to make sight distances as great as possible and to provide abundant illumination.

The optical trick of obscuring horizontal and vertical lines of reference may be used to reduce the apparent steepness of ramp grades. Ramp walls can be painted with stripes contrasting to wall color, parallel to ramp surface or at steeper angles. The normal angles between vertical columns and the travelway can be obscured by paint markings, or adjacent structural features may be built with architectural lines parallel or perpendicular to ramp surfaces.

Ramp structures should be as open as practicable, to provide sight distances and to reduce closed-in impressions. In locations where icing conditions are common, ramp systems should be placed in building interiors or otherwise protected from weather.

Ramp illumination should be given special attention. Wall openings should not be allowed where outside light sources could blind drivers. Artificial lighting should take the form of diffused illumination, and reflectors should be pointed away from the direction of travel.

MECHANICAL GARAGES

Mechanical garages are space-efficient, and traditionally have been developed for areas of high land cost and limited space. Many designs have been proposed but relatively few have been developed sufficiently to reach construction and actual operation. Problems of aesthetics and environmental compatability—principally caused by vehicles queuing outside the facility—coupled with relatively high maintenance costs and, typically, the need for attendant-operation, have limited mechanical garage application.

Early Mechanical Garages

The early mechanical garages used freight elevators. However, since elevators could handle only one vehicle at a time (two in some garages), peak periods of arriving and departing vehicles required long waiting periods and large reservoir areas. Electrical and mechanical failures were common.

Multiple elevators, each serving a vertical bank of parking stalls and equipped with power-operated dollies to load-unload waiting vehicles, were a forward step in garage mechanization. These designs, as used today, have no storage floors per se, but have stalls—sometimes three deep on each side of an elevator.

Several large garages of this type were built in the 1920s, one 24 stories high, with each elevator serving over 100 stalls. Although a great improvement over single freight elevators, many disadvantages remained—such as high initial cost, inability to accommodate peak flows, and hazards of mechanical or electrical failure.

Modern Mechanical Garages

Electronic controls and faster, more reliable elevators have improved mechanical garages. Some lifting mechanisms can move laterally to serve several banks of stalls. Horizontal movement capability permits improved reservoir operation and reduces the seriousness of individual elevator breakdowns, since each tier of stalls can be reached by more than one elevator. Some elevator lifting mechanisms are also counterbalanced to rise without power when empty, and to descend (with automatic braking control) once a vehicle is on the elevator. This provides a means to empty stalls in the event of power failure.

The newer mechanical garages are faster than their predecessors, and can store or deliver a single vehicle in less than a minute. When a vehicle is stored and another delivered on the same trip, the total time required can be about 90 seconds with some designs (compared to measured average times of 125 seconds in older-type elevator garages). The rate of handling vehicles is fixed by the speed of the mechanism and the number of elevators.

The demand for vehicle storage and delivery usually occurs in random patterns, with large numbers of customers arriving in short periods. Since elevators can store and deliver vehicles only at a fixed rate, the effect of a short interval of higher demand rate may extend over an appreciable time period. This results in waiting times for individual customers as long as 20 minutes.

An additional problem is that mechanical equipment has tended to wear out long before the garage facility has paid for itself. Historically, maintenance costs have been much higher than those experienced for ramp garages.

Chapter VI

PEDESTRIAN CIRCULATION

Parking garage planning and design should provide attractive pedestrian circulation within the garage and between the garage and final destinations. Three basic movements are normally accommodated:

1. horizontal movement from parked vehicle to stairs or elevators—usually along the parking garage driving aisles,
2. vertical movement—by stairs, ramps, or elevators, and
3. connections to street and adjacent buildings—usually separate walkways.

PLANNING

In most parking garages, pedestrian regulations are difficult to enforce. Pedestrians tend to walk in a path representing the shortest distance, and they have a basic resistance to changing grades or following a prescribed path that is obviously circuitous to an alternate travel route.

Design Concepts

When possible, it is desirable to separate pedestrians from major vehicular movements. However, within a garage it is nearly impossible to separate the horizontal movement of pedestrians from circulating vehicular traffic. Raised or separated walkways on parking floors usually do not receive enough use to merit their expense and, when provided, are often discontinuous. The two basic design concepts involved are pedestrian-vehicular coordination and pedestrian-vehicular separation.

Pedestrian-Vehicular Coordination. Parking garage designs must anticipate moving pedestrians off of storage floors over the shortest possible distance, via the vehicular circulation system. This is accomplished by locating pedestrian access points around the structure perimeter (see Figure 53). Garages with large floor areas, or garages located underground or under office structures or other types of activity centers, frequently provide centrally located pedestrian access points (see Figure 54). It is desirable to have all

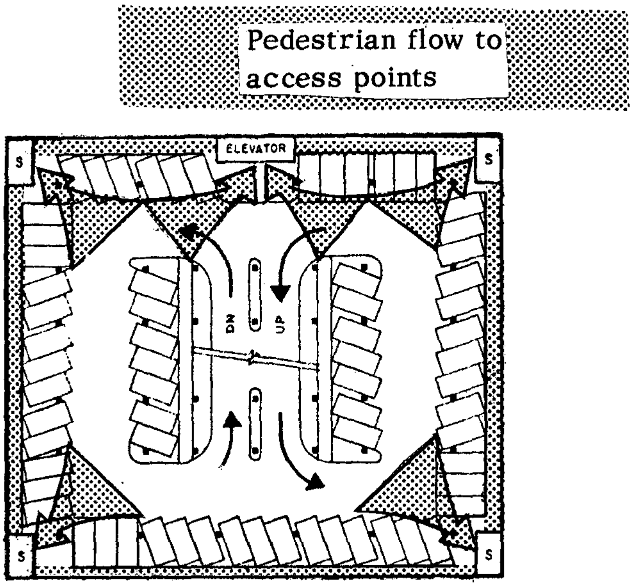


FIGURE 53. Pedestrian access around perimeter of garage.

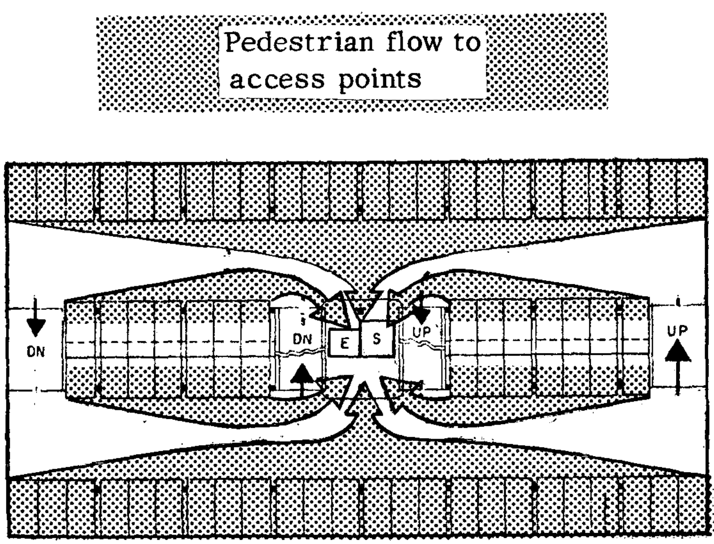


FIGURE 54. Pedestrian access centrally located in garage.

parking spaces no more than 100 feet (30.5 meters) from the nearest pedestrian access point on parking levels.

Sight distance, adequate lighting, and well-marked pedestrian access points, coupled with signing for pedestrians, driver orientation, and clearly defined vehicular movements, will aid pedestrian circulation on parking floors.

Pedestrian-Vehicular Separation. The physical separation of pedestrians and vehicles can be essential for a location where major flows of pedestrians and vehicles are likely to cross. Basically, pedestrians can be segregated from vehicular traffic by providing separate walkways or by pedestrian tunnels or bridges.

Pedestrian-vehicular separation measures increase construction costs and require more space. However, pedestrians must be afforded safe walking paths. Separated pedestrian systems offer the opportunity to provide direct, climate-controlled connections to adjacent buildings and/or other pedestrianways, adding to the attractiveness of both the trip generators and the parking facility. In areas of intense pedestrian activity, separated systems are especially desirable from aspects of safety, reduced walking distance, convenience, and comfort.

Pedestrian Service Facilities and Amenities

Features such as signing for pedestrians and illumination are essential for safe and orderly movement. Facilities offering functional convenience and visual amenity can help to make pedestrians comfortable and pleasantly aware of their surroundings.

Pedestrian Signage. A parking garage informational system for pedestrians is indispensable. When properly designed, it can improve pedestrian safety and perceptions of the facility, while simultaneously contributing to a smooth flow of pedestrian traffic. The parking garage layout is in itself an information system that, if poorly designed, necessitates more add-on visual graphics and signing.

A garage pedestrian information system should be uniform in location, color, size, and style, and continuous between the parking spaces and generator for both directions of pedestrian movements. The clear orientation of pedestrians is essential. Good graphics suggests the use of one style of lettering, locating messages at decisionmaking points, segregating informational and directional signing from advertising, and avoiding advertisements at critical decision points in order to provide maximum visibility.

A study of visual design aspects for signing at terminals[45] emphasized these guidelines:

1. Messages should be direct and simple, using short, familiar terms.
2. The number of independent informational messages should be kept to a minimum.
3. Message content should be consistent in terms and units, not requiring translation.
4. Continuity and consistency in graphic design, and clear lines of sight, should be provided throughout the pedestrian signage system.

In multiple-use developments, pedestrian signage in parking areas should be consistent with signing elsewhere in the development. It should clearly identify routes to generators, parking areas, special garage service facilities, and to bus stops or taxicab stands when these facilities are pertinent to the parking facility.

Illumination. Lighting, a necessity for security and pedestrian movement, creates a psychological impression of the walking environment on pedestrians. Adequate lighting can create a feeling of comfort and security, but it can also emphasize the cleanliness (or uncleanliness) of a parking facility. Generally, minimum lighting should be in the range of 10 to 20 horizontal footcandles (106 to 212 Lux).[46] However, other considerations such as maximum discomfort glare rating, reflectance, and emergency lighting require detailed design based on accepted standards.

Lighting patterns should emphasize floor areas, particularly where elevation changes exist. Natural lighting should be provided for daytime operation wherever feasible.

