THESIS

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PLANNING OF INTRA-AIRPORT
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F. McKelvey
Major professor
Francis X. McKelvey

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PLANNING OF INTRA-AIRPORT
TRANSPORTATION SYSTEMS

By

William James Sproule

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ABSTRACT

PLANNING OF INTRA-AIRPORT TRANSPORTATION SYSTEMS

by

William James Sproule

As terminal buildings are expanded to accommodate growth in air passenger traffic, walking distances will increase as the physical dimensions grow and in many cases these distances will become unacceptable. At some airports it may not be possible to expand an individual terminal due to site constraints and an additional terminal site must be constructed elsewhere on the airport site. As a result, consideration and analysis of various transportation systems to reduce walking distances and provide for the efficient movement of passengers on an airport site is expected to become an important component in terminal planning studies.

A framework for the planning of intra-airport transportation systems has been developed in this study and techniques have been prepared to assist the terminal planner in the conceptual phase of the terminal design process. These include nomographs to determine service characteristics for a system and cost estimating procedures. Modifications have also been made to the Federal Aviation Administration's Airport Landside Model to expand its capabilities to assess the impact of an

intra-airport transportation system on other passenger processing facilities and average passenger processing times.

Using the framework and techniques, minibuses, conventional buses, automated guideway transit operating on a loop alignment, automated guideway transit operating on a shuttle alignment, and moving walkways have been incorporated in generic terminals of various concepts and for different passenger demand levels to identify guidelines for the use of these systems.

TO MY PARENTS

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INTRODUCTION

1.1 The Problem

Air passenger traffic is expected to continue growing and forecasts (50)* by the Federal Aviation Administration indicate that domestic enplaned passengers flying on U.S. carriers are expected to increase at an average annual rate of 4.7 percent to 470 million passengers in 1994. International enplaned passengers on U.S. air carriers are forecast to be 35 million in 1994, an average annual growth rate of 5 percent. Figure 1.1 illustrates the growth in passengers on U.S. air carriers.

This growth in air passengers will put added pressure on the nation's airport facilities and at many airports, especially the large hub airports**, congestion and delays will become unacceptable.

In fact, in a recent study (5) of conditions at major airports, it was found that 33 of the large hub airports are already experiencing capacity and delay problems. Conditions will worsen as air passenger traffic increases.

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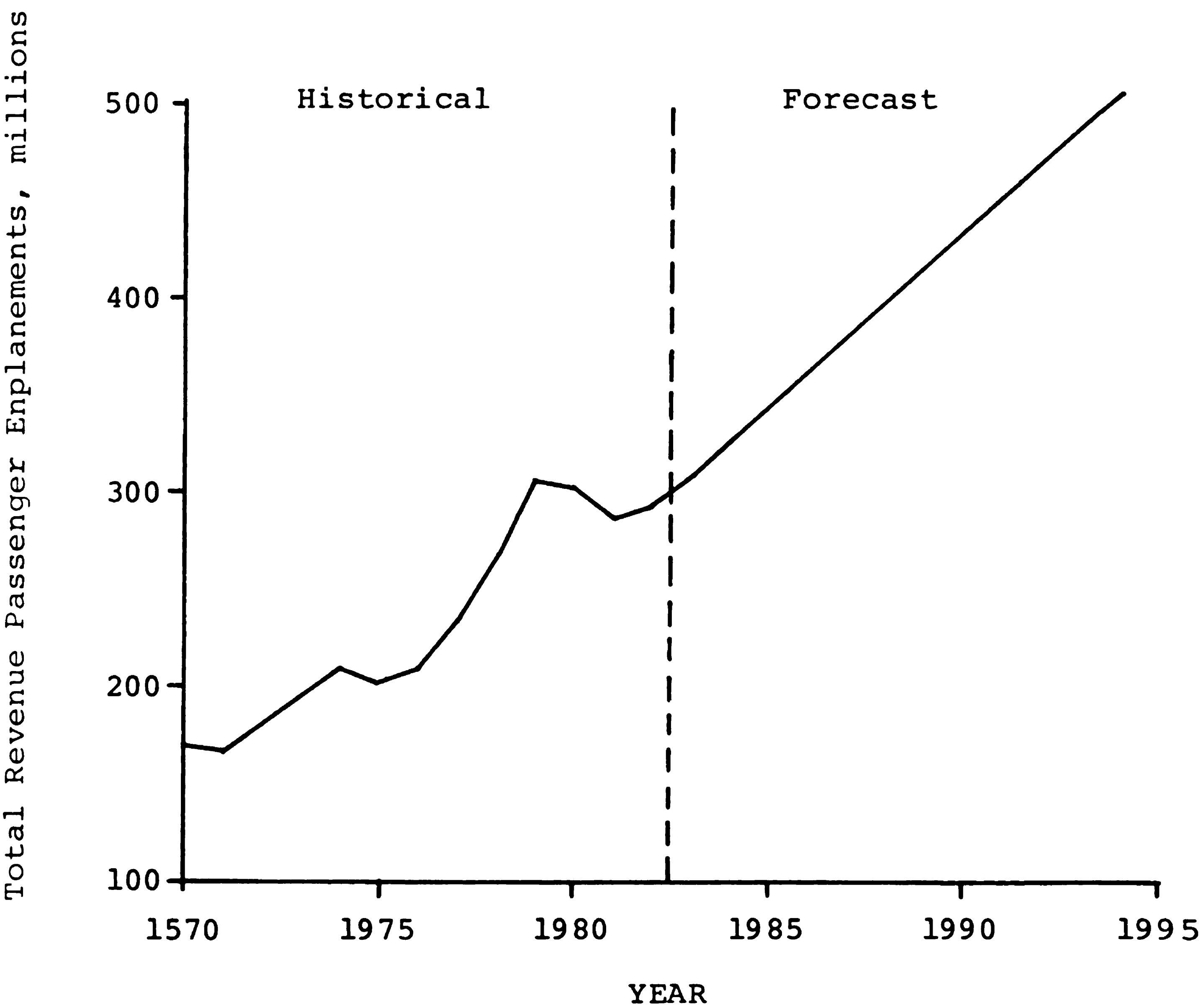
* Figures in parentheses indicate reference numbers in the List of References.

** The large hub airports are the largest airports and each enplanes over one percent of the nation's total enplaned passengers. In 1980, the 43 airports in the large hub areas handled over 75 percent of all enplaned air passengers in the United States.



'igure 1.1 Total Revenue Passenger Enplanements on United States Certificated Route Air Carriers

Source: FAA Aviation Forecasts, Fiscal Year 1983-1984. February, 1983.

The ability of airports to accommodate traffic can be expressed in terms of "airside" or "landside" capacity. Airside capacity is defined as the number of air operations - landings and takeoffs - that the airport and supporting air traffic control system can handle and primarily describes the capabilities of the runway system. Landside considerations, such as the number of gate positions, number of ticket counters, or the adequacy of baggage handling equipment, affect the number of passengers that the terminal building can accommodate. In addition, ground access, which includes the roadways and parking areas for automobiles, is another important part of airport landside capacity, and at some airports, it has become the limiting factor in an airport's ability to handle passengers. Because it is widely agreed that few new large commercial airports will be built in the near future, many airport authorities have called for the expansion of existing airports, and at most airports this will involve an expansion of landside facilities.

In the development of a terminal area plan, the objective is to achieve an acceptable balance between passenger convenience, operating efficiency, facility investment, and aesthetics.(51) One measure of convenience is walking distance and most authorities agree that 600 to 700 feet is a reasonable design criterion for passenger walking distances within a terminal and anything longer than 1000 feet is unacceptable.(27) However, as terminal buildings are expanded, walking distances will increase as the physical dimensions grow and in many cases these distances will become unacceptable. At some airports, it may not be possible to expand an individual terminal due to site contraints and an additional terminal must be constructed elsewhere on the airport site.

As a result, the consideration and analysis of various transportation systems to reduce walking distances and provide for the efficient movement of passengers on the airport site will become an important component in studies as major airports review their terminal facilities to accommodate future air passenger demands. These systems will be referred to as "intra-airport transportation systems" in this study and include vans, buses, moving walkways, and automated guideway transit systems that operate within the airport boundaries.

In recent years there has been considerable interest in the application of automated guideway transit at airports. Such systems are currently in operation at Atlanta Hartsfield, Dallas-Fort Worth, Houston, Miami, Orlando, Seattle-Tacoma, and Tampa Airports and are being considered at several other airports. The potential of automated guideway transit was identified at a 1975 conference (2) on Airport Landside Capacity that discussed issues and research needs related to airport landside operations. Among the identified needs was the development of analytical tools to establish cost and service characteristics of automated guideway transit systems at airports.

Although studies of intra-airport transportation systems have been done at several airports, they have been site specific and many basic questions have been raised:

- At what volume does it become appropriate to employ an intra-airport transportation system or combination of systems?
- Can criteria or guidelines be established which will assist the terminal planner in planning an intra-airport transportation system in the air passenger terminal complex?

As air passenger demands increase, terminal planners will be facing intra-airport transportation problems at many airports. A need for planning guidelines and analytical tools to assist in the selection of the appropriate system to reduce these problems has been identified.

1.2 The Terminal Planning Process

The planning of an intra-airport transportation system must be done in conjunction with the terminal. The development of a terminal design is performed in a series of four steps (14) - programming, concept development, schematic design, and design development - and the principal parties involved in this process will include the airport authority, the airport consultants, the airlines, and other tenants such as rental car agencies and concession operators.

(1) Programming

The initial step in the process defines objectives, and includes approximations of overall space requirements and preliminary estimates of anticipated capital investment, operating and maintenance costs.

(2) Concept Development

The space requirements determined in the programming phase are then allocated to various terminal arrangements or concepts. The terminal concept is a function of a number of factors, including the size and characteristics of traffic demand, the number of airlines to be served and the type of aircraft operated by these airlines, the traffic split between domestic, international, scheduled and charter flights, the available physical site, and ground access modes. Many alternatives are examined in this phase. For example, at the Fort Lauderdale-Hollywood International Airport, 48 basic alternatives for terminal and ground access system development were examined.(34)

Consideration and analysis of intra-airport transportation systems must begin in the concept development phase as a decision to incorporate such a system will shape the terminal plan and its operations.

(3) Schematic Design

Schematic design translates several of the alternatives examined in the concept development phase into plans which show the general size and location of the various elements in the terminal plan. Passenger routes through the terminal are specifically examined during this phase of the process and modelling techniques are beginning to be employed to identify passenger processing, travel and delay times, and the generation of lines at processing facilities. These analyses are used to determine the extent and size of facilities needed to provide a desired level of service to passengers and the impact of an intra-airport transportation system on other passenger processing facilities would be considered in this phase.

(4) Design Development

Detailed plans of a specific design are prepared in this phase. Capital budgeting, operating, maintenance, and administrative costs over the lifetime of the project are determined, and a revenue plan is adopted. Acceptance of the project by the airport authority, airlines, and tenants is the end result, and agreements are made on rate and charge structures for the airlines, concessionaires and other tenants to recover the costs of the development.

The project then moves on toward implementation through the preparation of construction documents, tendering and awarding of contracts, construction, and operation of the facilities.

1.3 Study Objectives

The purpose of this study is the development of a planning technique to assist the terminal planner in the concept development and schematic design phases for incorporating an intra-airport transportation system. Specifically, the objectives are to:

(1) Develop a framework for examining the application of intra-airport transportation systems.

(2) Identify the appropriate intra-airport transportation system for different terminal concepts at different total and transfer air passenger demand levels.

(3) Identify factors and guidelines that should be considered in the planning of an intra-airport transportation system.

1.4 Outline of the Research

Past work in intra-airport transportation system planning, and development and applications of automated guideway transit are initially summarized. Then a methodology for the planning of intra-airport transportation systems and techniques that have been developed for this study are described. Using these, intra-airport transportation systems have been incorporated in "generic" terminals to develop general guidelines for the use of intra-airport transportation systems, and to identify appropriate systems for various passenger demand levels and terminal concepts.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Ground transportation within the airport boundaries traditionally has been planned and designed in the context of terminal area development programs. As traffic volumes increased, cargo service and supply vehicles were separated from passenger cars, limousines, and buses. Further improvements were achieved by providing separate curb levels for departing and arriving air passengers, and ultimately completely new terminal concepts were developed in order to accommodate the steadily increasing flow of passengers.

In 1962, Tampa Florida's Hillsborough County Aviation Authority decided to take an innovative approach to planning new terminal facilities. Instead of simply collecting space, gate and concession requirements, the Authority engaged Leigh Fisher Associates, airport consultants, to survey, evaluate and compare all major U.S. terminals and make recommendations for the design of a new Tampa terminal.

In their review of thirty major airports (10), it was found that walking distances tended to increase with the growth of air passengers as lengthening piers was the common means of expanding capacity. In virtually all cases, the walking distances were greater than generally accepted maximum guidelines and walking distances were especially long for those passengers who must transfer between airlines. A separation of landside functions from airside functions was advanced as an effective solution for airport terminal design to reduce walking distances and more efficiently group related passenger and aircraft processing. This concept became known as the "satellite" concept. However, it was realized that the success of any such concept would be dependent upon a means of transferring air passengers efficiently and comfortably between airside and landside. The satellite concept was adopted for Tampa Airport, in which a clear separation between landside and airside functions was delineated and a system developed by Westinghouse was selected to shuttle passengers between the airside and landside components of the terminal. This marked the first application of a transit technology known as "Automated Guideway Transit" (AGT), and many felt that airports would be an ideal application of this type of system.

The Westinghouse system (also known as "Skybus" or "Transit Expressway") was being developed with the support of the U.S. government through an urban transit technology program. In the early 1960's, the Urban Mass Transportation Administration (UMTA) of the Federal Department of Transportation (U.S.DOT) decided to support investigations into advanced transit technology as a means of reviving urban transit and one of the early projects in this program was assistance to the Westinghouse Electric Company for the development of an automated guideway transit system.

2.2 Automated Guideway Transit

Automated Guideway Transit (AGT) describes a class of transportation in which unmanned vehicles are operated on fixed guideways in exclusive rights-of-way. Within the general category of AGT, three classifications have been identified according to different service concepts, routing, and scheduling capabilities.

(1) Shuttle-loop transit or single line transit (SLT)

(2) Group rapid transit (GRT)

(3) Personal rapid transit (PRT)

The SLT is the simplest AGT system. The system utilizes larger vehicles (carrying mostly standees) along a single route with stops at stations along the way. The vehicles are usually confined to one line, which can be a linear shuttle or closed into a loop, and stop at all or most stations on the line.

A GRT system generally uses fleets of medium sized vehicles that provide service on interconnecting routes. The system is typified by a moderate amount of networking and the use of off-line stations.

PRT describes a system of small vehicles (two to six passengers) that provides origin-to-destination, demand responsive service at very short headways. PRT systems have off-line stations that are connected by an integrated guideway network.

The Westinghouse system that was installed at the Tampa Airport is an example of the SLT system classification and the layout is shown in Figure 2.1. Vehicles shuttle passengers between the central landside terminal building and an airside building. Several other SLT systems were built in the late 1960's and early 1970's in other airports, amusement parks, and exhibition grounds. The system at the Seattle-Tacoma Airport, as shown in Figure 2.2, consists of two one-way loops located in tunnels under the apron, and a shuttle in the main terminal building.

Following the initial interest and identification of potential, the Federal government initiated a program to further develop AGT technologies. In 1970, funding was made available for three major demonstration projects - the TRANSPO 72 exhibition and GRT installations at the new regional airport for Dallas-Fort Worth, and on the campus of West Virginia University, Morgantown, West Virginia.