Pedestrian Service Facilities. Special service facilities such as package checkrooms or areas, waiting areas, vending machines, and restrooms can be provided in parking garages as customer conveniences. When provided, these facilities are usually located on the main level of pedestrian activity, and preferably where they can be easily monitored by garage personnel.

Garages frequently provide maps showing nearby stores and other parking facilities, including informational brochures on

[45] J. Fruin, "Environmental Factors in Passenger Terminal Design," *Transportation Engineering Journal* of the American Society of Civil Engineers, 98 no. TEI (February 1972): 89-101.

[46] James Antoniou, "Planning for Pedestrians," *Traffic Quarterly*, 25 no. 1 (January 1971): 55-71.

operating procedures. In attendant-park garages, it is customary to provide waiting rooms or areas. Public restrooms generally have disappeared from newer self-service garages, possibly because of the associated security and maintenance problems.

Some parking facilities have enhanced their service and customer relations by providing baby strollers, diaper-changing areas and bottle warmers, wheelchairs, umbrellas, and other items for customers' convenience. These items also can provide a profitable means of advertising for local business firms and the parking facility.

Vending machines inside parking garages are a matter of policy. Anticipated vending machine revenues and patron convenience should be compared to the costs of space, maintenance, refuse removal, signing, and control of vandalism and loitering.

Public pay telephones are usually placed in parking garages simply as a convenience, since they generally do not receive enough use at parking facilities to justify their existence by telephone company standards. Public telephones are normally located near the main pedestrian entrance on ground level.

Trash receptacles should be adequate in number and located where they are easy to use. They must be conspicuously recognizable, yet designed to compliment their environment.

Aesthetics. Pedestrian malls and walkways connecting parking facilities with trip generators offer opportunities for interesting and varied visual treatments. This can be accomplished with the use of different textured (or colored) paving materials arranged in decorative patterns, and with landscape plantings.

Materials for doors, walls, floors, and other surface areas along pedestrianways should be able to resist and endure abuse. Surface areas should be of materials resistant to breakage and marking, and should be easy to clean and maintain.

Maintenance. Attention should be given to water drainage and to cleaning pedestrian areas. Water hose connections should be provided at convenient locations—generally not more than 120 feet (36 meters) apart—to facilitate washing walkway areas and watering landscape plantings.

For mechanized sweeping, attention should be given to adequate dimensions along pedestrianways, and their load-bearing capacity. For extensive pedestrian systems, provision for mechanized cleaning can also serve double duty in providing access for emergency vehicles and snow removal equipment.

PEDESTRIAN TRAVEL FACILITIES

The type and size of pedestrian facilities depends on how they are to be used and what degree of comfort is to be provided. Pedestrian walkway widths should be related to the particular pedestrian flows they are expected to accommodate. For example, the capacity of a walkway used by special-event crowds (high pedestrian demand in a short time period) may be quite different from requirements for shoppers (less intense pedestrian demand, spread over a longer time frame). Because pedestrian traffic generated in most parking garages is light, traditional level-of-service standards are rarely relevant. Design of walkways and pedestrian areas becomes more concerned with spatial composition and amenities influencing the pedestrian environment.

Walkway Widths

Minimum walkway widths for light pedestrian flows typically range from 4 to 5 feet[47] (1.2 to 1.5 meters), with the principal consideration being to provide enough space for two persons to walk abreast or to pass each other. If the walkway is obstructed laterally, effective width is decreased, and an extra 1.5 feet (0.5 meter) of walkway width should be provided. Walkways adjacent to display windows or sales counters should provide an extra 3 feet (0.9 meter) of width.

Wider walkways should be used for sidewalks along streets bordering parking facilities. A walkway having an effective width of 7.5 feet (2.3 meters) is considered a minimum for lightly used urban sidewalks. This width will provide an open-flow level of service for pedestrian volumes up to approximately 200 persons per hour. Figure 55 illustrates several design situations providing an effective 7.5-foot (2.3-meter) walkway width. These designs allow couples to be passed by individuals without significant psychological interaction or physical restriction.

Pedestrian Grade Separations

Grade-separated walkways provide additional space for pedestrian movements, eliminate pedestrian-vehicular conflicts, permit opportunities for views and vistas, and offer more opportunities for people-interaction between multi-level structures. However, for grade-separated walkways to be justified on a traffic basis only,

[47] Ibid., p. 149.

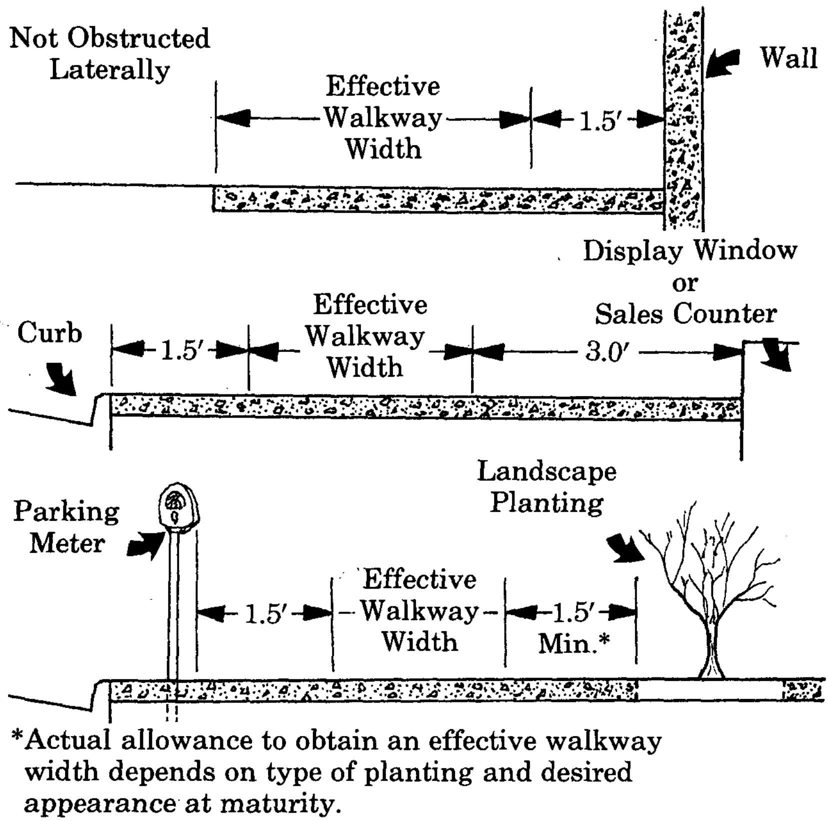


FIGURE 55. Several design situations illustrating where effective walkway width is measured.

exceptional pedestrian travel demand is generally required at the structure levels to be served by the separated walkways.

Pedestrian bridges and tunnels may be desirable when the generator is separated from the parking garage by heavily-traveled streets, where abnormal hazard or inconvenience to pedestrians would otherwise result. They are also feasible to improve access to malls, shopping complexes, and major buildings, particularly in areas having a scarcity of space. A desirable objective is to provide weather-protected and vehicular traffic-free connections to encourage use of both the garage and surrounding land uses. Such an approach, carried to its ultimate, allows the garage system to be integrated with other existing and proposed pedestrian systems.

Pedestrian tunnels or underpasses, as compared to pedestrian overpasses, require less grade transition and less horizontal space on approaches. They also present less visual obstruction to the cityscape, while providing weather protection. Pedestrian overpasses, on the other hand, can generally be provided at lower costs[48] and provide greater visibility and a more positive sense of security for pedestrians.

Generally, pedestrians are more reluctant to use tunnel underpasses than bridge overcrossings. Pedestrian tunnel problems can be minimized by locating underpasses in line with approach walkways and gently ramping walkways to permit continuous vision through the underpass from walkway approaches. It is essential that the underpass be well-lighted and designed to avoid sharp curves and concealed corners.

At pedestrian overpasses, vertical clearance over vehicular roadways should be slightly higher than the minimum vertical clearance required for vehicle structures, to reduce overheight vehicle impact possibilities. Typically, a minimum clear height of 17 feet (5.2 meters) is required, measured from the pavement crown to underside of structure. Small-opening screening (fencing), transparent wall panels, or complete enclosure, should be provided for protection of vehicular traffic. Complete weather protection of the enclosure is most desirable.

Pedestrian bridge or tunnel walkways should have widths no less than the approach walkway width at each end. A width of 8 feet (2.4 meters) is a generally accepted minimum criterion, although greater widths—from 10 to 15 feet (3 to 4.6 meters)—are preferred, even though seldom justifiable on a capacity basis.

Pedestrian tunnels and bridges, when enclosed, should have a minimum clear height of 8 feet (2.4 meters) to minimize the restrictive nature of enclosed pedestrian walkways and to allow access to mechanized cleaning equipment.

Pedestrian Ramps

Pedestrian ramps are often more acceptable than stairs to persons who must carry packages or push shopping carts or baby strollers. They also can be used by the physically handicapped. Compared to stairs, short, gently sloping ramps appear to require

[48] Underpass construction is likely to be hindered by excavation costs, a high water table, and/or existing underground utility services that may involve considerable expense in relocating or diverting.

less effort to travel; however, ramps use space less efficiently and require greater travel distances than stairs.

Pedestrian ramp gradients should not exceed 15 percent, and preferably should be less than 10 percent.[49] Ramps should not exceed 120 feet (36.6 meters) in length, measured horizontally. Where greater lengths are required, level sections with a minimum length of 15 feet (4.6 meters) should be provided approximately midway in the ramp length. To reduce space requirements, ramps (and stairs) may be made more compact by reversing directions—usually at a mid-point location—or by winding the alignment helically.

Neither walking speed nor spacing in pedestrian streams is affected by mildly sloping ramp walkways (under 6 percent).[50] However, some studies indicate almost a 30 percent reduction in horizontal walking speed on a 12 percent grade.[51]

Provisions for access by handicapped persons are essential in most new structures. A nonslip surface should be provided on all walkways, including curb-cut ramps—that should be at least 4 feet (1.2 meters) wide plus rounding near the curb. Gradients should be less than 12 percent.

Stairs

Stairways are usually used for grades exceeding 30 percent. Because of restricted walking space and the energy needed to overcome gravity, stairs reduce pedestrian speed in ascent to roughly one-third, and in descent to roughly one-half, of level walkway speeds.[52]

Architectural standards[53] for exterior stairs recommend a riser height of 6 inches and a tread depth of 12 inches (15 and 30 centimeters), which provides a 50 percent grade. Several studies[54] have determined the optimum steepness of stairs to be 50 percent; however, inside parking structures, inclines between 58 and 70 percent

[49] American Association of State Highway and Transportation Officials, *A Policy on Design of Urban Highways and Arterial Streets*, p. 426.

[50] Litterton C. MacDorman, "An Investigation of Pedestrian Travel Speeds in the Business District of Washington, D.C." (Ph.D. dissertation, School of Engineering and Architecture, Catholic University, 1967).

[51] John Baerwald, ed., *Traffic Engineering Handbook*, 3rd ed. (Washington, D.C.: Institute of Traffic Engineers, 1965) p. 111.

[52] Pushkarev and Zupan, *Urban Space for Pedestrians*, p. 100.

[53] J. H. Callender, *Time Saver Standards: A Handbook of Architectural Design*, 4th ed.

[54] Pushkarev and Zupan, *Urban Space for Pedestrians*, p. 100.

are commonly used[55] to conserve space. These steeper stair grades may be practical where stairs serve principally for emergency access, and where elevators are the normal interfloor access means. Stairs in multi-level garages are unattractive to pedestrians, particularly if pedestrians are expected to use them for traveling between more than two floor levels.

The adverse psychological effects of stairways can be improved by providing a landing every 5 to 6 feet (1.5 or 1.8 meters) of vertical elevation, which approximates eye level. This can be especially effective in reducing the appearance of stairway steepness.

Stairways in parking garages are typically 4.5 to 6 feet (1.4 to 1.8 meters) wide. Pedestrians need less room on stairways than on level walkways because their movement is inherently impeded. In special cases, comfort and convenience can be increased by assisting pedestrian movements with moving walkways, elevators, or escalators.

Moving Walkways

The moving walkway concept is often used for pedestrian movements in major urban trip-generating locations where large numbers of people must walk considerable distances between parking and trip destinations. Major airports have been principal users of moving walkways because passenger circulation involves walking and carrying luggage from parking spaces to terminal buildings, often requiring extensive walking distances.

TABLE XIII—MOVING WALKWAY CHARACTERISTICS

	Maximum Moving Walkway Width in Inches	
Maximum Treadway Slope At Any Point On Treadway	*140 fpm Maximum Treadway Speed*	*140 to 180 fpm Treadway Speed*
0 to 3 degrees	Unlimited	40
above 3 to 5 degrees	110	40
above 5 to 8 degrees	78	40
above 8 to 12 degrees	40	N.P.
above 12 to 15 degrees	40	N.P.

Source: *American Standard Safety Code*, American Society of Mechanical Engineers, New York, 1965.
Note: N.P.—Not permitted by Code.

[55] Ibid.

FIGURE 56. A moving walkway used in an enclosed pedestrian bridge connection between a multi-level parking structure and air terminal facilities at La Guardia Airport, New York, N.Y.

Moving walkways are practical for distances under 1,000 feet (304 meters). They allow pedestrians to add their own speed to that of the moving belt (tread) to save time and effort. Moving walkways (and escalators) are governed by the American Standard Safety Code.[56] This code requires a handrail along each travel lane, and limits the maximum speed to 180 feet per minute (54.9 meters) and treadway slope to a maximum of 15 degrees (Table XIII). Most insurance companies will only underwrite moving walkway installations that are in accordance with the code.

Escalators

Accepted standards[57] limit maximum escalator speed to 125 feet per minute (38.1 meters) and to a maximum slope (angle of inclination) of 30 degrees. Escalator tread width is normally 32 or 48 inches (81 or 122 centimeters), and escalator speeds in the United

[56] The American Society of Mechanical Engineering, *The American Standard Safety Code for Elevators, Dumbwaiters, and Moving Walks*, 1971.
[57] Ibid.

States are usually 90 to 120 feet per minute (27.4 to 36.6 meters). At 90 feet per minute (27.4 meters), capacity ascending is approximately 3,000 persons per lane[58] per hour, and 2,000 persons per lane per hour on descending escalators.

Escalators are used in some parking garages, but generally are considered impractical for garage application when compared to elevators on the basis of cost, space-use efficiency, and reliability. They may be appropriate, however, for special high-turnover parking situations that produce large pedestrian volumes.

Elevators

The modern passenger elevator has features such as automatic leveling and self-opening doors that permit self-service operation. Elevators are faster than stairs or ramps, require minimal effort to use, and are considered safer. However, they involve high initial cost and continual maintenance costs. When service demand is heavy, people must wait while the elevator is servicing other floor levels.

Elevators should be used in parking structures three or more levels high, and installed in banks (number of elevators located together) of two or more. They should be located as near as possible to the principal pedestrian generators. If the main pedestrian generator is located at one end of the parking structure, elevators should be located accordingly.

Elevators are raised and lowered either electrically or hydraulically. Figure 57 illustrates typical elevator towers for a hydraulic elevator and electric hoist elevators, using either an overhead machine room or a grade-level machine room. Hydraulic elevators are limited to heights of approximately 50 feet (15.2 meters), which is equivalent to about five parking levels. They generally have speeds around 100 feet per minute (30.5 meters), and are considered slow compared to electric elevators having speeds up to 350 feet per minute (106.7 meters).

The actual time of vertical travel in a garage elevator is a small part of the total travel time required for each pedestrian trip. For this reason, high-speed elevators are not usually necessary in garage applications serving fewer than five parking levels. Hydraulic elevators may be adequate for a two to five level parking struc-

[58] Generally, a 32-inch (81-centimeter) tread width is considered one-lane and a 48-inch (122-centimeter) tread width is sufficient to allow two people to stand side-by-side for two-lane operation.

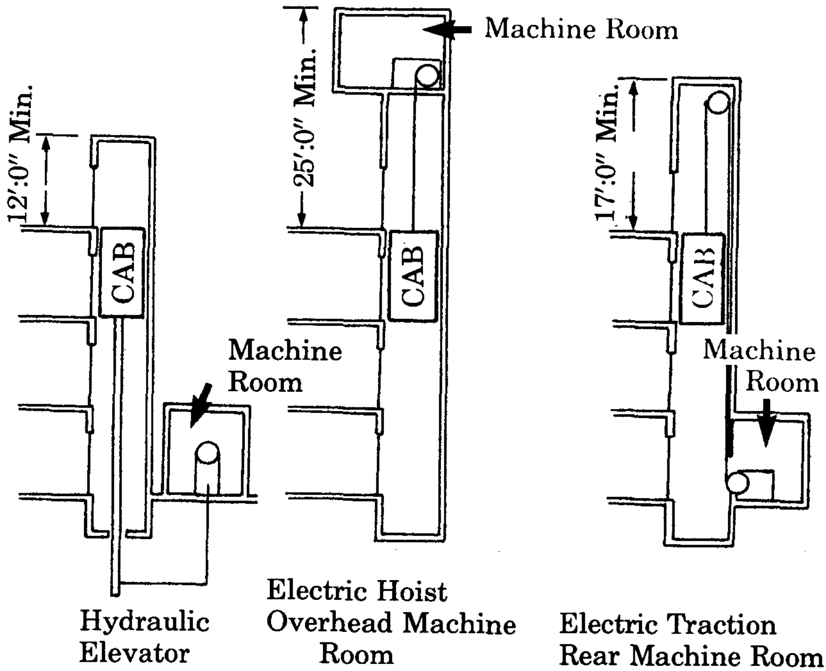


Figure 57. Types of elevators.
Source:

ture; however, electric elevators are generally specified for higher structures. Above 7 levels, higher speed (350 feet or 106.7 meters per minute) electric elevators should be considered.

Design elements for passenger elevators are fairly well standardized. The number and size of elevators to be installed is based on expected peak loads and the allowable maximum average waiting time. The actual number of passengers to be handled affects the time of operation only in the loading and unloading times. A garage with a large demand will normally have more parking levels, which increases the number of possible stops. The maximum average waiting time is more or less arbitrarily selected to meet the desires of owner and designer. One minute is the time usually selected as a maximum average waiting time.

In design of elevator systems for a particular building and passenger load, computations of total travel time should be made for each combination of floor heights and number of passengers, with special attention to multiple-destination trips to higher floors.

The number and design of elevators should be such that the average waiting time for any expected trip will not exceed the selected maximum. If it exceeds this maximum, a need for additional elevators is indicated.

Such computations are best developed by elevator engineers, who should be consulted in establishing the number and type of elevators. The garage architect, engineer, and planner should be prepared to state the estimated flows of passengers per unit of time (usually by five-minute periods) and the maximum average waiting time selected.

As a general rule, two elevators should be adequate for parking garages up to 600 spaces, with another elevator for each additional 600 spaces or substantial fraction thereof. Elevators in parking structures are commonly rated for 2,500-pound capacity (approximately 1,134 kilograms). Elevator cabs should be lighted to 20 horizontal footcandles, and should have all surface areas including floor and doors designed to be vandal-resistant.

If horizontal expansion capability is planned as a part of the initial structure, provisions should be made for adding elevators to the existing elevator banks. This is accomplished by providing the structural framing and special knock-out panels when constructing the original facility.

In addition to adding new elevators, vertical expansion requires provisions for extending existing elevators. Hydraulic elevators are simplest to extend, requiring only additional elevator guide rails if the original installation provides for future expansion in the length of the hydraulic plunger. Electric hoist elevators with machine rooms at grade level are cheapest to extend compared to overhead machine room types, but are more expensive initially. The grade-level machine room type of electric elevator also offers expansion capability, with minimum downtime during the expansion period.

Chapter VII

PARKING GARAGE OPERATION

The success of a parking garage depends on operating procedures as well as functional design. Major variables include methods of operation, revenue collection and control, maintenance, and management.

Parking garage operations vary in procedures used for vehicle handling and revenue collection. Vehicle handling differences affect space utilization and traffic control measures, and depend on the extent to which customers (parkers) are expected to handle their own vehicles inside the parking garage. Revenue collection systems differ in terms of how and where parking fees (if any) are collected.

Regardless of whether parking is considered as a public service or a business enterprise, it must compete to some extent for users—and the most effective advertisement is the parking operation itself. This operation can be thought of as a public relations statement, in that it says something about security, convenience, cleanliness and maintenance, and determines whether or not the parking experience is acceptable.