Today, there are over two dozen AGT systems in operation and nine are located at airports. Characteristics of these airport systems are summarized in Table 2.1. The majority are SLT type and provide transportation within a terminal. At the William B. Hartsfield - Atlanta Airport, the AGT system is operated in an underground transportation mall that connects four satellite terminals to a central processing building. In

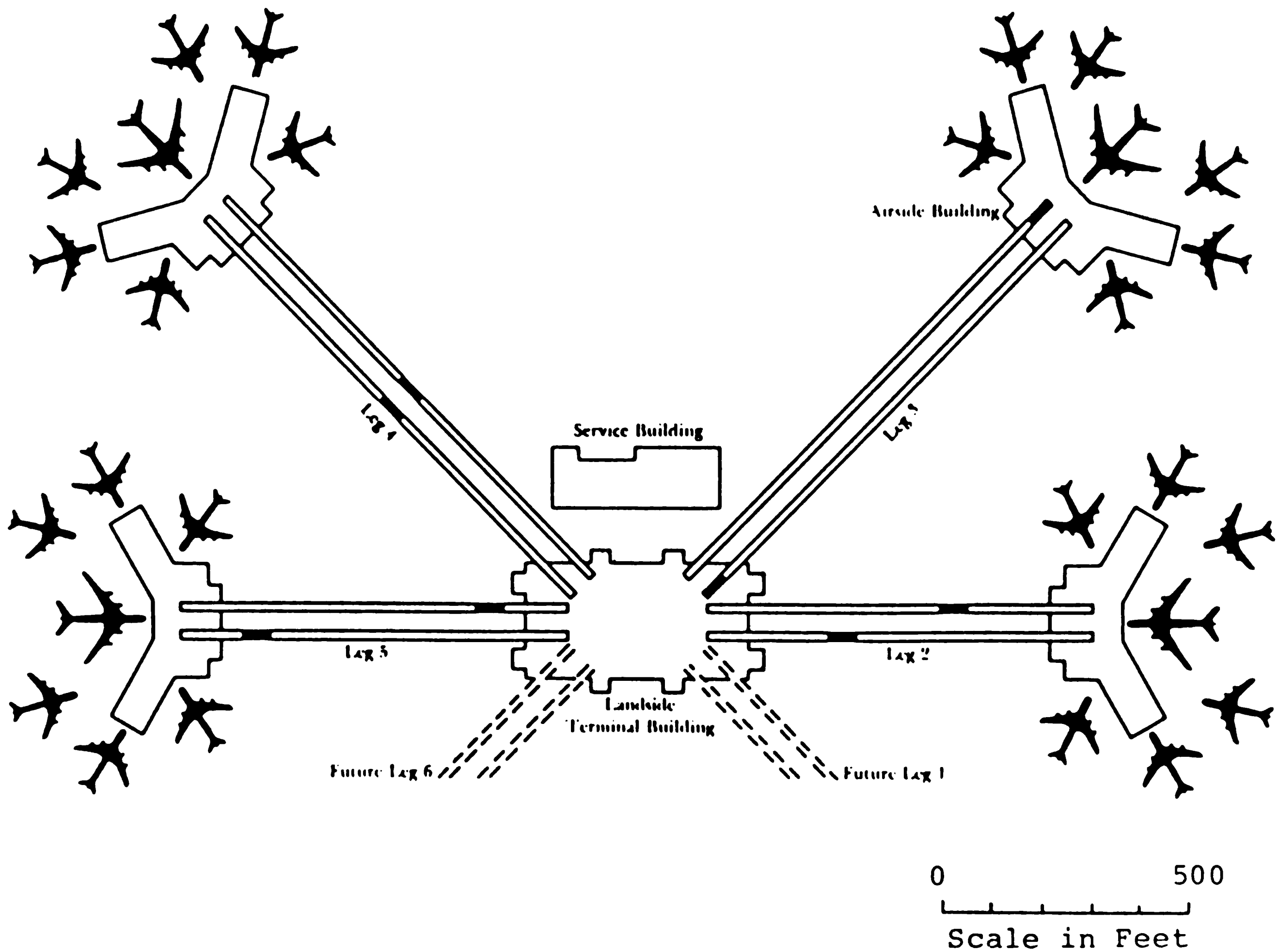


Figure 2.1 Layout of the Automated Guideway Transit System at Tampa Airport

Source: "Automated People Mover is a Success at Tampa," <u>Airport Services Management</u>, October 1977.

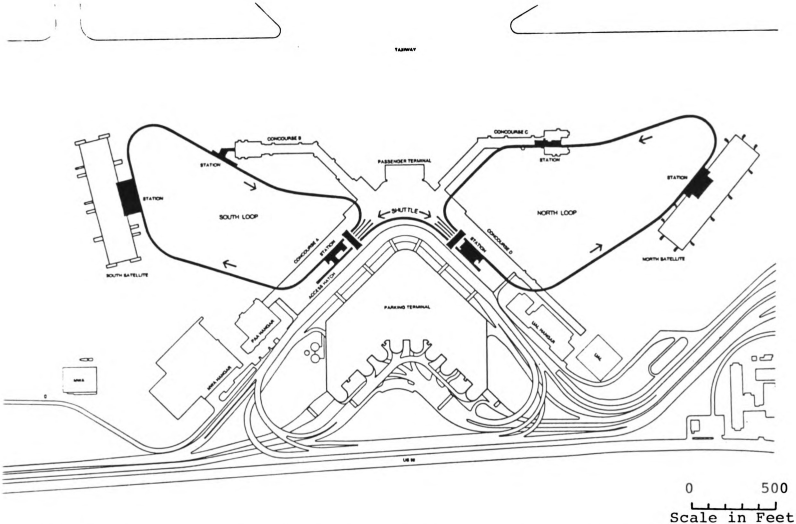


Figure 2.2 Layout of Automated Guideway Transit System at Seattle-Tacoma Airport

Source: <u>Seattle-Tacoma International Airport Satellite Transit System - Information Package</u>, 1971.

Table 2.1 Automated Guide Transit Systems at Airports

System Location	Description	Start of Service	Length & Type of Running Surface	Number of Loops or Legs	Number of Stops or Stations	Operational Characteristics	Fare	Vehicle	Manufacturer
Tampa International Airport	A passenger shuttle system fully automated connecting a landside building with 4 airside buildings. The trackways, 800 to 1000 ft. long, are elevated.	1971	1.4 miles concrete guideway with center steel I-beam for guidance.	4 dual	8	Single vehicles operate at 15 mph average trip time, 30 sec average dwell time.	None	Vehicle is 36 feet long, 9 feet wide and 11 feet high. Vehicle capacity of 100 passengers (all standees).	Westinghouse Electric Corporation
Houston Intercontinental Airport	Fully automated closed loop in which the vehicles are propelled by linear induction motors. System connects 3 air terminals, a hotel, and a remote parking area.	1972	1.5 miles structural steel tubing track is bolted to a concrete bed. The linear induction motors are placed between the guide rails.	1 closed loop. Located in tunnel	9	3 car trains operate at 15 mph maximum speed. 14 min. average trip time around loop, 20 sec. station dwell time.	None	Each vehicle is 13 1/2 ft. long, 5 ft. wide and 7 1/2 ft. high. Vehicle capacity of 12 passengers (6 seated, 6 standees).	WEDway Transportation Systems Inc. Replaced an original system by Rohr Industries Inc. in 1981.
Seattle-Tacoma International Airport	A completely automated passenger system consisting of 2 loops connected by a shuttle service. The south loop is 3700 ft. long and the north loop is 4100 ft. long. Each loop is operated in one direction and links the central terminal with a satellite in a tunnel under the apron. The system is known as the Satellite Transit System (STS).	1973	1.7 miles concrete guideway with center I-beam for guidance.	2 loops and a shuttle leg	8	Single or two vehicle trains operate at an average speed of 20 mph. Six min. average trip time on a loop, 2 minute headways and 25 sec. dwell time.	None	Vehicle is 37 ft. long, 9 ft. wide and 11 ft. wide. Vehicle capacity of 102 passengers (12 seated, 90 standees).	Westinghouse Electric Corporation

Table 2.1 (Cont'd.)

System Location	Description	Start of Service	Length & Type of Running Surface	Number of Loops or Legs	Number of Stops or Stations	Operational Characteristics	Fare	Vehicle	Manufacturer
Dallas-Ft. Worth Regional Airport	A fully automated passenger and cargo moving system which connects 4 terminal buildings, a hotel, remote parking areas, commissary facilities, and an airmail facility. The system uses electrically powered, rubber-tired vehicles operating on a dedicated guideway. The system is called AIRTRANS (Airport Transportation System).	1974	13 miles. Reinforced concrete U-shaped channel guideway. 80% at grade, 20% elevated.	Network of overlapping routes	32	Single vehicle or two-vehicle trains operating at 17 mph cruise speed, 15 sec. average dwell time, 30 second average headways.	$.25	Vehicle is 21 ft. long, 7 ft. wide and 10 ft. high. Vehicle capacity of 40 passengers (16 seated, 24 standees).	Vought Corporation
Atlanta Hartsfield International Airport	A fully automated reverse turn-around loop system linking 2 landside terminals with 4 remote air-side buildings. System operates in a Transportation Mall - tunnel located under the apron. Moving walkways are located in mall.	1980	2.3 miles. Concrete guideway with center steel I-beam for guidance.	One reverse turn-back loop	11	Single or multi vehicle trains, 10-25 mph operating speed, 25 second dwell times, 100 second average headways.	None	Vehicle is 39 ft. long, 9 1/2 ft wide, and 11 ft. high. Vehicle capacity of 80 passengers (16 seated, 64 standees).	Westinghouse Electric Corporation
Miami International Airport	A fully automated shuttle system with dual guideways and two car trains on each guideway. One car is reserved for exclusive use of passengers who have not completed U.S. customs entry procedures.	1980	0.5 miles. Concrete guideway with center steel I-beam for guidance.	2 legs	2	Two vehicle train, 10 1/2 mph, 1 minute average trip time, 20 second average dwell time.	None	Vehicle is 36 ft. long, 9 ft. wide, and 11 ft. high. Vehicle capacity of 100 passengers (all standees).	Westinghouse Electric Corporation

Table 2.1 (Cont'd.)

System Location	Description	Start of Service	Length & Type of Running Surface	Number of Loops or Legs	Number of Stops or Stations	Operational Characteristics	Fare	Vehicle	Manufacturer
Orlando International Airport	A passenger shuttle system, fully automated, connecting a landside building with two airside buildings.	1981	1.5 miles. Concrete guideway with center steel I-beam for guidance.	2 legs	4	Two vehicle trains operate at 15 mph average speed. 90 sec. average trip time, 20 second average dwell time.	None	Vehicle is 36 ft. long, 9 ft. wide, and 11 ft. high. Vehicle capacity of 100 passengers (all standees).	Westinghouse Electric
London, U.K. Gatwick Airport	A passenger shuttle system, fully automated, connecting a landside building with an airside building.	1983	0.4 miles. Concrete guideway with center steel I-beam for guidance.	1 dual	2	Two vehicle trains operate at 15 mph average speed, 45 sec. trip time, 30 sec. dwell time.	None	Vehicle is 36 ft. long, 9 ft. wide and 11 ft. high. Vehicle capacity of 100 passengers (8 seated, 92 standees).	Westinghouse Electric Corporation
Birmingham, U.K. Airport	A passenger shuttle system, fully automated, connecting new air terminal with a British Rail station.	1984	0.4 miles	1 dual	2	Two vehicle trains. Maglev suspension, linear induction motor.	None	Vehicle capacity of 40 passengers (6 seated, 34 standees).	The People Mover Group - a consortium of British Rail, British Gov't. and Engineering Companies.

Source: Survey of Ground Transportation Systems for Airports, Aviation Industry Working Group, 1978 (revised 1982), and updated information.

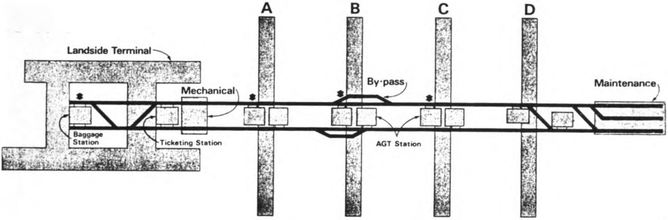
addition to the AGT system, moving walkways have been located in the mall. The system layout and typical cross-section of the mall is shown in Figure 2.3. The most extensive system is the GRT system (called "Airtrans") located at the Dallas-Fort Worth Regional Airport and it is used to provide airport circulation on a thirteen mile network as shown in Figure 2.4, that links four terminals, a hotel, and remote parking areas on the site.

2.3 Intra-Airport Transportation Systems

The interest in automated guideway transit and its potential application for intra-airport transportation was first documented in the late 1960's.

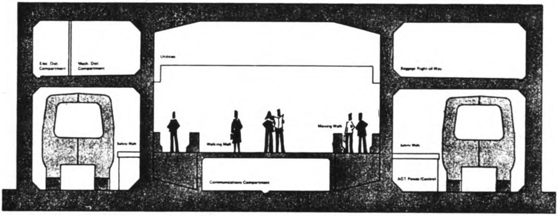
One of the initial studies (11) was completed in 1969 by the Institute for Defense Analyses for the U.S. Department of Transportation as one of a series of studies done to provide tools and techniques for planners of major activity centers to select systems for the efficient movement of goods, vehicles, and people. The study summarized the intra-airport transportation problem and identified the airport as an excellent showcase for AGT. Three possible applications were identified:

(1) airport circulation - to provide for the transportation of people on the airport site between the terminal buildings and parking lots, or a regional rapid transit station. Cargo areas, hotels and other activity centers could be incorporated on this network. (Example system: "Airtrans" at Dallas-Fort Worth Regional Airport.)



AGT Guideway Layout

0 1000
Scale in Feet



Cross Section of Underground Transportation Mall

Figure 2.3 Layout and Mall Cross Section of Automated Guideway Transit System at Atlanta Hartsfield Airport

Source: <u>William B. Hartsfield - Atlanta International Airport Information Folder</u>, 1979.

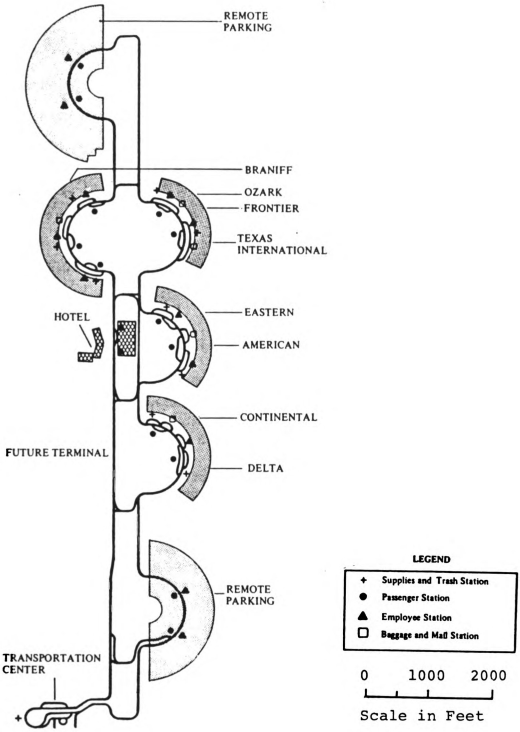


Figure 2.4 Layout of Automated Guideway Transit System (Airtrans) at Dallas-Fort Worth Regional Airport

Source: Transit Technology Evaluation - A Literature Capsule, UMTA, U.S.D.O.T., 1981.