Vehicle Handling

Normally, operating costs are higher for attendant-park operations because of associated labor costs. However, experienced attendants are able to park 10 to 25 percent more cars in a given space as compared to self-parking. An attendant-park facility also can use minimum-size parking stalls, since attendants are paid to endure restricted geometrics.

Attendant-parking may be justified in special locations when the additional parking capacity provided by this operation can produce sufficient additional revenue to offset the higher labor costs. It may also be justified for operations that call for special convenience service, such as parking for hotel and restaurant patrons.

Self-park designs must provide parking geometrics that can accommodate drivers with widely varying driving skills, and drivers who may not be familiar with the parking facility. This requires dimensions of parking stalls, driving aisles, and turning radii to be more generous than those of attendant-park facilities.

Attendant-Park Operations

Entrance problems can be severe with attendant-park operation, since a change in vehicle drivers is required. During peak periods, traffic backups and delays can result if reservoir space is inadequate and/or if there are not enough parking attendants on duty. The entrance reservoir absorbs peak inbound movements when vehicles arrive at a rate greater than that at which attendants can store them. From an operating standpoint, it is the most important area in the attendant-park garage.

The number of attendants, the time needed to move each vehicle to the storage levels, and the size of reservoir space are closely related. The rate of storage varies directly with the number of attendants and inversely with the time to store each vehicle. More explicitly, the rate of storage per hour equals the number of attendants times sixty, divided by the time in minutes required for an attendant to make a round trip (driving a vehicle to the storage level and returning).

On average, the rate of storage must equal or exceed the rate of vehicle arrivals during the peak period. Reservoir space takes care of spurts that exceed the average arrival rate, and of accumulated vehicles when attendants fall below their storage average. An adequate reservoir can be partly compensated for by additional attendants, while a large reservoir will allow employment of fewer attendants.[59]

Vehicle Handling Procedures. Detailed procedures should be established for handling cars, based on experience, physical design of the garage, and patronage characteristics. Cars should be removed from reservoir space to storage floors in an orderly manner so that attendants can move without confusion to the next car to be stored. It is customary to empty the reservoir space one lane at a time, in rotation. This allows maximum use of reservoir space and gives customers time to unload.

General rules on right-of-way within the garage should be established to help prevent accidents and speed up car handling. An example of such a rule is one that gives cars traveling down the ramp the right-of-way over those traveling up or entering the ramp.

[59] When an attendant-park garage is filled, the reservoir space also should be full since this area is valuable and usable for parking.

Order of Filling Stalls. At any particular time, parking activity should be spread throughout the garage to reduce interference between cars. The placement of cars may be left to the judgment of attendants or controlled by the floor man through pre-marked tickets. Cars known to be stored for long periods or all day should be placed in rear rows of double parking, or in stalls adjacent to ramps. This leaves the most accessible stalls for short-term, high-turnover parking.

Emergency Procedures. Standard procedures should be established for handling emergencies such as fire, accidents, or mechanical failure of vehicles. Whenever cars fail to start or have flat tires, they should remain parked until the rush period is over. The owner may be invited to make his own repairs or to wait, but an extended delay that affects other customers should not be tolerated.

Despite good location systems, cars will sometimes be lost and cannot be identified without extensive searching. This delay can be reduced by having customers accompany attendants to the storage floor.

Undelivered Cars. Occasionally when a car is delivered to the outbound reservoir, the customer will not be there to claim it. To avoid blocking the exit, it is a good plan to provide space in the reservoir where such cars can remain out of the way until claimed.

Self-Park Operations

A self-park operation must provide more directional information for drivers. Potential for problems is increased further by introduction of pedestrian traffic in the self-park garage.

Self-Park Entry. Depending on whether a parking fee is charged, it may be necessary for parkers to stop at garage entrances. However, most self-park garages that charge a fee use time-stamped parking tickets that are typically dispensed by machine. This requires parkers to stop and pull a ticket from the machine.

To assure that drivers are able to remain in their cars to reach the machine-dispensed tickets, the entrance way is channelized by using curbing, traffic cones, or other means to encourage drivers to stop near the dispenser. Gates are often used to ensure that drivers stop and take tickets. The ticket dispenser should be located far enough in from the street to provide adequate reservoir space during peak periods. Vehicle entry can proceed quicker during peak periods if an attendant is stationed near the ticket dispenser to pull out and hand tickets to entering drivers.

Signs and markings are an essential part of the entrance operation. It is important to have a large, highly visible "full" sign that can be seen by drivers approaching the garage entrance. This sign should be positioned in such a way that drivers will receive the message prior to entering the garage.

Other signs that should be prominently displayed at the entrance include maximum allowable vehicle height signs and signs indicating parking rates and hours of operation.

Traffic Circulation. The operational concern for traffic movement in a self-parking garage involves driver guidance through a search pattern to locate a vacant parking stall. For convenience and safety, vacant stalls must be located as quickly as possible, with minimum travel past vehicles already parked. Self-parkers will attempt to locate a parking stall as near as possible to their external destination. Driver orientation to external destinations in small garages is rarely a problem and often requires no particular guidance system. In larger garages, driver orientation, as well as efficient use of available stalls, can become a problem requiring special guidance measures.

Circulation problems are exemplified in one large garage studied, which was essentially two sloping floor structures joined end-to-end with a crossover at the middle. The design provided for one-way continuous traffic movement, with the sloping floor ramps in one-half of the structure used for up-movements, and those in the other half for down-movements, with a crossover where the two structures were joined. The design is similar to that shown in Figure 45.

During peak periods this garage experienced difficulties in getting parkers to drive through more than three 180-degree turns on the up system before crossing to the down system to find available spaces. Lower parking levels became full on both sides of the structure, causing patrons to return to the exit point before space was found. Secondary problems arose when drivers would stop on the ramp to wait for unparking vehicles to empty spaces. As an immediate cure for this situation, attendants were placed at the crossover (where up and down ramps meet) to direct traffic to upper ramp levels that were virtually empty.

The management of this particular garage is now considering changeable message signing, and possibly flashing lights, to attract driver attention to the availability of space on upper levels. Such electronic internal guidance systems are rapidly increasing in popularity, including the use of sensors and differential counters that continuously compute entry and exit volumes for each parking level or section as a function of capacity. Signs are automatically turned on or off as the parking demand varies.

Self-Park Exiting. When parking fees are collected, it is common to collect them at the exit. During peak periods, backups can result while drivers wait to have the charges calculated and pay the cashier. Under heavy exiting demands, this type of operation can be speeded up by using an attendant outside the cashier's cage to collect parking tickets, make the necessary fee calculation, and mark it on the ticket. This saves the cashier time and alerts drivers to have correct change ready.

In larger garages, customers sometimes experience difficulty in locating their parked cars. Some devices developed to alleviate this condition include (1) painting of columns on each parking level a distinctive color, sometimes issuing tickets of the same color or color coding elevator buttons, (2) marking columns or overhead floor beams with large identifying numbers, and (3) posting signs to remind customers to note the location of their cars before leaving.

REVENUE COLLECTION AND CONTROL

Revenue collection and control requires a system designed to record all entering and exiting vehicles and tickets dispensed, and an accounting of the amount of money each cashier on duty handles. The information gathered in a revenue control system further serves as a check for revenue losses that could occur for varied reasons.

Cashiering Methods

Three types of cashiering methods are used to collect parking fees—free entry/pay on exiting, free entry/pay before exiting, or pay on entry/free exit. The last method can increase reservoir requirements and queuing on surrounding streets.

Exit Cashiering. Free entry/pay on exiting is the most common cashiering method used in self-parking operations. It is used in conjunction with a ticket-dispensing machine located at the garage entrance that enables parking charges to be levied commensurate with time parked.

While exit cashiering greatly reduces space requirements for entrance reservoirs and backups onto the street system, it requires reservoir space at the exit where cars are likely to queue during peak discharge periods. Many garages do not charge for the time customers wait to pay in the exiting line; the customary grace period is 6 minutes.

Central Cashiering. Free entry/pay before exiting is a method of cashiering that requires parkers to return to a central location in the garage to pay a parking fee before proceeding to their parked cars. Central cashiering is used for attendant-park operations and is suitable for self-park operations when parkers must return to the garage over a common path.

Like exit cashiering, ticket-dispensing machines are used at the entrance when charges are varied according to time parked. Central cashiering is also suitable for collecting flat-rate parking charges. To assure that parkers pay for parking before driving out of the facility, it is necessary for them to present a paid receipt at the exit, thereby requiring drivers to momentarily stop. Even so, central cashiering usually enables traffic to exit faster than exit cashiering, since money transactions are eliminated at the garage exit point. Compared to exit cashiering, exit lane capacity can be doubled or tripled by using central cashiering.[60]

Entrance Cashiering. Pay-on-entry with free exiting permits collecting flat-rate charges for parking. It is best suited for major generators, such as sporting or recreational facilities that attract large numbers of parkers who would leave simultaneously after the event concludes. It is also commonly used to collect evening parking fees at garages that may be unattended when the parker returns, and in some cases at facilities serving long-term or all-day parkers.

Attendants generally collect the parking fee; however, coin machines are also available to collect the fee automatically. A serious disadvantage of entrance cashiering is that it requires a large reservoir area to handle peak surges in vehicle arrivals.

Parking Meters

Parking meters may be either manual or automatic. In the manual type, a clock mechanism is set in operation when the meter is used, either by turning a crank or moving a lever after inserting the proper coin(s). The clock mechanism is wound each time it is used by the parker. The automatic version is set in motion by inserting coins only, requiring no further action. The automatic meter clock mechanism is wound periodically by meter service personnel, usually when coins or coin boxes are collected.

[60] Hunnicutt, "Parking, Loading, and Terminal Facilities," p. 694.

Sealed and unsealed coin boxes are available for meters. The unsealed coin box can be opened and emptied directly by the service attendant, where with sealed box systems the box is removed, replaced by an empty box, and opened later under more secure circumstances. Portable collection units are available that accept contents of the sealed box, keyed so that the contents cannot be removed while being emptied into the collection unit. The attendant then replaces the emptied coin box in the meter. This prevents attendant access to money and eliminates need for additional meter coin boxes.

Advantages and Disadvantages. In addition to generating revenue, parking meters simplify detection of overtime parkers by providing an accurate time check on parking, and discourage all-day parkers, especially where enforcement is effective. But when used in garages, parking meters are not necessarily preferable to other revenue control systems. Meters are used to promote short-term parking and to increase turnover, which means that continued enforcement by police personnel is required. And unless frequently monitored, some parkers may park for long periods by "feeding" the meters, which are usually priced low to attract shoppers and encourage short-term rather than long-term use.

There is also the possibility of a substantial amount of paid-for but unused time at metered spaces being appropriated by subsequent parkers. A successful means of erasing unused time from meters was not identified in this study. Traffic problems can also develop as a result of drivers searching past the first available stall in hopes of finding an empty stall with time remaining on the meter. Since metered garages usually do not have an attendant on duty, many drivers are reluctant to use these garages if they are in locations where security problems exist. This has been a primary reason why some metered garages have converted to ticket-type operation, with an attendant on duty to monitor the facility.

Meters Versus Ticket Operation. Entrances can be the first operational bottleneck in a garage's circulation system. With meter operations there is no reason for traffic to stop at an entrance point, and the likelihood of traffic queuing on entering, due to drivers stopping to receive tickets, is eliminated. Entrance backups are more commonly associated with attendant-park operation than with self-park operation. For the latter, even in ticket-type operations, entrance backups are usually related to other breakdowns in the circulation system and not to the momentary pause to take a parking ticket from a machine or an attendant.

In ticket-type operations, all entrance lanes must be manned by garage personnel or controlled by automated equipment, which constitutes an expense that increases directly with the number of entrance lanes. Meter operation requires no entrance control, thereby allowing multiple entrance points from different street frontages without increasing operating costs. However, on a lane-by-lane comparison, there would be only marginal capacity advantages of metered garages over those using ticket operations.

Exit delays in self-park facilities are usually traceable to an inadequate number of exit lanes, poor exit lane design, and/or insufficient personnel on duty. Metered garages can eliminate most of these delays, since personnel are not a factor and operating costs are not increased with multiple exit points. Metered operations are probably more effective in reducing exit delays than ticket operation using exit cashiering, because motorists may use every surrounding street for exit purposes, thereby reducing traffic loads on adjacent streets.

Metered facilities are credited for reducing labor costs because attendants are not required at entrances and/or exits. However, metered operation requires labor for enforcement, meter maintenance, and collecting and accounting of meter-box revenues, including overtime charges and parking fines. One study,[61] based on two similar-capacity garages in the same city, found labor cost of a ticket operation to be $23.40 per space per year more than the metered operation.

However, facilities that have converted from metered to ticket operation report increased revenue as a result. Frequently such conversions also involve a change in parking rates, making it difficult to identify clearly whether the increased income associated with conversion is related to the method of operation or the changed rates.

One way to estimate the possible income difference that might be realized by converting a metered facility to ticket operation is to station personnel at entrance and exit points to a metered facility, issuing time-stamped tickets and collecting and time stamping tickets of exiting patrons. (No fees are collected, since customers are still obliged to operate the meters.) The elapsed parking time of each vehicle can be tabulated and parking fee totals can be computed according to desired rates. (If direct comparison is to be made, the existing meter rates must be used in the computations.)

[61] Edison Parking, "Parking Space," (Newark, New Jersey: Edison Parking, March 1974).

If the meters are emptied immediately prior to and after completion of the test, revenue differences can be accurately compared. Such a test must assume that the presence of the personnel conducting the study does not influence the amount of meter collections. Increased revenues could provide a substantial basis for considering conversion to ticket-type operation.

Parking Tickets

Parking tickets provide a means for supplying customers with receipts, indicating acceptance time, and identifying customers as the operators of parked vehicles; as a means of identifying and locating parked vehicles (more often the case in attendant-park garages); and as an accounting device to indicate parking durations and charges.

Ticket size, color and content vary. The number of ticket parts or sections can range from one to five parts (Figure 58).

Customer's Claim Check. The portion of a multiple-part or a one-part ticket given to the customer has several purposes. It identifies the parking facility to the customer, with the facility's name and address printed on it; it can also be used to identify the cus-

FIGURE 58. A four-part ticket example used for attendant-parking.

tomer as the operator of a parked vehicle. In addition, tickets can be used to advertise services offered by the garage or nearby merchants, which may help offset ticket printing expenses. However, such advertising is not a common practice.

The customer's portion of a ticket should contain a short quasi-legal statement on the extent of garage liability and hours of operation. Other information may be included to inform the customer on movement of vehicles between different facilities if vehicles are not claimed within a certain length of time. Some garages use tickets with numbers corresponding to stall locations so customers can circle the number of their parking space on their tickets as an aid to locating parked vehicles later.

The time stamped on the claim check is used as a reference for the customer and as a basis for computing parking charges by the garage cashier. The serial number appearing on the ticket, and common to all parts of a multiple-part ticket, is also important to the garage operator, because it allows each ticket to be accounted for, facilitating bookkeeping and auditing procedures.

Most self-park operations use only a single-part ticket, while most attendant-park operations use a three-part ticket.

Office Stub. The office stub is primarily a bookeeping device that is used to keep records of parking durations, money amounts collected and, in the case of attendant-park operations, the location of parked cars. In garages offering automobile servicing, this portion of the ticket can also be used for marking a customer's requested services and the corresponding charges.

Attendant-Park Ticketing Procedure. As customers arrive at attendant-park facilities, they are given a claim check stamped with the arrival time. A second ticket part (vehicle identification stub) is attached to the car. This stub should contain only the ticket serial number, printed in large enough type to be read at a distance of about 15 feet (4.6 meters).

A third ticket part (office stub) is retained by the cashier. The vehicle location is usually noted on the office stub, but in some operations a fourth ticket part is attached to the office stub until the customers calls for the vehicle, at which time it is detached and placed in a rack to signify that the vehicle is wanted. The location stub contains the identification number and any other information necessary to locate the parked vehicle.

The operator of a parked vehicle must surrender the claim check when returning for the vehicle. The claim check is then stamped with the departure time and the fee is computed and paid. After delivering the vehicle to its operator, the attendant removes the vehicle identification stub from the vehicle and gives it to the cashier, who staples all parts of the ticket together as a completed transaction.

Some operations use a fifth ticket part (release stub) that is given to the customer after the parking fee has been paid as a temporary receipt to identify the customer with the right vehicle on delivery. If the vehicle is not delivered promptly, the release stub also gives the customer the identification number of the parked vehicle in asking for a recheck. Release stubs are collected at the exit to ensure against vehicle theft.

Audit Control

A ticket-printing time clock is indispensible to accurate audit control in garage operations. Multiple entrances and exits should be controlled by a master clock system to assure that parkers are timed on exactly the same time base when entering and leaving.

The clock works should be tamper-proof. The access key should be controlled by a person not involved in collecting parking charges.

Ticket Audits. It is not practical to audit every ticket; however, periodic checks should be made. A commonly used checking method involves checking all transactions for an entire day, which should be selected randomly. The frequency of ticket audits should be a management decision.

For an audit period, each ticket should be checked for elapsed time and applied charges. Total calculated receipts can be checked against reported receipts and receipt patterns for comparable days. Each ticket should be checked for the correct charge calculation shown on the ticket face as a cash register transaction.

To ensure proper audit control, randomly timed garage inspections should be made. The sequence of tickets in use and those stored should be checked, including time clock operation. Overcharging patrons for parking can be prevented by having an illuminated sign connected to the cash register to display the total charge in full view of the motorist.

Lost Parking Tickets. When a customer loses the parking ticket, it is impossible to determine the exact charges to be made. The customary practice is to accept the customer's word on the time the garage was entered.

In such cases, the cashier should use a blank ticket, marking it "lost ticket," and register it in the same manner as a normal ticket. Repeated lost-ticket problems by the same person should be called to the attention of the garage manager, who is responsible for discussing the problem with the customer and taking proper administrative action.

Voiding Parking Tickets. All parking tickets should be subject to audit, and no parking ticket should be destroyed. The garage manager or assistant manager should be the only person having authority to void a parking ticket, and should signify that a ticket is void by signing it. The serial numbers of voided tickets should be recorded on the daily record sheet.

Cash Control. Normal operating procedure is to issue to each cashier a cash drawer containing a specified sum. The garage manager is responsible for determining and recording the cash amount. Cashiers are responsible for their own cash drawer when going on and off duty.

Cashier Shift Changes. At a shift change, the oncoming cashier should record the beginning ticket number at each ticket spitter. The outgoing cashier should be informed of these numbers in order to be able to record the ending ticket number for the shift ending, which is one ticket number lower than the beginning ticket number for the next shift.

Automation

Fully automated computer control for both traffic and revenue is expensive and requires considerable maintenance, but serves to reduce labor needs while providing a high level of audit and traffic control. Because of their expense, computer control systems have been limited to large facilities or used to control a number of smaller parking facilities simultaneously.

The municipally-owned Cherry-Marshall Parking Deck, Winston-Salem, North Carolina,[62] is a good example of computerized control of parking, revenues, and traffic. Planning of this parking deck had to consider a control system that, in addition to handling hourly-rate transient patrons and monthly-rate patrons, could bill an adjacent hotel for spaces actually used rather than reserving a specific number of spaces.

Additionally, it was necessary to have a system that permitted the hotel to reserve an adjustable number of spaces for varying periods while providing that the hotel would only be billed for unused reserved spaces when these spaces were actually denied to the public.

[62] Roy D. Williams and Fred L. Orcutt, Jr., "Revenue, Parking, and Traffic Control for North Carolina Deck," *Parking*, no. 2 (April 1975): 26–30.

The city already had one parking facility in addition to the Cherry-Marshall Deck and plans to construct two other parking facilities. Thus the consultant employed by the city suggested using a computerized revenue and traffic control system interconnected between all four facilities, enabling a higher level of revenue control in the additional three facilities and the opportunity to amortize the cost over all four parking operations.

The nerve center of the system is a 24K-word minicomputer tied to the several cash terminals in each facility. Each cash terminal is also a self-contained minicomputer, capable of providing a satisfactory level of revenue control should the main terminal computer be temporarily out of service. The remote facilities are connected to the main computer by voice-grade telephone-type lines. Additional features of the Winston-Salem system are as follows.

Traffic Control Phase. The traffic control portion provides three types of information to patrons by means of variable message blank-out signs. The system monitors the number of available parking spaces in each facility. When a facility becomes full, signs facing the streets are illuminated, displaying the message "FULL."