(2) <u>intra-terminal</u> - to provide for the movement of people between the central area of a terminal and a remote area of the terminal, or a remote satellite terminal where aircraft gate positions are located. (Example systems at Seattle-Tacoma and Tampa airports.)

(3) <u>inter-terminal</u> - to link several terminal buidings together and provide transportation primarily for passengers transferring from one terminal to another. (Example system at Atlanta Airport.)

A conclusion of this study was that "AGT may be unable to compete economically with more conventional manually operated transportation alternatives because the automated systems are capital intensive relative to the wage intensive manually operated systems. However, automated transit may produce additional benefits (e.g. greater comfort and more convenience) to more than justify the greater costs." No analyses were included in this study to quantify these costs and benefits.

One of the objectives of the study was to determine the applicability of analytic techniques for studying intra-airport transportation problems. The study chose to discuss specific examples of analytical techniques and how they relate to airport problems. Two models were developed to illustrate what could be done with fairly simple techniques and included a Simple Model for Loop Transportation Systems, and an Airport Parking Cost Tradeoff Analysis.

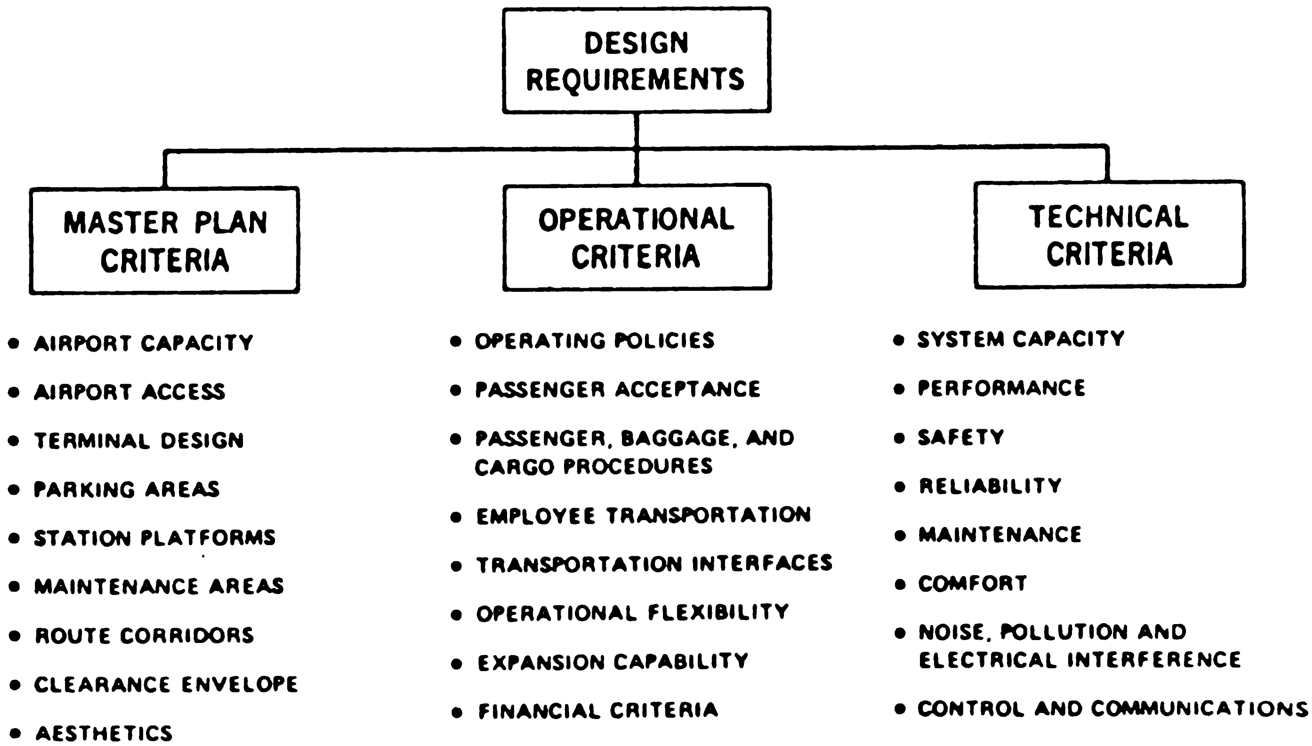
The study also recognized that simulation was a vital tool, and several simulation models have been developed for airport planning. However, the study stated that wherever possible, "analytic models should be used first to help structure the problem and bring to light those questions that can only be efficiently answered with simulation."

The intra-airport transportation system was also separated into the same three elements or sub-systems by Leonard H. Quick in a paper (33) presented at the 1969 ASCE National Meeting on Transportation Engineering, and suggested that each must be examined individually to determine if the total requirements can be satisfied by a single system type, or if separate transportation devices will be required. "The decision on basic system type is primarily dependent on such factors as system design capacity, overall route length, station separation, and desired start of operation. The choice of an optimum system type can be made only after an in-depth analysis of the specific requirements of an individual airport."

The paper includes a list of items which must be considered in the development of design criteria for the intra-airport system and these are presented in Table 2.2.

In a 1971 review (29) of intra-airport passenger systems by John Nammack, it was indicated that "no single people mover system can satisfy all of the transit requirements encountered at different types of airports and the selection of a system is largely a matter of local

Table 2.2 Factors to Consider in Developing Design Criteria for Intra-Airport Transportation Systems



Source: "Design Criteria for Intra-Airport Transportation Systems," Leonard H. Quick, 1969.

decision, based upon local requirements and desired standards of service determined by individual airport technical committees and their consultants."

In a 1970 Society of Automotive Engineers (SAE) presentation (36) before a National Air Transportation Meeting, Shields and Lindell discussed performance specifications that should be considered in the use of automated guideway transit for intra-airport service. Such aspects as capacity, seating, operating frequency, trip time, verification testing, and service life, and requirements for maintainance areas, train control, communications, power supply, and safety are described. They also stress that "the development of the terminal building and intra-airport system must begin in the concept phase and proceed in parallel through planning and design."

Much of the early literature on intra-airport transportation systems describes the potential for use of automated guideway transit but few techniques are presented to assist the planner in incorporating these systems in the airport.

2.4 AGT Development

Following the federal investments in the three demonstration projects in the early 1970's, the U.S. Senate Transportation Appropriations Committee directed the Congressional Office of Technology Assessment (OTA) to investigate the potential of AGT systems as a general form of urban transit. In 1975, OTA published "Automated

Guideway Transit: An Assessment of PRT and Other New Systems," (30) which reviewed the state-of-the-art of U.S. and foreign developments in AGT, and recommended substantial additional research into AGT technology, cost, and socioeconomic and environmental impacts. In response, the Urban Mass Transportation Administration (UMTA) began several major research programs in 1976.

The AGT Socio-Economic Research Program (52) was structured to perform a systematic analysis of the operation, social, economic, institutional, and environmental issues related to AGT to determine where and under what conditions AGT would prove feasible. The program consisted of five principal activities.

(1) Assessment of existing U.S. and foreign operational AGT systems to compile information on the technical, economic, performance aspects, and limitations of AGT. Assessments have been conducted for the AGT systems operating at six airports - Atlanta (20), Dallas-Fort Worth (42,43), Houston (40), Miami (21) , Seattle-Tacoma (39), and Tampa (38).

(2) Cost Studies using data from the assessments to analyze information on capital, operating, and maintenance costs. An initial summary was made in 1978 (22) and supplements have been completed in subsequent years (23,45,46,47).

Size, configuration, type, and cost vary widely among AGT systems, and thus it is difficult to develop construction, operating and maintenance cost estimates for a proposed system. "A site specific analysis is required to prepare an estimate of costs at a particular location."(22)

A computerized model (13) to calculate the life cycle costs of an AGT system was developed to assist in the evaluation of proposed alternatives.

(3) Alternatives Analyses to examine the ability of AGT systems relative to other modes. The most extensive project of this activity was the "Generic Alternatives Analyses" (35) and its objective was to identify appropriate applications for AGT. This was done by comparing AGT systems against automobile, bus, rail, and pedestrian systems in several potential urban applications. Basic service characteristics were identified by which modes could be matched against transportation needs. Comparative demand levels, capital and operating costs, and the socio-economic and environmental impacts were examined at a sketch planning level of detail. It was concluded that AGT systems are competitive with bus and rail modes in major activity centers, corridors, and for area-wide networks in metropolitan regions with populations of more than half a million, and the most promising applications of AGT systems are in activity centers. The activity centers that were examined included downtown business districts, diversified centers, and university campuses. Airports were not considered as it was felt that AGT in the airport

environment is unlikely to have to compete significantly with other modes. Any AGT installation would probably be the only mode for the primary passenger movement involved.

(4) Market Research to ascertain the nature and magnitude of the potential market for AGT systems. A forecast of the national market for AGT applications was made and summarized in the report, "An Analysis of the U.S. Market for Automated Guideway Transit."(19) The work included the development of hypothetical AGT networks for eleven case study sites and analyses of cost and benefits for potential AGT applications. It was recognized that airports are already a developed market for AGT and federal intervention to facilitate deployments appeared to be unnecessary. The growth in air traffic has necessitated such substantial expansions in the physical size of many airports that longer walking distances separating terminals are unacceptable. Although no estimate was made of the number of airports involved, it is anticipated that as airports grow, the use of AGT is likely to increase as the physical dimensions grow or space constraints require that additional terminals be constructed in inaccessible locations.

(5) Communications to disseminate findings and conclusions of the other four research activities.

A concurrent research effort was the AGT Supporting Technology Program that included a series of "hardware" oriented studies. One series of reports (7) dealing with

AGT guideway and stations, provides extensive data in the current state-of-the-art in AGT facility design, including station and guideway elements, construction techniques, materials selection, and weather protection. Other reports deal with vehicle design, power distribution, safety and security, system operations, and other technological matters. A major activity in this program was the development of a set of AGT system planning models (24) which permit the user to prepare detailed cost and service information for a proposed AGT deployment given zone to zone trip demand data, feeder characteristics, station locations and configurations, and network geometry. These models have been prepared primarily for urban networks and would be used in the detailed design phase of a project.

A third program involved demonstration projects that would use AGT to provide downtown circulation. UMTA solicited proposals for the design and implementation of such projects and the systems adopted the name "DPM" - Downtown People Movers. Several cities responded, however following the planning, review, and selection process, only two cities have proceeded with DPM projects. Systems are now under construction in Detroit and Miami. To assist cities proposing or considering downtown circulation systems, reports (44) have been prepared that bring together state-of-the-art in planning concepts, methods and data. Methodologies are described that range from the simplest, initial review of potential feasibility to the most detailed DPM impact assessments involving computer simulations.

2.5 Planning of AGT for Airport Application

As a result of the federal programs, fairly extensive work has been completed on AGT and its application in urban areas. Although some of this work is applicable to all deployments, the airport does provide some differences and the techniques developed for the urban setting cannot be directly transferred. However, recognition of AGT has been made in air terminal planning studies.

A 1973 study by the Ralph Parsons Company (32) identified that the increased use of wide-body aircraft and the steady, long term growth of traffic volumes have resulted in a need for larger terminals. More expansive facilities, in turn, have caused walking distances within terminals to increase and the use of various people moving systems have been adopted in recent terminal expansion programs to avoid the long walking distances inherent in some terminal designs.

"Moving walkways have been found to be useful for distances of 400 to 500 feet and a series of moving walkways may be used for distances greater than 500 feet. When the travel distances exceed 1000 feet, AGT systems would seem to have potential application."(32)

Some have felt that since present moving walkway systems operate at less than normal walking speed, their applications have been limited so work has proceeded on the development of accelerating walkways. These units would be boarded at speeds of present walkways and would accelerate the standing pedestrian to speeds up to 10 mph and then decelerate so that the pedestrian can alight safely. The Port Authority of New York and New Jersey, the Tri-State Planning Commission, and UMTA are currently involved in a research program (12) leading to the demonstration of an accelerating walkway system.

Studies conducted at Washington National (6) and Seattle-Tacoma (4) Airports indicate that accelerating walkways would be well suited to many intra-airport transportation requirements and in some cases comparable to AGT.

The Parsons study stresses that detailed analyses of the intra-airport transportation requirements and the interrelationship with other terminal activities, such as baggage handling, must be conducted to justify the expense that these systems impose upon the airport.

Planning recommendations for terminal building areas and apron space were developed in a 1975 study (31) by the Ralph Parsons Company. General material was included on the application of people mover systems and a list of factors was presented, Table 2.3, as a guide for the planning of such systems in the air terminal complex. However, no specific guidelines or analytical techniques for people mover systems were presented.

In 1975, a conference on Airport Landside Capacity (2)

Table 2.3 Identification List to Guide in Planning People Mover Systems at Airports

1. Identification of level of service

   - Convenience
   - Time
   - Distances travelled or walked

2. Identification of system users

   - Passengers
   - Well-wishers
   - Visitors
   - Airport and airline employees

3. Identification of areas of system utilization and distances to be travelled

   - Inbound

     (a) aircraft to terminal
     (b) terminal to baggage claim
     (c) baggage claim to parking - remote
- close-in
     (d) baggage claim to curb

   - Outbound

     (a) parking to check-in - remote
- close-in
     (b) check-in to waiting
     (c) waiting to aircraft

   - Transfer

     (a) aircraft to terminal
     (b) terminal to terminal
     (c) terminal to aircraft

4. Identification of peak flows

   - Airport passenger peaks

     (a) inbound
     (b) outbound
     (c) transfer

5. Identification of system capable of moving patrons within the terminal conveniently

   - Walking
   - Moving Walkways
   - Elevators

Table 2.3 (Cont'd.)

- Escalators
- Fixed Guideway Systems

  (a) wheeled vehicles
  (b) tracked vehicles
  (c) roadway vehicles - buses

6. Identification of interchange between internal system and external transit system

   - Rapid transit with total subsystem
   - Rapid transit direct to terminal check-in

7. Identification of transitions within the internal system

   - Vertical and horizontal systems
   - Moving walkways and vehicles
   - Vehicles and escalators
   - Vehicles and elevators

8. Identification of special terminal construction needed for transit systems

   - Rights-of-way for people moving systems and walkways, where required
   - Elevated guideways
   - Tunnels
   - Stations, platforms
   - Maintenance areas
   - Equipment storage areas
   - Blast protection
   - Power and control center

9. Identifcation of environmental problems of transit systems

   - Type of motive power
   - Power source
   - Power quantity required

10. Identification of maintenance and operations

    - Manpower
    - Substation
    - Backup systems
    - Maintenance
    - Monitoring operations

Source: <u>The Apron and Terminal Building Planning Manual</u>. Ralph M. Parsons Company, 1975.

was held in Tampa, Florida and sponsored by the Transportation Systems Center and Federal Aviation Administration, U.S.D.O.T. The conference brought together many groups and agencies that were involved in airport landside operations to discuss issues on this subject and identify research needs. The use of automated guideway transit systems at airports was identified as one of those needs.

"Although the initial impetus for the development of AGT technology was provided by the desire to develop less labor intensive solutions to urban transit problems, the major application of AGT has been at airports. This phenomenon is probably the result of a number of factors: intra-airport transportation problems are relatively self-contained, the capital cost of an automated transit system is a relatively low percentage of the total facility cost, airport authorities are generally more comfortable with high technology systems, airport operations demand a high level of transit service over long periods of operation, the airport may more easily integrate AGT, AGT permits increased flexibility in developing airport terminal configurations, and a more cost-effective solution may be provided by AGT than by more conventional transit modes."(2)

"Further research is needed to determine ways for reducing the risk involved in the deployment of AGT systems at airports, develop analytical tools to establish the cost and service characteristics of AGT systems, and perform cost-benefit studies to establish whether AGT is a feasible intra-airport transit solution."(2)

In a 1975 paper (48), E. Bryan Tutty indicated that virtually all terminal concepts, despite expansion, can maintain their efficiency and passenger acceptability by incorporating transit systems. The systems which can be employed vary, and "only the airport authority and the airlines at a particular airport can determine the installation best suited to their specific requirements." Tutty describes systems that can or are being used and provides examples on how the capacity of various terminal concepts can be extended by the use of people moving systems.