The system automatically keeps track of available parking spaces in each facility, by zones in the facility. Patrons are directed by means of a variable-message sign, to the most convenient zones that have space available. As a third function, the system provides directional information on which exit lanes are open to unparking patrons—again using variable-message signing.

Entrance and Exit Operations. Entrance lanes to each facility are equipped with a gate, a ticket-issuing machine, a card controller, and two loop detectors. When transient patrons enter they receive magnetically-coded tickets, imprinted with the date and time of entry. (The date/time imprint is actually a back-up system since this information is also magnetically coded on the ticket, which is machine-read.) Monthly patrons are issued individually coded magnetic key-cards that are inserted in the card controller to gain entrance to the facility.

Collection booths with cash terminals are located at each exit. The cash terminal contains a ticket reader and a card reader, and is capable of computing all fees automatically after obtaining the date and time of entry corresponding to the ticket or card from the central computer. The cash terminals have a back-up mode that allows an attendant to key in the date and time of entry that is printed on the ticket. The cash terminal then computes the fee based on its own internal clock.

Normally attendants are used to collect fees and make change. During off-peak periods, three of the facilities are equipped to read cards and tickets, and to automatically display the computed fee, whereby the patron is obliged to deposit the correct amount of change or use a permit card to raise the exit gate. This mode permits operation without an attendant, yet allows the collection of variable fees during off-peak periods, such as at night.

Communication System. Communication with the computer is through a teletypewriter. All input commands to the computer, as well as outputs, are printed in simple English language words and phrases. The computer is programmed to log all significant occurrences and malfunctions on the teletypewriter. The system automatically prints daily reports on each cashier when the work day for each individual ends. The facility supervisor can request various types of information and status reports at any time by simple commands on the teletypewriter.

Remote-controlled television monitors are used to display entrance area conditions. A master intercom permits each facility supervisor to monitor and/or communicate with personnel at each cash booth, patrons at each entrance, each zone control detector station, each elevator, and the computer room. Additional revenue control is provided by a nonresettable counter that records the number of vehicles and card customers using each entrance and exit lane. The control room in each facility also contains miniaturizations of each variable message sign and a manual override switch for each sign.

The revenue control features of the system include computing all fees and recording all aspects of each transaction. The system automatically prints out and sounds an audible alarm when situations arise involving unsatisfied fees or inappropriate attendant activity. The system also performs checks on card customers.

If the system determines that an improper condition exists, it prints a message on the facility's teletype, sounds an alarm, automatically captures the card and illuminates an appropriate message space on the associated cash terminal to inform the patron or the attendant of the problem. An improper condition can be a card that is invalid because the patron failed to pay a monthly charge, a monthly patron attempting to park more than one vehicle in a facility at one time, or a patron attempting to park more than one vehicle in two or more of the facilities controlled by the total system.

Operational aids are also provided by the system to attendants.

The system gives audible and visual alarms, and prints a diagnostic message on the teletype each time a problem is detected. The alarm conditions include low ticket supply in a ticket dispenser, empty ticket dispenser, gate malfunctions, and attempts by patrons to enter the facility improperly.

MAINTENANCE

The amount of maintenance necessary depends on age of the garage and equipment, garage usage, and climatic conditions (a major factor in locations with heavy snowfalls and freezing weather). A good preventive maintenance program can pay off in savings in both maintenance and operating costs.

Routine maintenance is normally carried out by garage personnel as part of other duties. However in large garages, or where several facilities are operated by the same management, there may be enough work for a full-time maintenance crew. Major maintenance jobs requiring special skills and/or equipment usually require outside expertise.

Routine Maintenance

Discarded trash and dirt accumulation are inescapable in garage operation. Weekly or even daily sweeping is necessary to prevent trash buildups. If water connections are available, hosing down of floor and wall surfaces can be an effective cleaning means.

Floor drains must be kept free of sediment and trash debris. Broken surface areas and floor cracks should be patched promptly to prevent further deterioration, and water dripping onto parked cars on lower parking levels.

Support columns are frequently located near parking stalls, where they are occasionally contacted by vehicle bumpers. Columns and other structure appurtenances should be protected to a height of 2 feet 6 inches (0.76 meter) up from the floor by use of concrete encasement, guardrails, or steel plating. Protective barriers should be able to withstand impacts of 300 to 350 pounds per lineal foot (446 to 521 kilograms per meter) sustained at a point 2 feet (0.61 meter) above the floor.[63]

While painting of interior wall surfaces can improve appearance, the paint requires periodic maintenance. Lighting fixtures and

[63] Seymour Gage Associates, *Medical Center and Hospital Parking Structures—Design and Construction*, (July 1974), p. I-48.

signs also require maintenance and should be designed and located for maximum replacement economy and servicing convenience.

Snow Removal. Snow removal may be accomplished by pushing it to the sides of the top level with a jeep or light truck equipped with a front-end plow. This method is not completely satisfactory for several reasons: (1) piles of snow may become large and eventually turn to ice, making them difficult to remove; (2) parking structures are usually not designed to sustain heavy concentrated loads likely to result with large snow piles; (3) periods of rapid thawing may overburden the drainage system, causing flooding; and (4) piling snow on parking levels may reduce parking capacity.

Snow accumulations may be dumped over the side if the structure is low to the ground. In addition to a snowplow, a front-end loader is also needed. If possible, the snow is piled and stored on the ground; otherwise, it must be carried away. Care should be taken that snow piling and heavier equipment operation (such as a front-end loader) are performed near a structure corner or as close as possible to column supports, to minimize chances of structural damage.

Snow melting pits may be justified in northern climates but are relatively expensive, particularly if they were not constructed with the original structure. A melting pit consists of a large pit, normally covered with a steel grate when snow is not being dumped into it. Melting pits usually have gas-fired burners to melt snow and drain it into the storm sewer system. They can be an effective means of removing snow from the top level of a multistory garage; however, they require year-round maintenance.

OPERATING COSTS

Parking garage operating costs vary by method of operation, facility size and type, management, and in some cases, by geographic area and city size.[64] Personnel costs typically account for over half of total garage costs. The remaining operating expenses include utility, maintenance, and a variety of miscellaneous cost items such as insurance, supplies, depreciation on equipment, taxes, and telephone.

Figure 59 shows the average distribution of the operating dollar for 37 municipal self-park garages for the 1974 fiscal year. Labor costs accounted for 51 percent of the total; utilities, 21 percent;

[64] Highway Research Board, *Parking Principles*; and Wilbur Smith and Associates, *Parking in the City Center*.

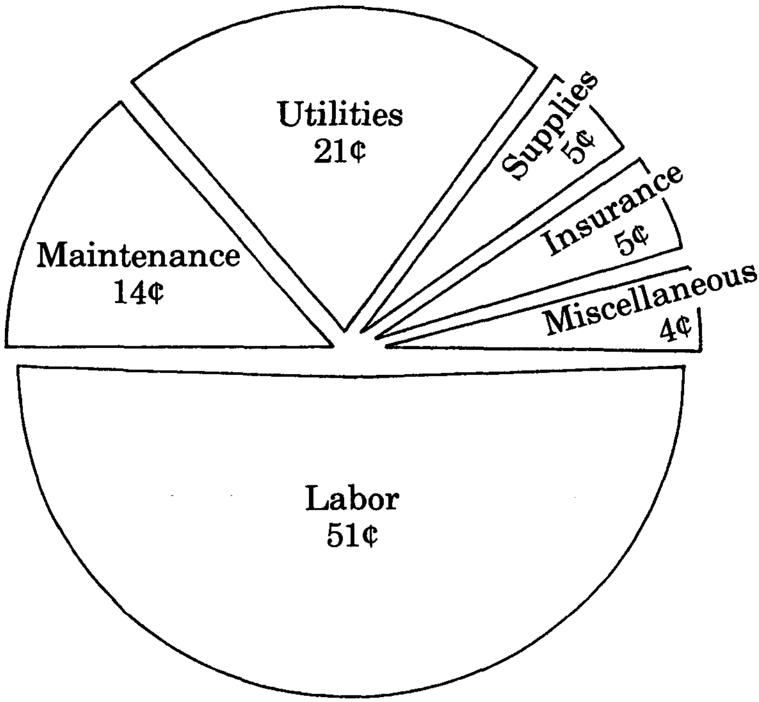


FIGURE 59. Distribution of the parking garage operating dollar.
Note: This chart illustrates the percentage distribution of annual operating costs for self-park garages, based on analyses of 37 municipal garages, using 1974 fiscal year data.

maintenance 14 percent; and supplies, insurance, and miscellaneous, 14 percent.

Accounting and bookkeeping procedures followed by owners or operators can also result in a wide variation in apparent costs. This is particularly true in items charged as miscellaneous expenses.

Personnel Costs

Since the largest single operating expense item is payroll and related costs, parking garages are usually designed for self-park operations. In every parking garage, manpower requirements must be geared to characteristics of their particular parking demand. High turnover short-duration parking generally requires more manpower in the operation than garages predominately serving all-day parkers.

Personnel costs are the most variable of all operating expenses. Whether or not garage personnel are unionized, as well as the general cost of living in the geographic area, can cause a significant differential in labor expense. Larger cities generally experience the highest wage rates. In addition to these factors, physical features of the garage can affect personnel costs. Garage factors influencing personnel expenses include internal design of the facility, number of access points, and type of cashiering used. Automation can reduce, but not eliminate, labor costs.

Cost Comparison. Table XIV compares annual personnel cost on a per-stall basis and by method of operation. This table is compiled from 1974 data furnished by 50 municipal garages questioned for this study.

Highest personnel costs ($264 and $225 per stall) were reported for two self-park garages having 480 and 1,500 spaces respectively. Both garages are municipally operated and serve high turnover, short duration parking. The smaller garage is also used for special-event parking during evenings and on Sundays.