AGT has been examined for possible application at many airports and the studies have generally been site specific following a conventional "systems approach," namely developing measures of effectiveness, generating alternative courses of action, modelling performance, carrying out a multi-criteria evaluation of the alternatives, and then selecting the preferred alternative.

One recent study (26), conducted by Transport Canada, examined intra-airport transportation on a wider scope, although it was site specific to Pearson (Toronto) International Airport. The study included an assessment of systems at other airports, a literature review, and the development of a two-stage framework for analyzing the wide range of ground transportation options available to airport planners. The first phase evaluated several circulation system alternatives using a "short list" of the most vital measures of effectiveness. The measures were grouped under four general headings and included:

Transportation

- convenience - walking time, waiting time
- accessibility - coverage of activity centers
- reliability - dependability of service

Financial

- flexibility - ability to modify the system to meet changes in demand
- cost - life cycle costs of installation, operation and maintenance.

Social

- ease of implementation - number of external factors, disruptiveness, magnitude of initial investment.

Environmental

- environmental impact - emissions, noise, visual intrusion

A subjective ranking scheme was used to measure the performance of each of the system alternatives. Weightings were developed for each measure of effectiveness according to the perspective of the group impacted. Six impact groups were identified as airport management, airport users, airport employees, airlines, ground transportation operators, and other levels of government. In the first phase of the evaluation process the impact group weightings were estimated by the study team. In the second phase, these weightings were actually measured using focus group market research techniques.

The result of the first phase was the pruning down of the alternatives to three promising candidates. To permit more detailed evaluation, representative hardware systems for each of the three alternatives were chosen and manufacturers of these systems were requested to provide expertise on what they considered to be the optimal application of their systems to the Toronto airport problem.

In the second phase, the shorter list of alternatives were compared using an expanded list of measures of effectiveness that included the following measures in addition to those evaluated in the first phase.

Transportation

- compatability with plans, programs and priorities of the airport and surrounding community
- compatability with air operations
- comprehensibility (i.e. ease of understanding how to use the system)
- baggage handling capability
- cargo handling capability
- comfort

Financial

- revenue generation potential
- energy conservation
- industrial development potential

Social

- safety and security
- equity of treatment of all sectors of society (i.e. ability to handle handicapped travellers)

Environmental

- preservation or enhancement of quality of life

The alternatives that were studied for the Toronto Airport were designed to provide intra-airport circulation and a wide range of possible operating policy and land use alternatives had to be incorporated in the planning process. Since each of these alternatives would generate unique demands on the intra-airport circulation system, a decision tree of development options was used, Figure 2.5. Once a path through the decision tree was established, the design demand for the system could be determined and then the system could be laid out and sized to serve the demand.

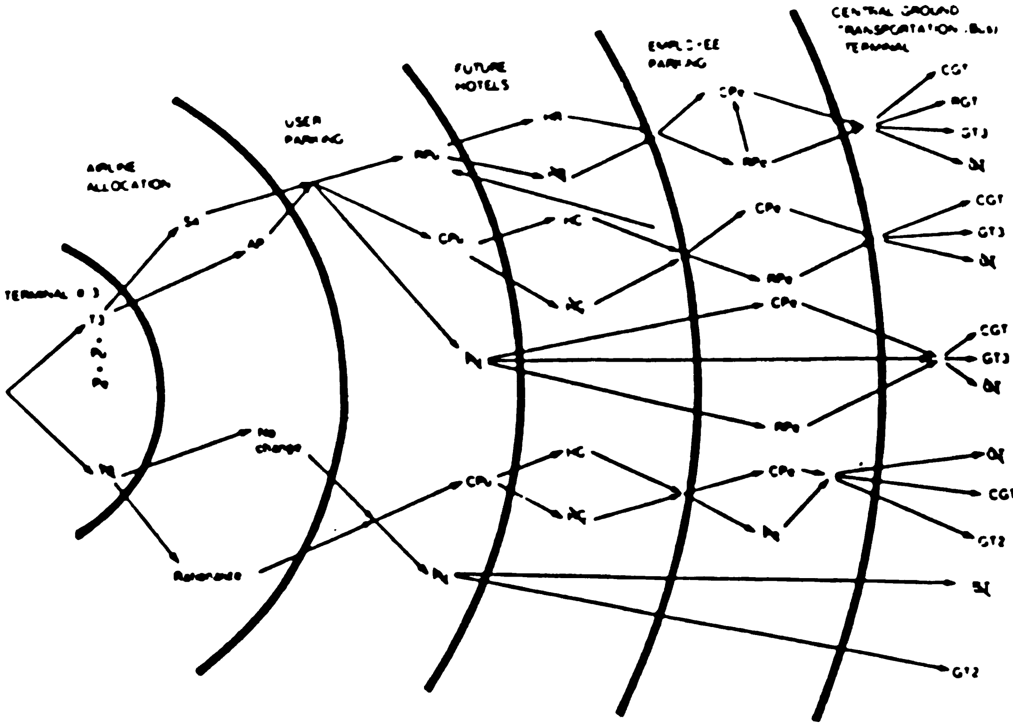
The selection of an intra-airport transportation system represents tradeoffs among several factors. In a paper by McCoomb (25), the tradeoffs that decision makers must make in choosing between automated guideway transit systems and conventional bus alternatives were summarized as follows:

Factors favoring AGT systems

capacity

level of service

- convenience
- reliability



Development Decisions Include:

- will there be a third terminal (T3), or not, in the short to middle run?
- how will the airlines be allocated between the terminals? Will it be according to a transfer minimizing strategy (ST) or according to some other plan (AP)?
- will additional airport user parking be constructed remotely (RPu), centrally (CPe) or not at all?
- will a hotel be constructed remotely (HR), centrally (HC), or not at all?
- where will the employee parking be located which is dislocated by the construction of Terminal #3 (RPe), centrally (CPe) or not at all?
- will there be a central (bus) ground gransportation terminal provided remotely (RGT), as part of the Terminal #3 (GT3), centrally (GTC), at Terminal #2 (GT2), or not at all?

Figure 2.5 Decision Tree of Development Options for Pearson (Toronto) International Airport

Source: "Planning Intra-Airport Transportation: A Framework for Decision Making," L. A. McCoomb, 1983.

- comfort
- equity

environmental impact

Factors favoring bus systems

cost

flexibility

ease of implementation

2.6 Summary of Literature

Considerable work has been done on automated guideway transit (AGT) and the planning for these systems in urban areas, but the literature on planning of AGT for airports and intra-airport transportation systems is very limited, and site specific. However, it has been identified that airports provide an ideal application for AGT and it is anticipated that as airports grow the use of AGT is likely to increase.

At the 1975 Tampa conference on Airport Landside Capacity the use of AGT at airports was identified as a research need and specifically the need for analytical tools to establish cost and service characteristics of AGT systems and studies to establish whether AGT is a feasible intra-airport transit solution.

This study will fill a need that has not been met by previous work by providing a framework to examine intra-airport transportation system alternatives in the concept phase of terminal planning. Analytical techniques to determine service characteristics and to incorporate the intra-airport transportation systems with other terminal planning models will be developed and guidelines will be identified to assist terminal planners in examining terminal and intra-airport transportation system alternatives.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The ability of many airports to handle future air passenger demands is constrained by the capacity of landside facilities and airport authorities are now faced with the problem of either finding a new site, changing air terminal operations, or expanding terminal facilities. Due to financial, environmental and other factors, it is likely that few new large airports will be built in the near future.(2) Operational changes, such as airline scheduling and gate allocation, may only provide a short term solution. As a result, airport authorities will likely concentrate their efforts on terminal expansion. A number of questions must then be addressed in the conceptual phase of the planning process.

- Can an existing terminal be expanded or extended, or is a new terminal required?
- If a new terminal is required, where should it be located? What terminal concept should be used?
- Is an intra-airport transportation system required?
- If an intra-airport transportation system is required, what mode should it be? What route should it follow? How much will the intra-airport transportation system cost and what will its impact

be on overall terminal operations and costs? Figure 3.1 illustrates the decisions facing the terminal planner that can lead to the need for an intra-airport transportation system. Two categories or classes of systems are identified:

(1) intra-terminal - designed for the movement of passengers within an individual terminal.

(2) inter-terminal - designed for the movement of passengers between terminals. Consideration for this type of system would be made where an additional terminal is being planned.

Although not shown in Figure 3.1, a third class would be a circulation system that links terminal buildings with remote parking lots, cargo area, hotels and other facilities on or adjacent to the airport.

Among the factors that would be considered in the expansion of facilities is passenger convenience. One measure of convenience is walking distance and when distances exceed a specified level, consideration should be made to reduce the distances. A reduction might be made by examining alternative terminal layouts and locations, or it may be necessary to provide some type of transportation system.

A framework for the planning of intra-airport transportation systems and techniques that have been developed for this study are described in this chapter. Using these, intra-airport transportation systems have been

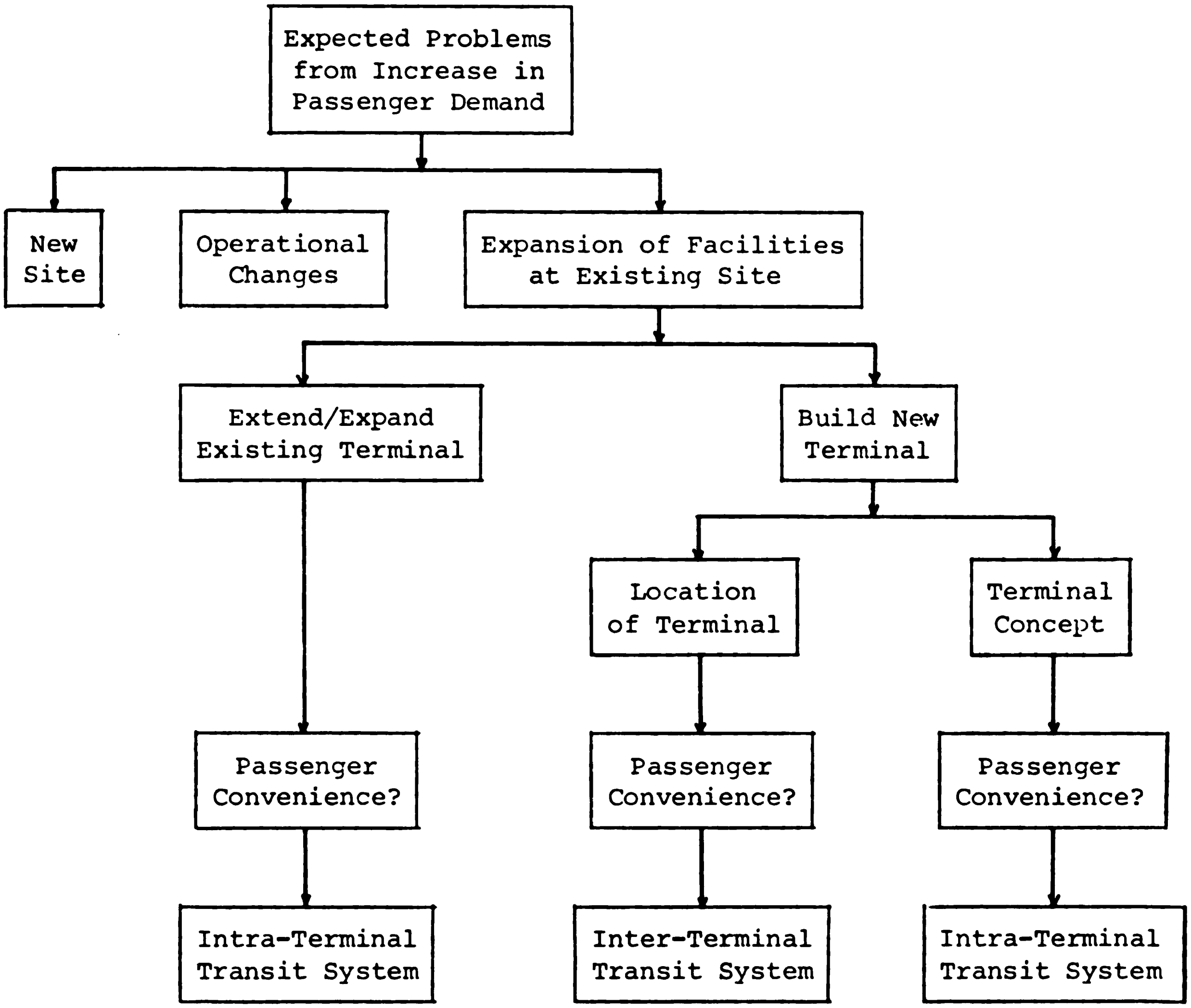


Figure 3.1 Decisions Facing Airport Terminal Planners

incorporated in "generic" terminals to develop general guidelines for the use of intra-airport systems, and to identify appropriate systems for various passenger demand levels and terminal concepts.

3.2 Planning Intra-Airport Transportation Systems

The planning of an intra-airport transportation system can be described by eight basic steps as shown in Figure 3.2.

(1) measure walking distances

(2) compare measured distances to guidelines

(3) identify potential application of intra-airport transportation system(s)

(4) develop alternatives

(5) test alternatives

(6) evaluate alternatives

(7) select preferred alternative

(8) prepare implementation plan

(1) Measure Walking Distances

An initial step in the planning of intra-airport transportation system would be to measure the walking distances for three types of air passengers. The distances that would be measured include:

(a) curb to departure gate for originating passengers

(b) arrival gate to curb for terminating passengers

(c) arrival gate to departure gate for connecting or transferring passengers

Typical routes through the terminal area can be scaled from

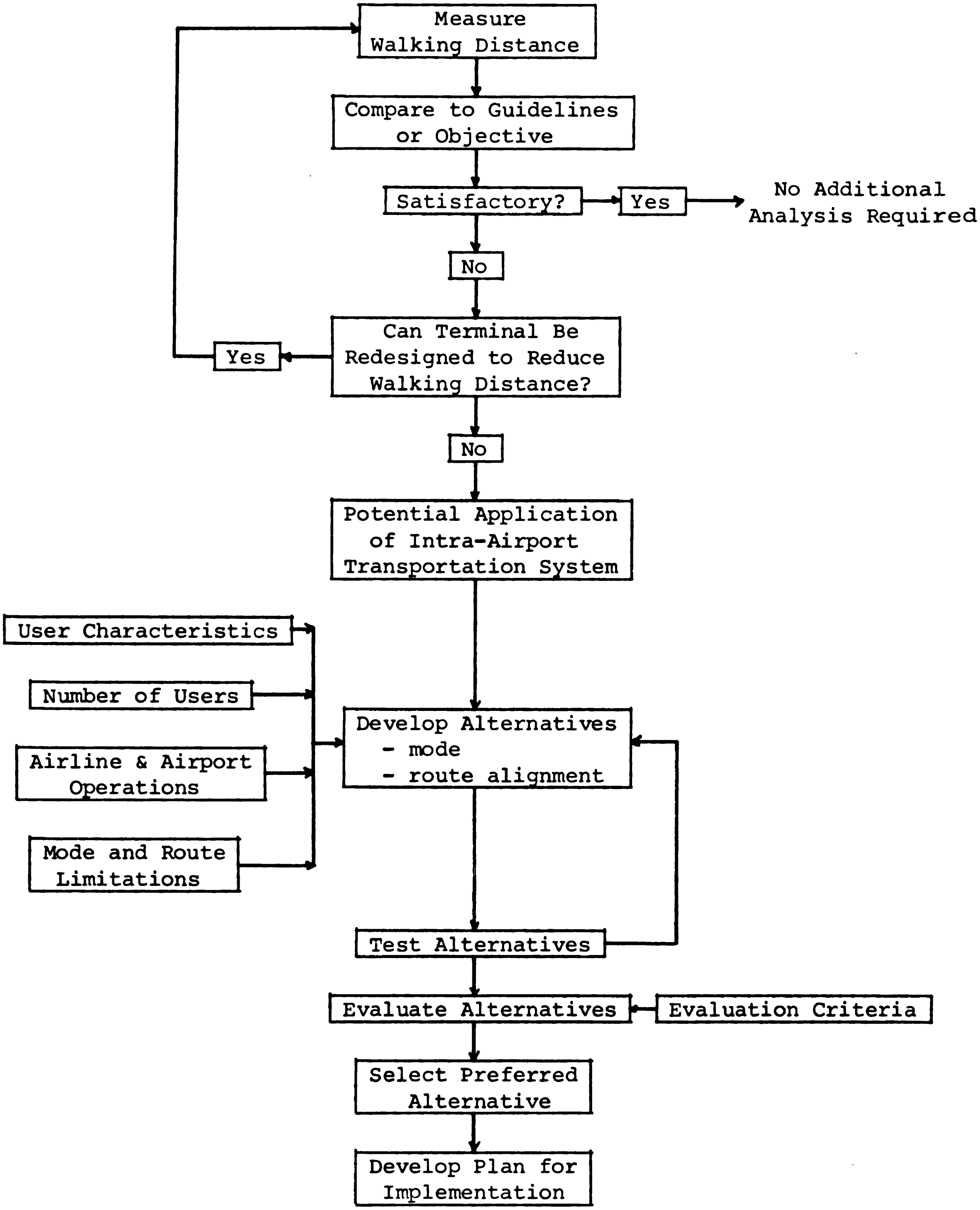


Figure 3.2 Framework for Intra-Airport Transportation System Planning

preliminary layout plans or taken from network diagrams that are prepared as input for terminal analysis models.

(2) Compare Measured Distances to Guidelines

The measured distances are then compared to an objective or guidelines identified by the airport authority. In most cases, maximum walking distances are specified. Most authorities agree that 600 to 700 feet is a reasonable design criterion for passenger walking distances within a terminal and that anything longer than 1000 feet is unacceptable (27). Specific guidelines are identified in International Civil Aviation Organization (ICAO) and International Air Transport Association (IATA) planning manuals.

"A walking distance of about 300 m (1000 feet) from the centre of the airside of the passenger building to the farthest aircraft parking position has been generally accepted as the reasonable limit."(17)

"Walking distances for the passenger should be as short as possible. In determining the distance between major functions in the terminal, the planner must consider whether baggage is to be carried or not, availability of baggage trollies, change in level, and passenger characteristics.

The suggested maximum walking distance between the major functions (i.e., car park to baggage check-in/baggage claim, and baggage check-in/baggage claim to furthest gate) is 300 metres (1000 feet).

Greater distances can be accepted provided a form of mechanical assistance is made readily available to passengers."(16)

On review of these guidelines it is realized that it becomes important to clearly specify walking distance objectives and identify whether average or maximum distances are to be used, and whether distance between major processing facilities (e.g. baggage check-in to furthest gate) or total walking distance within the terminal area is to be used. It is also not clear how the distance from car parking to the terminal should be incorporated in the analysis.

The following guideline has been used for this study:

Intra-airport transportation systems be considered when the average walking distance between curb and departure gate, arrival gate and curb, arrival gate and departure gate (connecting passengers), or between car parking and curb exceeds 1000 feet.

(3) Identify Potential Application of Intra-Airport Transportation System(s)

If the average distances fall within the specified guidelines, no additional analysis would seem necessary. However, if any distance exceeds the guidelines, a review of the terminal design should be made to determine if walking distances could be reduced. If it is not possible to reduce distances through redesign, an analysis of intra-airport transportation system alternatives would proceed.

Routes for affected passengers would then be examined to determine the distances between processing facilities and select components of the trip for which an intra-airport transportation system could be incorporated.

(4) Develop Alternatives

Three aspects are considered in the generation of intra-airport transportation system alternatives - mode, route, and service characteristics.

There are a variety of possible modes that could be used to reduce walking distances. The modes that are usually considered for each of the three categories or classes of intra-airport transportation systems would be:

intra-terminal

- moving walkways
- tow trains or carts
- automated guideway transit

inter-terminal

- moving walkways
- automated guideway transit
- buses and vans

airport circulation

- automated guideway transit
- buses and vans

Several alternative routes could be identified for each mode depending on system requirements. For example, automated guideway transit could shuttle between terminals or it could be operated on an one-way loop between terminals.

In addition, service characteristics, such as headway and operating speed, could be varied with resulting differences in level of service. Nomographs have been prepared for this purpose and their development and use are described in Section 3.3.

Among the factors that would be considered in the selection of intra-airport transportation system alternatives for analysis include:

- number of system users
- user characteristics
- airline and airport operations (e.g. location of processing facilities)
- mode limitations (e.g. passenger carrying capabilities; maximum length for moving walkways)
- route limitations (e.g. turning radii for automated guideway transit systems)

(5) Test Alternatives

It is important that the impacts of incorporating an intra-airport transportation system in the terminal complex be determined. For example, transporting passengers quickly from an arrival gate to the baggage claim area, only to have them wait for baggage to arrive may be unsatisfactory.

An Airport Landside Model (48) was developed by the Federal Aviation Administration to assist in assessing the landside facilities at an airport. It has become a valuable tool that can be used in the conceptual phase of terminal planning and its use provides the planner with the opportunity to vary parameters in the terminal and assess the impacts. With the additions and modifications that have been incorporated for this study, the model can now be used to determine the effects of an intra-airport transportation system on other passenger processing facilities in the terminal complex. The model is described in Section 3.4 and an example of its use is included in Appendix A.

Adjustments to the intra-airport transportation system alternatives, terminal layout, and number of passenger processing facilities, can be made to insure that a satisfactory level of service is provided to air passengers.

(6) Evaluate Alternatives

There are many factors that can be included in an evaluation of system alternatives. Some of the factors could be:

- cost
- convenience
- impact on other terminal activities
- environmental impact
- ease of implementation
- flexibility or potential for expansion
- reliability

The factors that are included in an evaluation vary from airport to airport as the airport authority evaluates system alternatives to best meet their needs. It is unlikely that any of the alternatives will rank highest for all factors, and it will be necessary to make tradeoffs between the alternatives and the factors. While cost is probably the most important issue facing the airport authority, many of the factors cannot be reduced to a dollar value. As a result, a multi-criteria evaluation technique would be appropriate to identify the tradeoffs between system costs and characteristics.

(7) Select Preferred Alternative

The alternative that best meets the needs of the airport can be identified.

(8) Prepare Implementation Plan

Following the selection of a preferred alternative, more detailed analysis of the alternative would be undertaken to define components of the system. Simulation models are particularly useful at this level of planning and would be used to determine optimum combinations of car (or train) size with headway, the extent to which passengers will be required to queue under peak conditions, and other similar design elements.

3.3 Development of Service Characteristics

When planning transit service, a key objective is to provide passenger carrying capabilities on the system to accommodate the demands at some specified level of service.

Moving walkways are continuous systems, so the passenger carrying capabilities are governed by operating speed, width, and an assumed passenger occupancy. A 40 inch width unit, operating at 120 feet per minute is generally recommended for airport applications as it provides sufficient width for passengers with baggage carts and hand baggage, and operates at a speed which pedestrians are comfortable in boarding and alighting (28). The design capacity for this unit, is about 7200 persons per hour (or 120 persons per minute). (40)

For bus, and automated guideway transit systems, individual vehicle capacity and frequency (i.e. number of vehicles per hour) are the basic parameters that affect the passenger carrying capabilities of the system. When preparing a transit schedule for a route, the traditional approach is to provide service to accommodate the demand at the maximum load point on the route (the point on the route where the largest demand occurs). The capacity of the route should be equal to or greater than the demand at this point.

The capacity or passenger carrying capability of a route is determined by multiplying the capacity of an individual vehicle by the number of vehicles that pass the maximum load point in one hour (frequency). The units for transit capacity are "passengers per hour per direction" (pphd). The capacity of an individual vehicle may be seating capacity or some scheduling capacity value that includes standees.

$$C_T = fC_V \tag{3.1}$$

where: C_T = capacity of a transit route, "passengers per hour per direction" (pphd)
f = frequency (vehicles/hour)
C_V = capacity of an individual vehicle, (passengers/vehicle)

To increase the capacity of a route, one increases the number of passengers that a vehicle could accommodate, or increases the frequency. For automated guideway transit systems it is also possible to increase route capacity by forming trains of two or more vehicles.

Given a passenger demand estimate at the maximum load point, the frequency of service required can be calculated for an assumed vehicle capacity.

$$f = \frac{Q}{C_V} \tag{3.2}$$

where: Q = passenger demand at the maximum load point (passengers/hour)
f = frequency (vehicles/hour)
C_V = capacity of an individual vehicle (passengers/vehicle)

Other important relationships can be developed.

Headway - the time between successive vehicles

$$h = \frac{60}{f} \tag{3.3}$$

where: h = headway (minutes)
f = frequency (vehicles/hour)

Vehicles Required for Route Service (N):

$$N = \frac{c}{h} \qquad (3.4)$$

where: c = round trip travel time or cycle time (minutes)
h = headway (minutes)

Total Vehicle Miles Travelled in an Hour (VM_T):

$$VM_T = \frac{60}{h} \times L \qquad (3.5)$$

where: L = round trip distance (miles)
h = headway (minutes)

Nomographs have been prepared (Figure 3.3 and Figure 3.4) for this study that incorporate these relationships and can be used to develop service characteristics of an intra-airport bus, or automated guideway transit system.

The input data to the nomographs includes:

(1) Passenger demand - estimate of maximum number of passengers to be accommodated at a point on the route (passengers per hour per direction).

(2) Vehicle capacity - number of passengers that an individual vehicle can accommodate (passengers/vehicle).

(3) Round trip distance - distance travelled by a vehicle to return to starting point (feet).

(4) Average speed - will depend on several factors including maximum operating speed, acceleration, station or stop spacing, dwell times at stations or stops, and interference caused by other traffic (miles per hour).

The output includes:

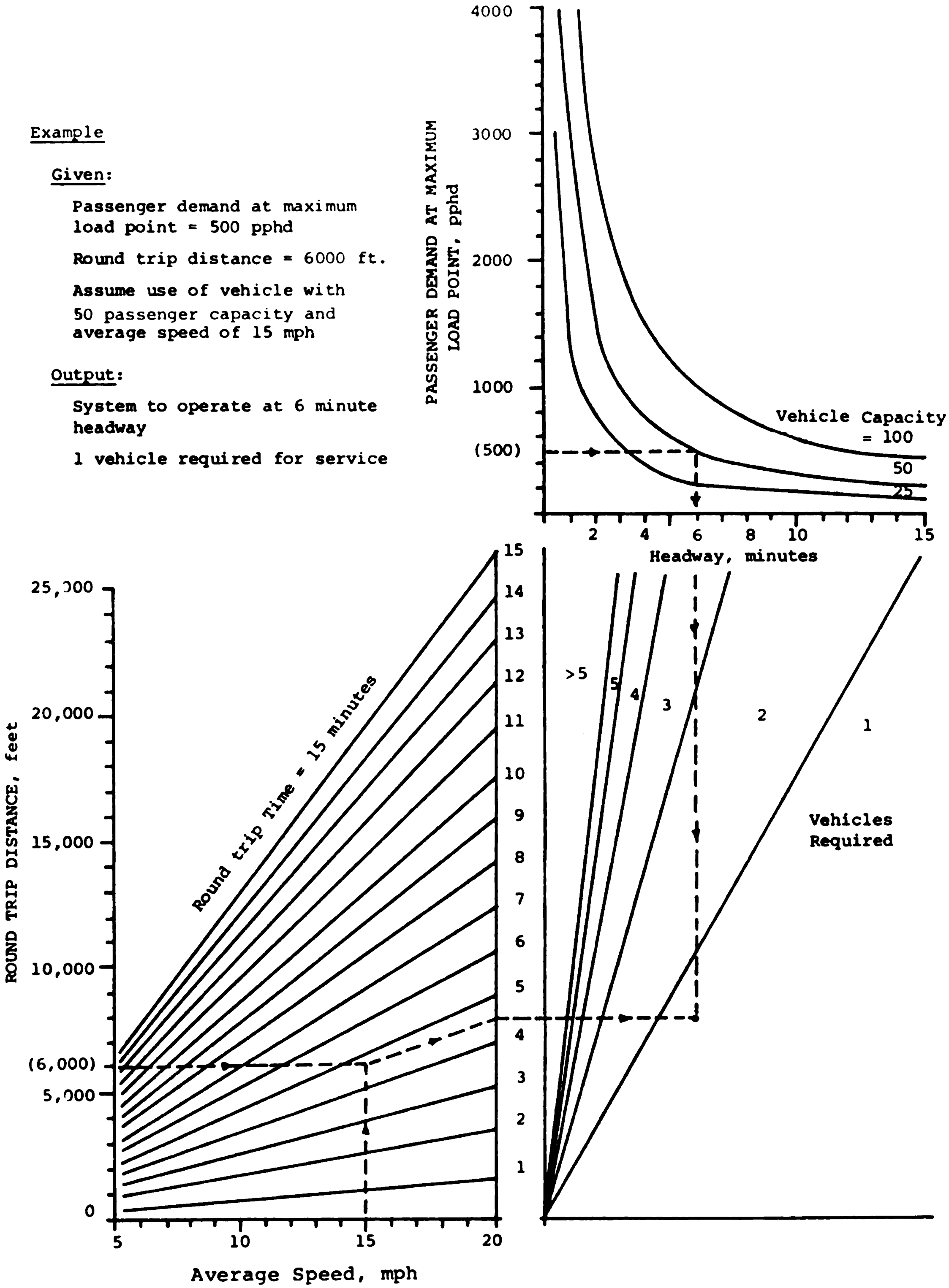


Figure 3.3 Nomograph to Develop Intra-Airport Transportation System Service Characteristics