During daytime peak operation, two cashiers, two attendants, and a garage manager normally work at the smaller garage, and a bookkeeper is shared with three other parking facilities operated by the city. A reversible entrance lane is used for exiting special-event crowds, with one additional cashier. This 480-stall garage has annual gross receipts of approximately $600 per stall. Thus, labor costs approximate 44 percent of gross receipts as compared to an average of 33 percent for the 35 manned self-park operations. Total annual operating costs, exclusive of debt service, were $377

TABLE XIV—ANNUAL PERSONNEL COSTS

	Cost Per Parking Space			
Type of Operation	*Minimum*	*Maximum*	*Average*	*Number of Garages*
Self-park with attendant	$18.32	$264.33	$77.22	35
Self-park with meters, without attendant	$12.72	$88.83	$50.27	11
Self-park without attendant or meters[a]	$3.20	$10.27	$6.74	2
Attendant-park[a]	$69.77	$146.92	$108.35	2

[a]This small sample may not be fully representative.

per stall for this smaller garage, making personnel cost over 70 percent of the operating expense as compared to 55 percent averaged for the other garage operations in this category.

The larger garage, with 1,500 parking spaces, had the highest reported annual gross receipts, at $925 per stall. Labor expense represented 24 percent of gross receipts and 63 percent of total operating costs. The lowest annual labor cost for a self-park operation without attendants or meters was $3.20 per stall. This 250-stall facility operates on a permit basis for long-term parking, and has free 2-hour parking for shoppers. The relatively small labor cost represents the amount allotted to the city clerk, whose responsibility it is to issue parking permits.

Personnel Requirements

Personnel required to operate a garage may include a manager, assistant manager, attendants, cashiers, maintenance, security, secretarial, and bookkeeping personnel. Duties of individual employees are generally varied and may include responsibility for covering several positions, depending on demand and operational characteristics of the garage. This is frequently the case in smaller garages where labor costs are often reduced by judicious scheduling of work assignments and reliance on the ability of personnel to perform several different job functions.

Garage Managers. The manager supervises the entire garage operation and is responsible for promoting the facility. He also is responsible for personnel training and job performance, and must anticipate periods of heavy or unusual demand in order to have sufficient personnel available. The manager is usually the person who must deal with the public concerning accidents, complaints, or other circumstances involving customer convenience, safety, and satisfaction. Managers must often perform the functions of other employees to assist in peak periods.

Assistant Managers. The assistant manager generally has the same responsibilities as the manager for a particular work shift.

Attendants. Duties of garage attendants depend on garage design and operation. In self-park facilities they may be required to issue or collect tickets, direct traffic and, in some instances, provide assistance in parking-unparking. In attendant-park operations, they handle vehicles within the garage.

Other Personnel. Cashiers are responsible for calculating and collecting parking charges. As a revenue control safeguard, they rarely double as the bookkeeper. The secretarial and bookkeeping functions, however, are often the combined responsibility of one individual not involved in parking fee collection.

Security and maintenance duties are routinely handled by attendants. Municipal police personnel, paid by the city, commonly provide regular security patrols in municipally-operated garages—an expense not typically shown as an operating cost. Some cities have agreed to extend police patrols on a regular basis to privately-operated parking facilities, and at no additional expense to the operator.

Employee Uniforms. Uniforms provide a means of identification and easy recognition of personnel for security and customer convenience, while assuring a higher level of personal appearance for employees. They also advertise the garage, and may contribute to better employee morale and relations.

Garage operators usually provide employee uniforms and are responsible for cleaning uniforms. Many garages have found it more satisfactory to rent uniforms, with laundry service provided. As an incentive for employees to take care of uniforms, they are sometimes required to pay a portion of uniform expenses.

Utility Costs

Utility costs include electricity, heat, and water. In over 50 garages providing utility cost data for this study, the cost per parking space for utilities ranged from $4 to almost $92, averaging $23 per stall. The principal utility cost is electricity used for lighting and powering equipment. Multi-level structures usually require lighting throughout the day in addition to evening hours. Underground garages typically have higher electrical needs than above-ground structures, since they usually require more lighting fixtures and a ventilation system. Water usage, and heating of the manager's office, cashier booths, restrooms, and enclosed pedestrian walkways, are generally not a significant portion of operating costs.

Maintenance Costs

Maintenance costs, including physical repairs, are traditionally underestimated. This study found annual maintenance costs to be extremely variable, ranging from $1.04 per stall to over $80.00 per stall. The lower figure represents a new two-level facility where the general housekeeping expense is a responsibility of municipal street sanitation crews, and is not charged directly to the garage operation.

Need for extensive repairs caused by a lack of proper preventive maintenance or other reasons can dramatically increase maintenance costs in a 1- or 2-year period. Major maintenance to passenger elevators, for example, averaged over $1,800 annually per elevator in five different garage facilities surveyed for this study. Deck resurfacing cost for 1974, reported by three garages, averaged $56.00 per stall, and contract snow removal averaged $3.25 per stall in garages surveyed.

Insurance Costs

Some cities operating parking facilities are self-insured while others carry either basic comprehensive liability or a complete program of insurance coverage—a factor that contributes to widely varying insurance costs between different parking facilities. A comprehensive insurance program may include, in addition to liability, garagekeeper's legal liability, workmen's compensation insurance, coverage against loss of money or securities, special equipment coverage, and fire and extended coverage. Comprehensive insurance programs may also include insurance coverage against rent and business interruption.

The annual cost of insurance varied widely between 33 garages reporting this cost. Insurance cost ranged from $0.36 per stall to $16.00, averaging $4.81 per stall for 1974.

Comprehensive Liability. This type of policy is usually written on an annual basis. It provides coverage for accidents involving injuries to persons other than employees, and damage to property of others arising out of the facility's use. Liability is always limited to a specific dollar amount per person, per accident for bodily injury, and per accident for property damage.

Special endorsements can be written to extend coverage or liability limits. Pedestrian elevators, for instance, are usually covered by special endorsements.

Garagekeeper's Legal Liability. This is the basic garagekeeper's coverage for damage to customers' automobiles in the garage's custody when caused by fire, theft, riot, malicious mischief, or vandalism. It supplements the comprehensive liability and is written on an annual basis.

Workmen's Compensation Insurance. The annual policy under state workmen's compensation laws provides specific benefits for injuries to employees during the course of their employment.

Equipment Coverage. This type of policy provides coverage for stated machinery, such as elevators and boilers. Liability is always limited to specific amounts, and inspection services are often included as part of the coverage. Policies are typically written for 3 years.

Money and Securities. This type of policy covers loss of money by holdup, robbery, theft, and mysterious disappearance from the premises, and loss in the same manner off the premises if money is in the custody of an authorized agent. It is commonly written on a 3-year basis.

Blanket Honesty Insurance. This coverage provides replacement of losses resulting from employee dishonesty, up to a specified amount. It is written on a 1 to 3-year basis.

Fire and Extended Coverage. This covers the garage itself against risks of fire. Special endorsements are commonly used to extend the coverage to practically an all-risks basis. Policies are typically written for 3 to 5 years.

Rents and Business Interruption. This policy provides the equivalent of 1 year's net income during business interruption. Such coverage is written for 3 to 5 years.

Miscellaneous Operating Costs

These costs include a variety of operating expenses, depending on the method of accounting. Cost items include uninsured damages, depreciation of equipment, office supplies, parking-charge ticket printing, telephone, employee uniforms, auditing fees, legal counsel, and taxes.

For this study, over 50 garages reported miscellaneous operating costs ranging from $0.48 per stall to $164.00. The overall average was $15.12 per parking space for 1974.

Self-Park Versus Attendant-Park Costs

The substantially smaller number of persons required to operate a self-park facility represents a significant saving in operating costs when compared to attendant-parking operations. Other costs of operation typically do not reflect as wide a differential between the two types of facilities. For illustrative purposes, four garages owned by the same city are compared financially on a per stall basis in Table XV.

Operating costs in two attendant-park operations (garages *C* and *D*), exclusive of major repairs, averaged 47 percent higher per stall than those for the self-park operations (garages *A* and *B*). This was due largely to labor costs, which were 45 percent higher in the attendant-park garages.

Figure 60 compares total annual operating costs per stall for the two self-park garages with the two attendant-park garages. It shows that the self-park garages averaged $139.12 in 1974 operating costs

TABLE XV—COST COMPARISON OF SELF-PARK AND ATTENDANT-PARK OPERATIONS[a]

	Self-Park Operation		*Attendant-Park Operation*	
General Facts	*Garage A*	*Garage B*	*Garage C*	*Garage D*
Date first began operation	1969	1963	1967	1961
Building type	Integrated structure with department store	Multi-level, ramp, free standing	One-level, underground	Multi-level, mechanical garage
Gross area per stall (square feet)	443	505	452	420
Number of stalls	800	600	125	220
Construction cost/stall	$6,177	$4,924	$17,278	$4,726
Land cost/stall	$3,123	$525	$2,260	$1,023
Annual Debt cost/stall	$338	$67	None	$227
Annual Gross revenue/stall	$277	$207	$211	$79
Annual Operating costs/stall	$139	$141	$404	$161
Annual Net revenue/stall[b]	$138	$66	($193)	($82)
Per Stall Annual Operating Expenses				
Labor	$60.83	$58.24	$146.92	$69.77
Utilities	26.94	31.01	91.43	12.62
Normal maintenance	19.60	15.38	21.50	17.67
Insurance	4.95	10.34	5.25	10.04
Supplies	2.81	2.89	0.39	1.05
Miscellaneous	6.45	3.78	4.83	3.33
Subtotal	$121.58	$121.64	$270.32	$114.48
Major repairs	-0-	2.15	120.00	26.92
Management fee	17.62	17.41	13.84	19.81
Total operating expense	$139.20	$141.20	$404.16	$161.21

[a]Table is based on reported 1974 cost data.
[b]Excludes debt service costs, which are met by municipal general-obligation bonds.
Source: Questionnaire survey conducted by the Eno Foundation in 1975.

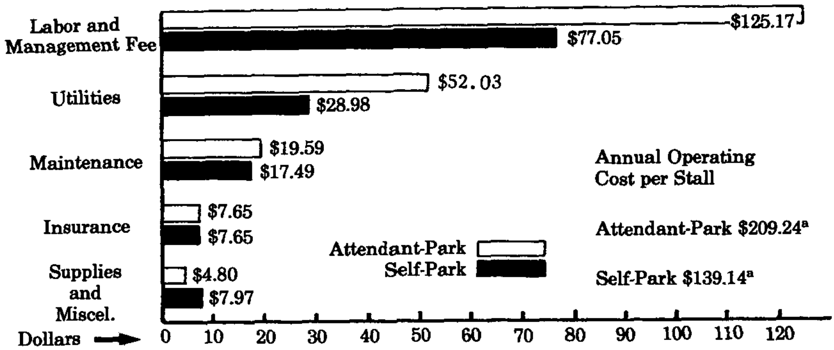


FIGURE 60. Self-park versus attendant costs on a per stall basis.
[a]Average annual costs per parking stall excluding major repairs.
Source: Based on data in Table XV.

per stall, compared to $209.24 for the attendant-park garages. Labor costs per stall averaged $77.05 for the self-park garages, and $125.17 for the attendant-park facilities. Utility costs were also higher for the attendant-park garages, largely because one garage is underground. Other costs were relatively similar for both types of operation.