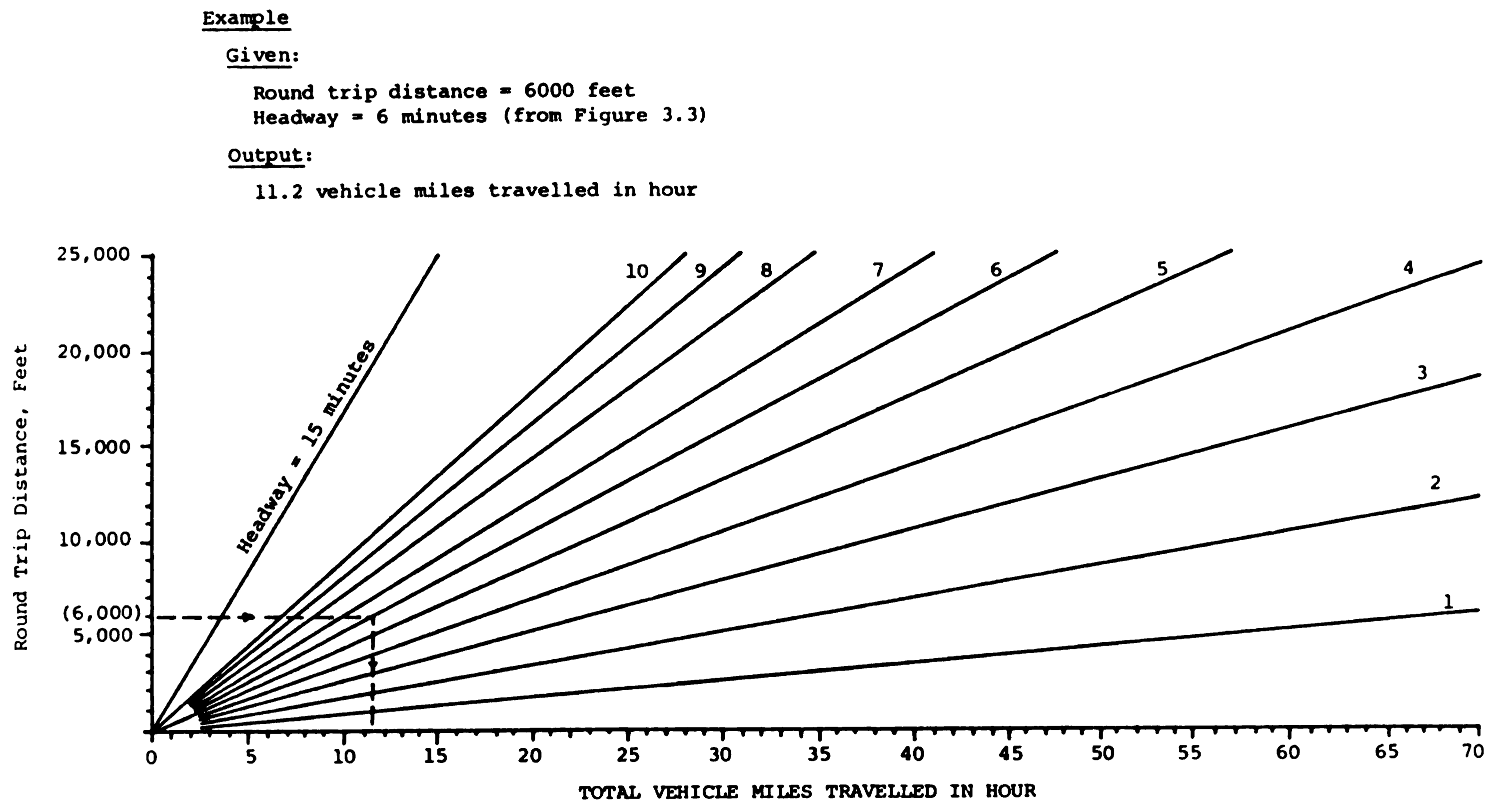


Figure 3.4 Nomograph to Estimate Vehicle Miles Travelled by an Intra-Airport Transportation System

(1) Headway - the time between successive vehicles (minutes).

An adjustment to headway derived using the nomograph may be necessary. For high demand levels, it may not be possible to operate a service at the headway indicated. For example, the minimum headway for a bus is probably about two minutes. For low demand levels, it may be preferable to set a headway to provide a minimum level of service. For example, service every 10 minutes could be specified.

(2) Vehicles required for route service - becomes input to an estimate of system capital costs.

(3) Total vehicle miles travelled in hour - becomes input to an estimate of system operating costs.

As an example, if the passenger demand is estimated as 500 passengers/hour, and vehicles with 50 passenger capacity are considered, the system would have to operate at a headway of six minutes to accommodate the demand. If the anticipated average speed is 15 mph and the round trip route length is 6000 feet, one vehicle would be required, and there would be about 11.2 vehicle miles of travel during the hour.

3.4 FAA Airport Landside Model

The FAA Airport Landside Model (49) was developed in 1978 as a tool to assist in the quantitative assessment of the airport landside. It consists of a set of computer routines which analytically model each component of the airport landside and a program and methodology for linking the routines to compute passenger delay and passenger processing time.

Two types of data are used by the model, control and network. The first type of data, control data, describe overall airport characteristics and includes the following parameters:

- annual passenger enplanements
- number of passengers processed during the peak hour (or design hour)
- number of passenger traffic peaks in a typical day
- number of aircraft operations in the peak hour (or design hour)
- aircraft fleet mix (percent wide bodies)
- percent of daily passengers processed during peak hour (or design hour)
- average load factor
- percentage of connecting passengers
- percentage of passenger arrivals by auto, taxi, bus, and rail
- average number of bags checked per passenger
- average number of passengers per vehicle using airport roads during the peak hour (or design hour)
- terminal splits
- main roadway capacity (in vehicles per hour)
- number of lanes on main roadway
- percentage of vehicles recirculating
- total number of airport parking spaces
- total airport deplaning curb frontage (feet)
- total airport enplaning curb frontage (feet)

The second type of data, network data, describe passenger flow and passenger servicing characteristics for each terminal unit. A terminal unit consists of one or more zones and a roadway area. A zone can be used to identify and model a portion of a terminal building. For example, large terminals housing several airlines can be divided into separate zones to facilitate network analysis for individual airlines. Separate enplaning and deplaning networks are specified for each zone and each terminal roadway area is modeled with an access network submodel.

The passenger flow descriptions include passenger routes used by the model to distribute arriving passengers to particular airlines and to the different processing facilities used by the airlines. These routes are specified as percentage splits in transition probability matrices. The passenger flow descriptions also include the distances (in feet) between the various facilities for each path followed by enplaning or deplaning passengers. These distances are specified in distance matrices. Service characteristics listed for each passenger processing facility include the facility type, the mean service time, the standard deviation of service time, and the number of units (e.g. number of ticket counters) in service during the peak or design hour.

The basic output is the total time spent by passengers enplaning or deplaning. The model does not account for time spent by passengers in optional activities such as visiting restrooms or newsstands, or voluntary waiting time experienced by passengers who arrive well in advance of their flight. The total time is calculated as the sum of three components:

(1) Delay time - the time spent by a passenger waiting in queues before being processed.

(2) Service time - the time it takes to service a passenger at all required processing facilities.

(3) Travel time - the time it takes a passenger to walk from facility to facility. Travel time is computed by using an average walking speed of three feet per second.

The model presents these times at various levels of aggregation - by facility, by zone, by terminal unit, and by an airport average.

The operations in the model are performed in the following steps:

- The number of passengers to be processed during the peak hour (or design hour) is input directly or computed from other input quantities.
- The total peak hour passengers are apportioned to obtain the number of enplaning or deplaning passengers during the peak hour (or design hour).
- The enplaning and deplaning passengers are allocated to particular airlines (terminal unit and zone) based on the passenger market shares of those airlines.
- For a particular airline, enplaning and deplaning

passengers are apportioned to various processing facilities according to the observed routes through a transition matrix.

- At each processing facility, service and delay times are computed according to equations that model the processing facility.
- The time spent in walking from one processing facility to the next is computed.
- Weighted per passenger averages and cumulative annual totals of service, delay, and travel times (and their sum) are computed in aggregations previously described.

The analytic models used in the landside analysis program are largely based on queueing theory which permits the estimation of delays and queue lengths for service facilities under specified levels of demand.

When the average demand rate over some period of time is less than the average service rate ("steady state" conditions), probability theory is used to generate mathematical functions to represent the arrival and service performance of the system. Specifically, it is necessary to define the arrival distribution, the service distribution, the number and use of the servers, and the service discipline. Many of the components in an airport terminal exhibit a random or Poisson arrival process and the service characteristics are usually exponential or constant. In most cases, there is more than one channel or server, and the queueing mechanism is a first-come, first-served basis.

Two types of queueing equations are used in the Landside Model to describe processing facilities within the terminal. The first type (designated as M/M/k) assumes that arrival rates are characterized by a Poisson distribution and the service rate is random and characterized as exponential or constant. System equations for this process are given by:

$$P_o = \left[\sum_{n=0}^{k-1} \frac{(\lambda/\mu)^n}{n!} + \frac{(\lambda/\mu)^k}{k!} (1-\rho)^{-1} \right]^{-1} \tag{3.6}$$

$$L_q = P_o \left(\frac{\lambda}{\mu}\right)^k \frac{\rho}{k!(1-\rho)^2} \tag{3.7}$$

$$W_q = \frac{L_q}{\lambda} \tag{3.8}$$

where: λ = arrival rate (users/minute)

μ = service rate (users/minute)

k = number of parallel servers

P_o = probability that there is no queue (n=0)

L_q = expected queue length

W_q = expected waiting time (excluding service), i.e. delay time

$$\rho = \frac{\lambda}{\mu k}$$

The second type (designated as M/G/k) assumes that arrival rates are characterized by a Poisson distribution and that the service rate is a general random variable characterized by its mean and its variance. System equations for this process are given by:

$$W_q = (\lambda^k S_2 s^{k-1})/2(k-1)!(k-\lambda s)^2 \left[\sum_{n=0}^{k-1} \frac{(\lambda s)^n}{n!} \quad \frac{(\lambda s)^k}{(k-1)!(k-\lambda s)}\right] \tag{3.9}$$

$$L_q = W_q \lambda \tag{3.10}$$

where: λ = arrival rate (users/minute)

s = average service time

S_2 = second moment of service time

k = number of parallel servers

L_q = expected queue length

W_q = expected waiting time (excluding service), i.e. delay time

M/M/k queues are appropriate in modelling situations where the service time is greatly influenced by individual passenger service requirements, whereas M/G/k queueing is considered to be more characteristic of routine service processes with well-defined endpoints. Table 3.1 presents the model type suggested for analysis that best represents the queueing conditions for the various processing facilities in a terminal.

The equations used for determining the average passenger delay assume that steady state conditions exist. However, if the arrival rate exceeds the service rate, the processing facility would never be idle. Since more passengers would arrive than could be serviced, the line

Table 3.1 Queueing Models for Terminal Processing Facilities

Processing Facility		Suggested Queueing Model
Enplaning	Passenger Curbside (Doors)	M/M/k
	Full Service Ticketing	M/M/k
	Express Baggage Check-In	M/G/k
	Security Screening	M/G/k
	Seat Selection	M/M/k
	Aircraft Boarding	M/M/k
Deplaning	Aircraft Alighting	M/M/k
	Baggage Claim*	-
	Car Rental	M/G/k
	Federal Inspection Service	M/G/k
	Passenger Curbside (Doors)	M/M/k

* Separate model developed for Baggage Claim.

would continually lengthen and the delays would grow larger. Under these conditions, the queue is said to be "saturated." Unless the arrival rate is decreased or the facility service rate is increased, the line would continue to grow indefinitely with people waiting to be processed. When saturation occurs at any particular processing point, a deterministic approximation of the additional delay has been incorporated into the model.

A separate algorithm is used to calculate delay at the baggage claim area. The model computes the difference in time it takes for passenger baggage to arrive at the claim area, and the time it takes for passengers to arrive at the claim area. If this difference is less than or equal to zero, the baggage arrives at the claim area before the passenger and no delay is experienced. Otherwise, the delay time is the time the passenger waits, starting from their arrival at the claim area, until their baggage is retrieved. A representation of the passenger delay at the baggage claim facilities is given by the relationship:

$$W_q = E[t_2] + \frac{nT}{n+1} - E[t_1] \qquad (3.11)$$

where: W_q = passenger delay

$E[t_2]$ = expected value of time when first price of baggage arrives at claim area

$E[t_1]$ = expected value of time passengers arrive at claim area

n = number of pieces of baggage to be claimed by each passenger

T = length of time from arrival of first bag until arrival of last bag at claim device

Other models simulate the activities at the three primary groundside components - parking, roadway, and curbside.

The parking model is a $M/G/\infty$ type of queueing model with the following basic assumptions about arrival and service patterns:

- Poisson arrivals of cars for parking, i.e., the number of cars arriving in time interval T will be equal to K with probability

$$P(k,T) = \frac{\lambda T^k e^{-\lambda T}}{k!} \quad k=0,1,2,3,... \tag{3.12}$$

- a general distribution for parking duration, i.e., a car parked at a given parking space for a time period s as described by a general probability distribution function

$$f_s(S_O) \text{ with } E[s] = \frac{1}{\mu} \text{ and } var(s) = \sigma_s^2$$

- an infinite number of servers (i.e., of parking spaces). It is initially assumed that the airport never runs out of car parking spaces.

For the roadways, delay is defined as the excess time required to travel a section of road. When there is no congestion the nominal travel time is

$$T_N = \frac{D}{V_o} \tag{3.13}$$

where: D = the distance traveled

V_o = the unimpeded driving speed which is assumed to be the posted speed limit

The actual average speed in traffic is similarly defined as

$$T = \frac{D}{V_r} \tag{3.14}$$

where V_r is the reduced speed due to roadway congestion. Therefore, the delay is

$$T_{delay} = T-T_N = (\frac{D}{V_r}) - (\frac{D}{V_o}) \tag{3.15}$$

The third component of the airport groundside is the vehicle curbside. The model used is basically an expansion of a M/M/k queueing model that incorporates the number of curbside lanes and the length of curb frontage in an algorithm to estimate the number of usable service (loading/unloading) slots available. The M/M/k model is used to estimate average passenger delay time.

Three changes or improvements were made to the FAA Airport Landside Model for this study to increase its capabilities. These changes permit the model to be used to examine terminal concepts on a more microscopic basis than was originally intended. The changes include:

(1) The addition of certain types of passenger

processing facilities.

(2) The development of a model for an intra-airport transportation system that could be used as a substitute for walking within a terminal or between terminals. (The FAA Airport Landside Model does not have the capabilities to include remote parking lots or hotels, so an airport circulation type of intra-airport transportation system is not included.)

(3) A technique to model the flow of connecting passengers.

(1) Additional Passenger Processing Facilities

Escalators have been added and their processing capabilities are described by queueing models similar to the other facilities in the terminal building. The mean service time, the standard deviation of service time and the number of units in service are the input variables used to describe the service characteristics.

(2) Intra-Airport Transportation System

In the original FAA Airport Landside Model, average walking speed was used to determine the passenger travel time from facility to facility. The capabilities of the model have been expanded by incorporating an intra-airport transportation system component that can be included in a network as a substitute for walking.

Three variables are used to describe the intra-airport transportation system for the model.

(a) length or distance travelled from where the passenger boards to where the passenger alights. The length is expressed in feet.

(b) average speed expressed in feet per second.

(c) headway expressed in seconds. For continuous systems, such as moving walkways, the headway would be zero.

The basic output of the FAA Airport Landside Model is the total time spent by passengers enplaning or deplaning. The total time is calculated as the sum of three components - delay time, service time, and travel time. When the intra-airport transportation system is used, the delay time for this facility is equal to one half of the headway - an approach commonly used to estimate average waiting time for an urban transit system. Service time is assumed to be zero, and travel time is calculated by dividing the distance travelled by the average speed. Time for passenger boarding and alighting and station dwell time have not been specifically included, although an adjustment to the average speed could be made to reflect these times.