Parking Fees

Parking fees are tailored to a garage's demand potential. Rates should depend on (1) what parkers will pay, (2) operating and development costs, and (3) operating policy. In all cities, central business district parking rates are highest near core areas, where land-use intensity and assessed land values are highest.

Parking fees can be set on an hourly, all-day, weekly, and/or monthly basis. Hourly rates are set to satisfy the requirements of short-term parkers, while rates based on longer periods of time satisfy regular and occasional customers with longer parking durations.

In high parking turnover situations, some operators consider a proper parking rate to be one that does not keep the facility 100 percent full. Private operators, seeking maximum income, suggest that 85 percent occupancy is most desirable. Many believe that with substantially higher use of available capacity, potential customers can become discouraged, thinking the facility has filled—a situation particularly true for lots, since parked vehicles there are usually more visible than those parked in garages. From an economic viewpoint, a facility constantly filled above 85 percent would indicate to these operators that the rates are too low—and usage less than 85 percent during peak periods would suggest that the rates are too high.

Since parking garages are usually situated in a competitive area, with an established rate schedule, prevailing rates must be taken into account to establish or change a schedule of charges.

Contract Parking. Contract parkers make an agreement with a particular parking facility to pre-pay for parking on a monthly or weekly basis. By doing so, they are guaranteed a parking space, usually at a lower cost than if paid for at the normal daily rates. Contract parking is sometimes called monthly or permit parking.

It is common practice to oversell contract spaces, knowing that not all of the contract parkers will be parked at any given time. Data from garages surveyed indicated that, on average, garages sold 13 percent more spaces for contract parking than they actually had available. However, these same garages averaged only 81 percent usage of the contract space sold.

Several methods are used to process contract parkers in self-park garages serving both monthly and transient parkers. Bumper or window stickers are used with some processing methods to visually identify contract parkers. The stickers are nontransferable and, once affixed to a vehicle, cannot be removed without destroying the sticker. This also prevents substitution of vehicles.

In garages having ticket-type operations, one of two methods is generally used to process contract parkers. With the first method, the contract parker takes a ticket on entering the facility. The ticket is given to the cashier in lieu of cash, with the customer's signature and contract account number. The second method does not require the parker to take a ticket. Variations are numerous, ranging from an attendant on duty who identifies and records the entry of contract parkers to mechanized automated systems that use magnetic card readers. With the costs associated with parking, daily accountings should be made of contract parking.

Monthly or contract rates are commonly set in the range of 14 to 22 times the maximum daily charge. An earlier 1960 study[65] found that the average ratio of monthly charge to maximum daily charge to be 17.8, while 1974 data from garages questioned indicated an average ratio of 14.4. Maximum daily rates in garages questioned for the latter study were four to five times the first-hour rates.

[65] Robert E. Whiteside, *Parking Garage Operation*, (Saugatuck, Connecticut: The Eno Foundation for Highway Traffic Control, 1961), p. 81.

Merchant Validation

Merchant validation enables one or more businesses to pay all or a portion of the parking fees incurred by their customers at designated parking facilities. Validation agreements, sometimes called "park and shop" programs, permit a customer of a participating business to receive a validation slip or token when purchase of a specified minimum amount is made. This is redeemed for parking time at a participating parking facility. Of 106 garages that supplied this type of data[66], 66 participated in a validation program.

Local merchants and professionals, offering a product or a service, usually group together to financially support a validation program. The "free" parking provided to this group's customers, and the associated advertising of the program, is paid for from membership dues and from profits that accrue to individual members as a result of offering parking validation to attract increased patronage.

The participating merchant purchases validation stamps or tokens from the merchants' association or group. Each stamp is worth a specified amount of parking time at a participating parking facility. In some cases, merchants give a customer one or more stamps, based on the dollar amount of the customer's purchases. In other cases, merchants provide only one validation for a specific amount of time, regardless of the dollar amount involved in the purchase above a minimum.

At the end of each month, the parking operator sends the validated tickets that have been collected to the sponsoring group for payment of validated parking. In most instances the merchants' group is able to negotiate with a parking facility for a lower parking fee than would otherwise be charged.

Problems with Validation Programs. Experience has shown that validation programs sometimes have problems. First, the success of the validation program closely depends upon the amount of promotion given the "free" parking aspects to attract larger volumes of retail customers and clients of professional services, and thus, parkers.

Program promotion has principally been the responsibility of the merchants' organization and its individual members. Participating parking operators are usually not required to be members of the organization, and therefore do not normally contribute financially to the program's support except for reduced rates—which can be a substantial expense to the garage or lot operator, particularly if

[66] Questionnaire survey conducted by the Eno Foundation in 1975.

the program does not increase parking volumes. Some parking operators have found that after granting lower rates for a validated parking program, it is difficult to adjust parking rates at a future date.

Control of validation stamps has presented other problems, such as customers removing extra validation stamps from their parking ticket to use at another time. Some garages have found that employees remove extra validation stamps as parking tickets are received. These stamps are saved until a cash customer pays for parking. The employee is then in a position to pocket the cash and affix the saved validation stamp to the ticket, thereby satisfying the accounting controls.

Customer and employee abuses of validation stamps can be eliminated to a large degree by changing stamp colors regularly and by using special pressure-sensitive stamps that are nearly impossible to remove after being affixed. Franking machines that mark tickets are also in use in lieu of stamps. This system is generally considered more costly for the merchant, but has been used successfully with high-volume situations. A validation program is also possible with metered parking where parking meters accept tokens as well as coins.

Marketing

User revenues sometimes can be increased through improved marketing techniques. The Parking Authority of Norwalk, Connecticut, for instance, increased user revenues in a relatively new but financially marginal garage facility by improving the quality of the parking offered and soliciting the help of local merchants.

First, the parking authority installed new signing by adding new informational signs and replacing makeshift graphics. New uniforms for differing weather conditions and job functions were provided to garage personnel. A lighting consultant was asked to establish correct lighting levels. Existing interior light levels were found to be far more than necessary, and subsequent reductions to garage illumination resulted in significant cost savings.

The second step involved meeting with local merchants, asking for their views and suggestions. This action resulted in local merchants promoting the garage facility through various advertising mediums. Merchants also organized special concurrent sale days, intensifying the area's attraction for customers. This marketing program filled the parking garage to near capacity for the first time since its construction.

Lease Agreements and Management Contracts

A lease is the conveyance of property by the owner to a second party, for the second party's use over a specified amount of time. In such arrangements, the owner is the lessor and the second party is the lessee. The lessor is compensated for the use of leased property by periodic payments from the lessee of rent and other value considerations.

When leasing a parking garage, the operator assumes all of the operating costs and pays the lessor a specified annual amount or percentage of the receipts. Historically, gross receipts have been the basis for a percentage payment; however, some parking garage lessors have agreed to various levels of net receipts. Normally, the operator (lessee) assumes all monetary risk in the successful operation of the parking garage.

A management contract is an agreement between a property owner and a second party for the second party to operate or manage the owner's property for a management fee. Typical management contracts provide that all gross income, less operating costs and management fee, be paid on a periodic basis (usually monthly) to the owner.

The owner, of course, has the decision on whether to lease or have a management contract. From the owner's viewpoint, a management contract is much more flexible than a lease, since in the management contract the operator's principal concern is providing the service that the owner wants. And if the owner is not satisfied with the service provided by the operator, he is generally in a position to terminate the agreement without penalties associated with breaking leases. Under contract management, the owner's responsibility for operating costs can be a possible disadvantage. The owner is responsible for paying the associated operating costs but has little direct control over these expenses other than terminating the agreement.

Contract Management Provisions. Contract management provides for a private operator (usually a parking company) to act as an agent for a parking facility owner. Contract management can hold certain advantages for operators—primarily less economic risk. The operator can be guaranteed the management fee, regardless of possible unfavorable developments affecting the parking facility's success. The security offered by contract management may require the operator to settle for smaller profits, as well as possible termination at the owner's discretion. Management contracts should have a term from 1 to 3 years.

Decisions on such items as pay rates, equipment purchases, operating hours, and parking fee schedules are the right and responsibility of the owner. Parking fee monies and documents related to revenue are the property of the owner, and usually deposited in the owner's account at the end of each day.

The operator provides a qualified resident manager, and provides all other employees necessary in the actual operation of the facility. Under contract management, parking companies generally are the operators because they are in a position to support the resident manager with experts in pertinent areas of concern such as legal, insurance, and personnel. Housekeeping and simple maintenance are the responsibility of the contract operator, as well as accounting reports and audits to the owner. The contract operator is obligated to maintain liason with the owner and to carry out the owner's instructions.

Management fees are negotiated between the owner and operator. While 40 of 69 management contract parking garages surveyed did not specify the fee basis, 6 of the parking garages indicated that the management fee is based on a percentage of the gross revenue derived from the garage operation, and 9 parking garages (3 in the same city) had a fixed monthly management fee.

Fourteen garage operators were paid a fixed fee plus a percentage of the gross receipts, which in some instances was limited to a maximum amount. The incentive portion of the fee is usually a small proportion of the total management fee. There are numerous options in determining the incentive portion, such as varying the percentage of the gross as the amount of the gross varies.

As a possible advantage to contract management, the contract operator acts as a buffer between the owner and the public in areas of rate changes, insurance claims, and minor customer inconveniences. Contract managers should have expertise in the area of revenue control, and management contract should have guarantees by the operator against employee thefts.

CONCLUSION

Because of increasing development and operating costs for parking garages, and the need to keep parking rates at levels the public is willing to pay, efficient management of parking facilities today is critical. Therefore, whether the facilities are operated under lease agreements or management contracts, a knowledgable and competent management and staff are essential. Without such persons, the best-located and best-designed parking garage can fail to succeed.