(3) Connecting Passengers

As originally written, the FAA Airport Landside Model subtracted connecting passengers at the deplaning gate or added them at the enplaning gate and did not follow their path through the terminal. Changes have been made to the model to identify the impact of connecting passengers on terminal facilities and estimate the total time spent by passengers connecting between gates. Additional input data is necessary to accomplish these tasks, and includes:

- A matrix to identify the origins and destinations of connecting passengers
- Identification of processors or facilities that connecting passengers use
- Networks that describe flow and servicing characteristics for connecting passengers

As an example, if the airport consists of one terminal building (and one zone), the network data would be input in the following order:

Deplaning Network Data

Enplaning Network Data

Roadway Network Data

However, if the airport consists of two terminal buildings that are served by one roadway system, the network data would be input as follows:

Deplaning Network Data, Terminal 1

Enplaning Network Data, Terminal 1

Connecting Network Data, Terminal 1 to Terminal 2

Deplaning Network Data, Terminal 2

Enplaning Network Data, Terminal 2

Connecting Network Data, Terminal 2 to Terminal 1

Roadway Network Data

By including separate networks for connecting passengers, the impacts of incorporating alternative intra-airport transportation systems for the movement of passengers between terminals can be examined. The model output includes total time information for connecting passengers in addition to the total time information produced for enplaning and deplaning passengers.

The revised FAA Airport Landside Model program and a sample showing the development of networks, input data, and resulting output are presented in Appendix A.

CHAPTER 4

APPLICATION OF METHODOLOGY

4.1 Procedure

One of the objectives of this study is to identify appropriate intra-airport transportation systems for various passenger demand levels and terminal concepts. Using the methodology described in Chapter 3, intra-airport transportation systems have been incorporated in "generic" air terminals and then evaluated to determine the appropriate system. A framework for this phase of the study is shown in Figure 4.1.

4.2 Generation of Terminals for Study

4.2.1 Terminal Concepts

Early air terminals in the major cities and the terminals in many small cities today are simple terminals that consist of a common waiting and ticketing area with one or two gates. Typically one or two airlines serve the airport and the aircraft are parked on the apron in front of the terminal and passengers walk across the apron to board and alight.

However, as the volume of air passengers increases, this simple terminal concept does not have sufficient capacity, so other concepts have evolved. There are four basic concepts, as shown in Figure 4.2, and many variations

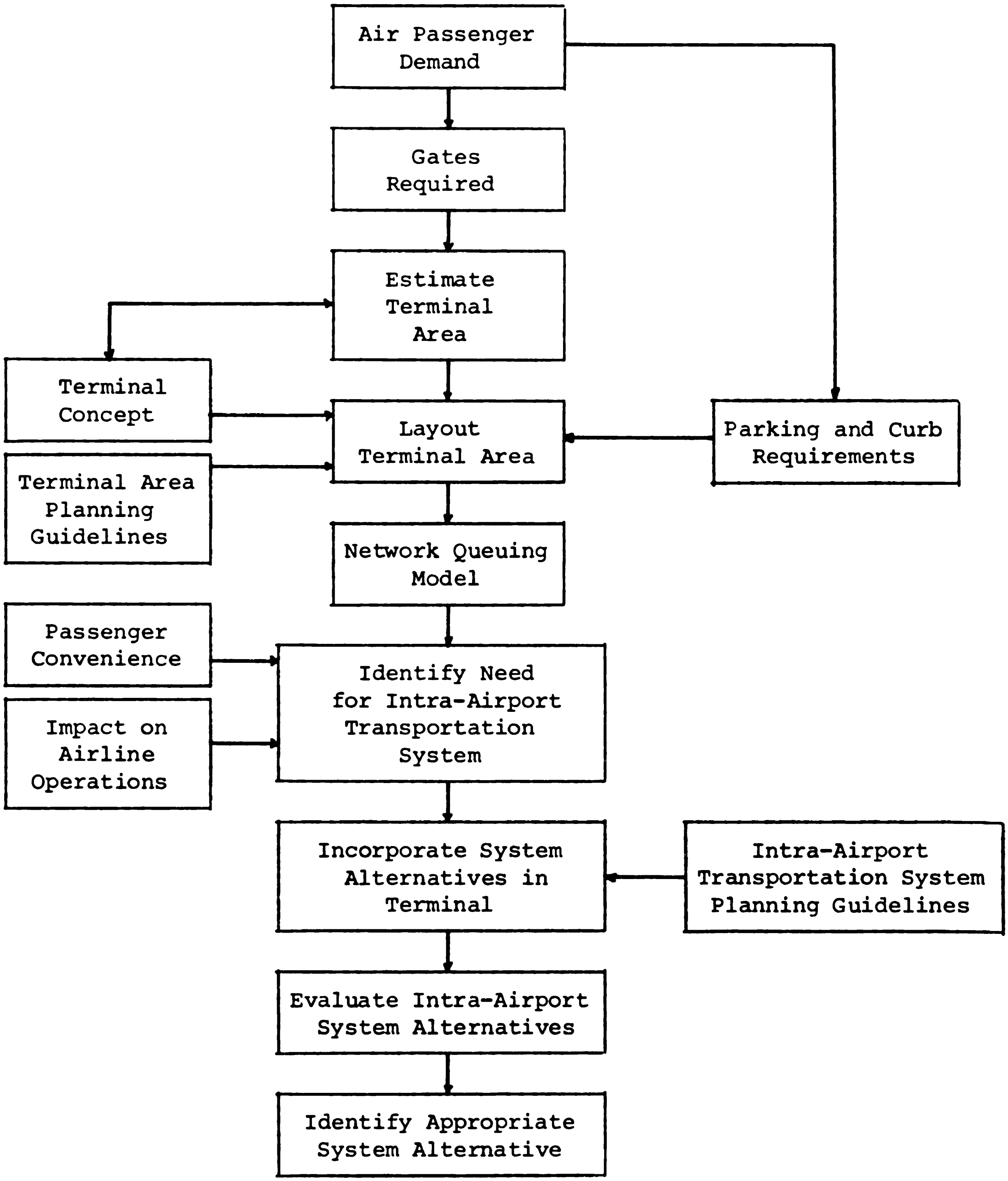
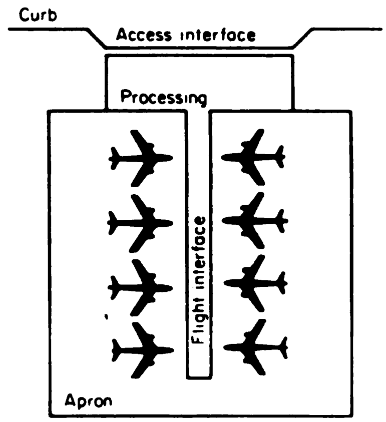
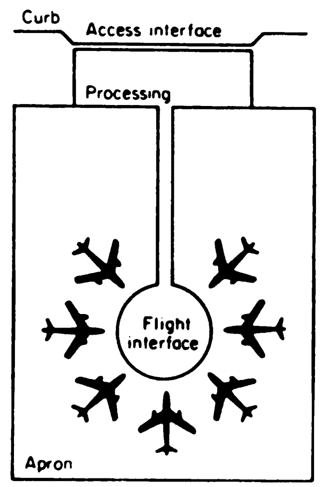


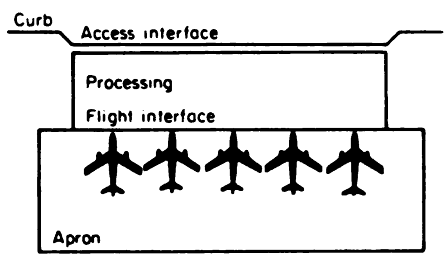
Figure 4.1 Methodology to Determine Appropriate Intra-Airport Transportation System



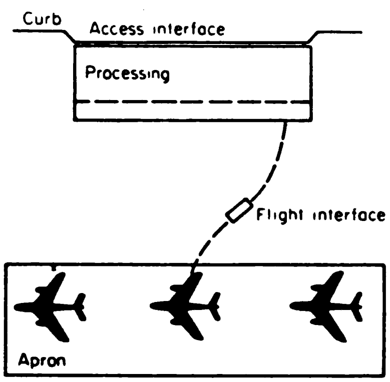
(1) Pier or Finger



(2) Satellite



(3) Linear



(4) Transporter

Figure 4.2 Basic Terminal Concepts

Source: <u>Planning and Design of Airports</u>, Third Edition, Robert Horonjeff and Francis X. McKelvey, 1983.

of these basic concepts.

(1) Pier or Finger Concept

The pier or finger concept evolved in the 1950's when gate concourses were added to simple terminal buildings. Aircraft are parked on either side of a pier or finger which is directly connected to a central terminal where the primary area for passenger and baggage processing is located. Chicago O'Hare and San Francisco airports are examples of this terminal concept.

The concept has often resulted in longer walking distances for passengers and moving walkways have been used in some instances to reduce the distances.

Although the pier concept has afforded an economical means of adding gate positions to existing terminals, its use for expansion is limited. Extension of a pier may be restricted by taxiway clearance requirements and the addition of gates would necessitate the expansion of passenger processing facilities in the central terminal area. Most successful additions have been made by extending the main terminal and then increasing the number of piers.

(2) Satellite Concept

The satellite concept consists of a single central terminal, in which the passenger and baggage processing is located, and one or more satellite structures. Aircraft are parked around the satellite building and these satellites are connected to the main terminal by a surface, underground, or elevated passageway. Examples of this concept are Houston, Orlando, and Tampa airports.

The distance from the main terminal to a satellite is usually well above the average distance to gates found with the pier concept, so inter-terminal transportation systems have been installed at several airports to reduce walking distances.

Terminals developed under the satellite concept are difficult to expand without disrupting airport operations. As a result, increases in terminal capacity are usually made by adding terminal units (i.e. an additional central terminal with satellite(s)).

(3) Linear Concept

The linear terminal concept is an extension of the simple terminal in that the simple terminal is repeated to provide additional apron frontage, additional gates, and more room within the terminal for passenger processing. The concept is sometimes referred to as the "gate arrival" concept and has been used at the Dallas-Fort Worth and Kansas City airports.

The passenger walking distance from the curb to gate is usually short and the linear configuration lends itself to close-in public parking. However, the walking distances for connecting passengers may be quite long.

The concept does not lend itself to common or central facilities such as waiting rooms, baggage check-in areas, or concessions, and as a result, these facilities are duplicated in the terminal.

Linear terminals can be expanded by extending the existing structure and this can be done with almost no interference to passenger processing or aircraft operations.

(4) Transporter Concept

Aircraft are parked on the apron some distance from the main terminal where the passenger and baggage processing takes place. Passengers are transferred between the terminal and aircraft by specially designed buses or mobile lounges. Washington Dulles and Montreal Mirabel airports are the only two airports that have been developed using this concept, although the concept has been used at other airports to supplement facilities during peak demand conditions.

Walking distances are held to a minimum since the passenger processing facilities are located in a relatively compact terminal building. However, when comparing this concept with the others, the purchase, operation and maintenance of the mobile lounges must be considered and the time required to transfer passengers between the terminal and the aircraft should also be taken into account.

The transporter concept can be expanded with little impedance to airport operations by acquiring additional mobile lounges and expanding the main terminal and apron area.

The selection of an appropriate concept is a function of a number of factors, including the size and characteristics of the passenger demand, the level of service to be offered, the number of airlines to be served, the traffic split between domestic, international, scheduled and charter flights, the available physical site, and ground access modes. A 1973 study (32) offered some guidance to the planner for the initial identification of concepts and Figure 4.3 summarizes these guidelines. Applicable concepts and physical aspects of the terminal are related to the level of annual enplaned passengers and the functional nature of the airport, as defined by the relative proportions of originating, terminating, and transferring passengers.*

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* There are several ways in which air passengers can be defined and each value is important in the planning and design of the terminal area.

  enplaned or enplaning passenger - a passenger who boards an aircraft at the airport.
  deplaned or deplaning passenger - a passenger who alights from an aircraft at the airport.
  transferring or connecting passenger - a passenger who transfers from one flight to another flight at the airport. An "interline transfer" is a transfer between airlines. An "intraline transfer" is a transfer beteween flights of the same airline.
  originating passenger - a passenger who starts their trip in the area served by the airport.
  terminating passenger - a passenger who ends their trip in the area served by the airport.

  originating passengers = enplaning passengers - connecting passengers.
  terminating passengers = deplaning passengers - connecting passengers.

	CONCEPTS APPLICABLE	LINEAR	PIER	SATELLITE	TRANSPORTER	PHYSICAL ASPECTS OF CONCEPTS	SINGLE LEVEL CURB	MULTI LEVEL CURB	SINGLE LEVEL TERMINAL	MULTI LEVEL TERMINAL	SINGLE LEVEL CONNECTOR	MULTI LEVEL CONNECTOR	APRON LEVEL BOARDING	AIRCRAFT LEVEL BOARDING
AIRPORT SIZE BY ENPLANED PAX/YEAR														
FEEDER UNDER 25,000		X					X		X				X	
SECONDARY 25,000 TO 75,000		X					X		X				X	
75,000 TO 200,000		X					X		X		X		X	
200,000 TO 500,000		X	X				X		X		X		X	
PRIMARY OVER 75% PAX O/D 500,000 TO 1,000,000		X	X	X			X		X		X	X	X	X
OVER 25% PAX TRANSFER 500,000 TO 1,000,000		X	X	X			X		X		X	X	X	X
OVER 75% PAX O/D 1,000,000 TO 3,000,000			X	X	X		X	X		X	X	X	X	X
OVER 25% PAX TRANSFER 1,000,000 TO 3,000,000			X	X			X	X		X	X	X	X	X
OVER 75% PAX O/D OVER 3,000,000			X	X	X		X	X		X	X	X	X	X
OVER 25% PAX TRANSFER OVER 3,000,000			X	X			X	X		X	X	X		X

Figure 4.3 Applicable Terminal Concepts Related to Air Passenger Demand Levels

Source: <u>The Apron-Terminal Complex, Analysis of Concepts for Evaluation of Terminal Buildings</u>. Ralph M. Parsons Company, 1973.

Combinations of concepts and variations are quite common and are the result of changing conditions experienced at an airport. An airport may have many types of passenger activity, varying from originating and terminating passengers using the full range of terminal services to passengers using limited services on connecting flights. Each may require a different concept. Changes in the function of the airport or the airlines serving the airport may necessitate modification or expansion of the facilities. Growth in aircraft size or a new combination of aircraft types serving the airport may affect the concept. In addition, physical limitations of the site may also cause a pure conceptual form to be modified by additions or combinations of other concepts. The combined concepts acquire both the advantages and disadvantages of each basic concept.

One common variation is the <u>Unit Terminal</u> concept. It consists of two or more terminals built around a system of interconnecting access roads. The terminals are usually spaced some distance apart and each terminal provides complete passenger processing facilities for one or more airlines. Each terminal unit may be of the same basic concept or quite different. For example, the unit terminals at the Dallas-Fort Worth and Kansas City airports are linear terminals; the unit terminals at the Houston airport are satellite terminals whereas the unit terminals at John F. Kennedy airport in New York vary as the airlines have developed to best handle their individual requirements.

Walking distances in a unit terminal are usually held to a comfortable distance since the terminals are usually smaller than large multi-airline terminals. However, for passengers transferring between units or terminals, an inter-terminal transportation system is usually required. Buses have commonly been used for this purpose.

4.2.2 Terminal Modules

Terminals have been developed for each of the four basic concept types using modules. Each module contains eight gates and the facilities necessary to serve the related passengers. As the demand increases, additional modules are added. By constructing terminals in this fashion guidelines for intra-airport transportation systems can be identified on the basis of air passenger demand levels and terminal concepts. If existing airports were used, other factors would make it difficult to isolate guidelines. A similar approach of using modules was used in a 1973 study (32) to identify applicable terminal concepts related to air passenger demand levels.

An initial estimate was made that an eight gate module could accommodate one million annual enplaned passengers and this was later verified following further development and analysis of the modules. Estimates of hourly passenger demand and aircraft activity were also made prior to computing terminal area requirements.

Using graphs and rules-of-thumb developed by the FAA (31,51), estimates have been made for individual components in the terminal area. The estimates have been made for six levels of transferring or connecting passengers - 0, 10, 20, 30, 40 and 50% of enplaned passengers. As the percent of connecting passengers increases, requirements for ticketing/check-in facilities, baggage claim facilities, and parking are reduced. A sample of the development of an estimate is presented in Appendix B, and Table 4.1 summarizes the terminal area requirements for an eight gate module.

The next step was a preliminary layout of modules in sufficient detail to locate activities so that walking distances could be approximated and the impact of passenger circulation in the module could be assessed.

For the layout of the eight gate modules the following assumptions were made:

- single level terminal
- single level curb
- all gate positions designed to accommodate the Boeing 767 aircraft
- power in/push out aircraft operations at gates
- surface parking for automobiles
- typical arrangement of passenger processing facilities.

In addition, factors considered in the layout included:

Table 4.1 Area Requirements* for an <u>Eight</u> Gate Module (Square Feet of Floor Area)

	Connecting or Transferring Passengers					
	0%	10%	20%	30%	40%	50%
Airline Counters	2,000	2,000	2,000	1,500	1,500	1,500
ATO/Support Space	4,500	4,500	4,500	4,000	4,000	4,000
Outbound Baggage	8,000	8,000	7,000	7,000	6,000	6,000
Baggage Claim	17,500	15,600	13,600	11,000	9,000	7,000
Airline Operations	8,000	8,000	8,000	8,000	8,000	8,000
Departure Lounges**	12,800	12,800	12,800	12,800	12,800	12,800
Other Airline Space	1,000	1,000	1,000	1,000	1,000	1,000
Lobby-Ticketing	8,000	8,000	7,000	7,000	6,000	6,000
Lobby-Waiting	7,000	7,000	6,000	6,000	5,000	5,000
Baggage Claim Lobby	9,000	9,000	6,750	6,750	4,500	4,500
Food and Beverage	9,000	9,000	10,000	10,000	11,000	11,000
Other Concessions	12,000	12,000	12,000	12,000	12,000	12,000
Other Rental Space	2,000	2,000	2,000	2,000	2,000	2,000
Other Circulation	15,000	15,000	15,000	15,000	15,000	15,000
	115,800	113,900	107,650	104,050	97,800	95,800
Mechanical Systems	13,900	13,700	12,900	12,500	11,700	11,500
	129,700	127,600	120,550	116,550	109,500	107,300
Building Structure	6,500	6,400	6,000	5,800	5,500	5,400
Total (square feet)	136,200	134,000	126,550	122,350	115,000	112,700
Parking Spaces	1,800	1,650	1,500	1,350	1,175	1,000

* Area requirements for <u>one</u> million annual enplaned passengers.

** Not included in Transporter concept.

- walking distances
- FAA guidelines for separation criteria between parked aircraft, and between moving aircraft and the terminal
- curb length requirements
- the combination with other modules.

The FAA Airport Landside Model was then used to check the preliminary module layouts to verify that they could accommodate the passenger demands placed on them. As design criteria, processing time limits were specified and the facilities were adjusted until the criteria were met. For enplaning passengers, the average processing time is not to exceed twenty minutes, and for deplaning passengers, the average processing time is not to exceed thirty minutes. Figures 4.4, 4.5, 4.6 and 4.7 show the modules for pier, satellite, linear and transporter concepts that have been used for further analysis in this study. Each module has been developed to accommodate one million annual enplaned passengers within the processing time design criteria.

The eight gate module is a single level terminal, so a sixteen gate module with two levels was also developed for the pier and satellite concepts to examine the use of a more concentrated arrangement and the effect on intra-airport transportation system requirements and planning. The same procedures that were used to develop the eight gate modules were followed for the sixteen gate

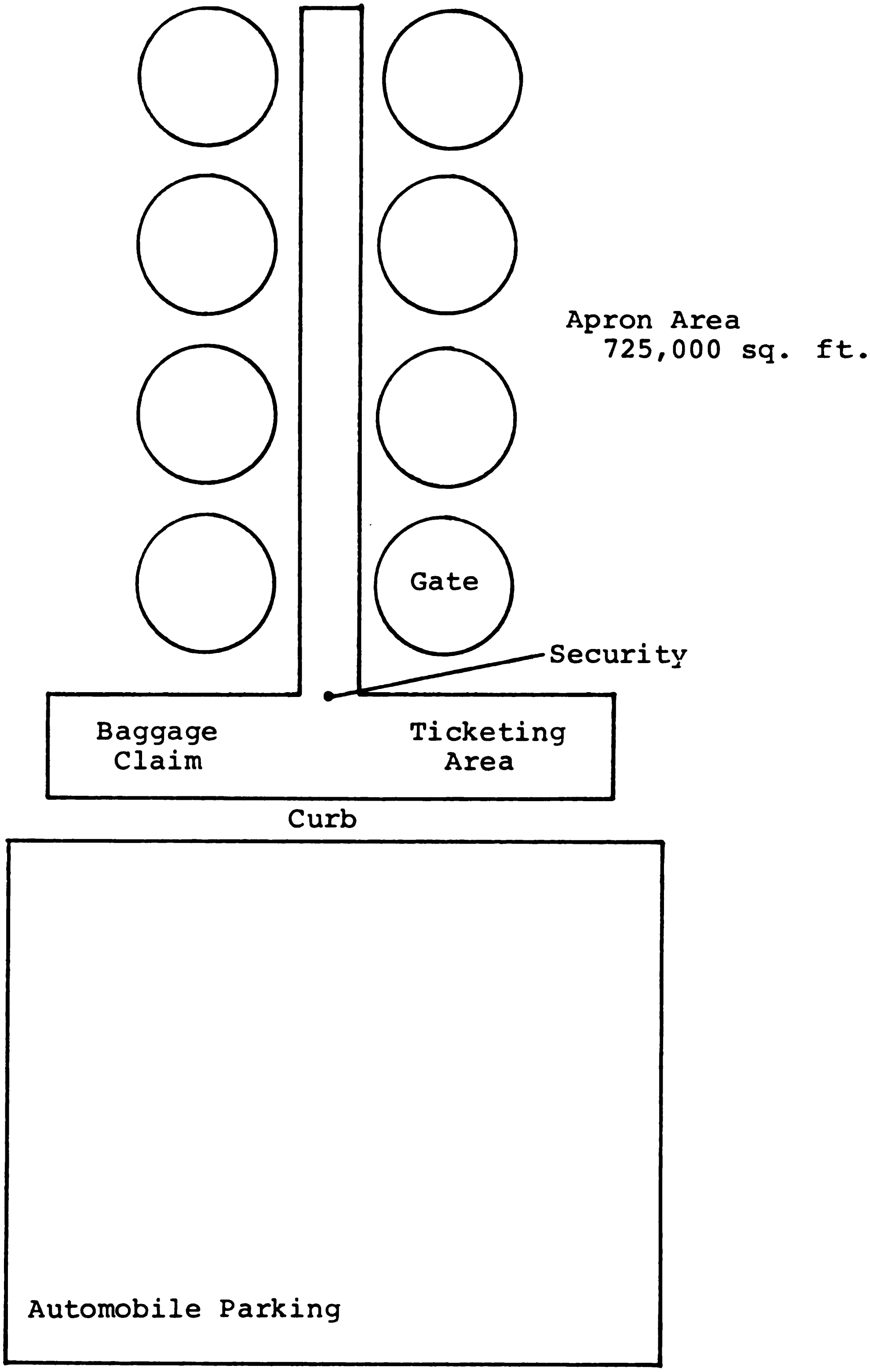
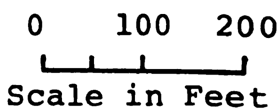


Figure 4.4 Terminal Module, Pier Concept



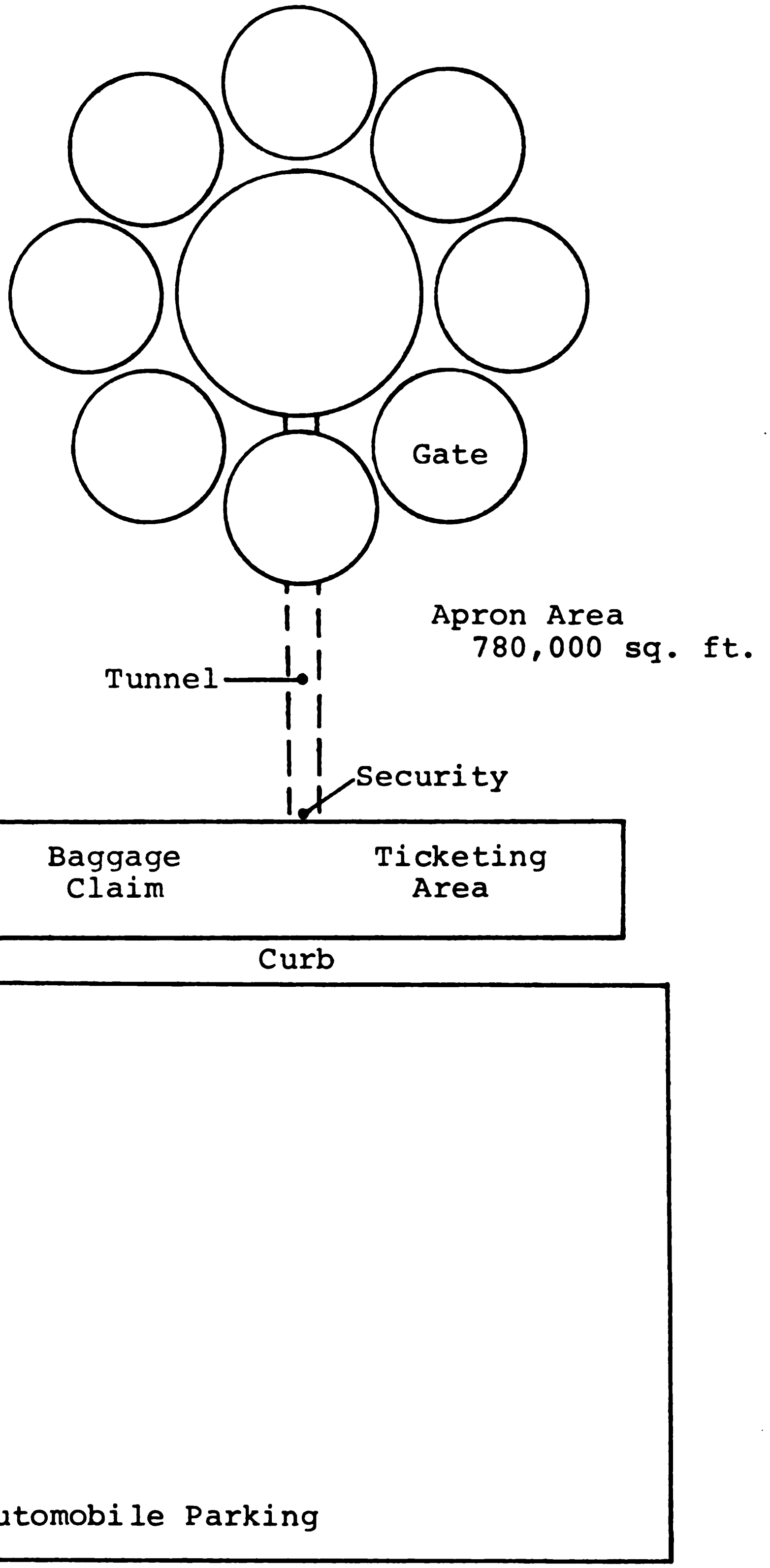


Figure 4.5 Terminal Module, Satellite Concept

0 100 200
Scale in Feet

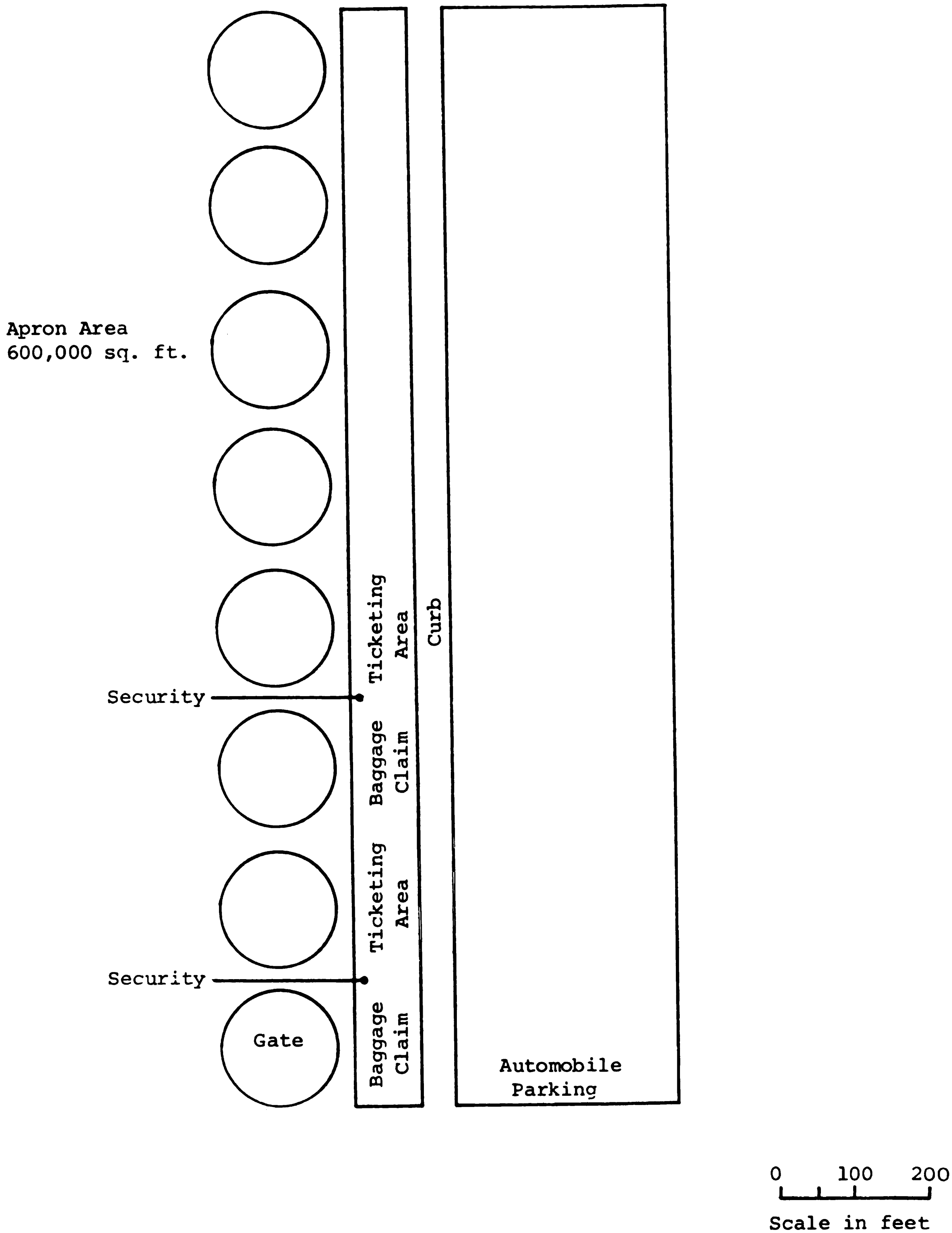


Figure 4.6 Terminal Module, Linear Concept

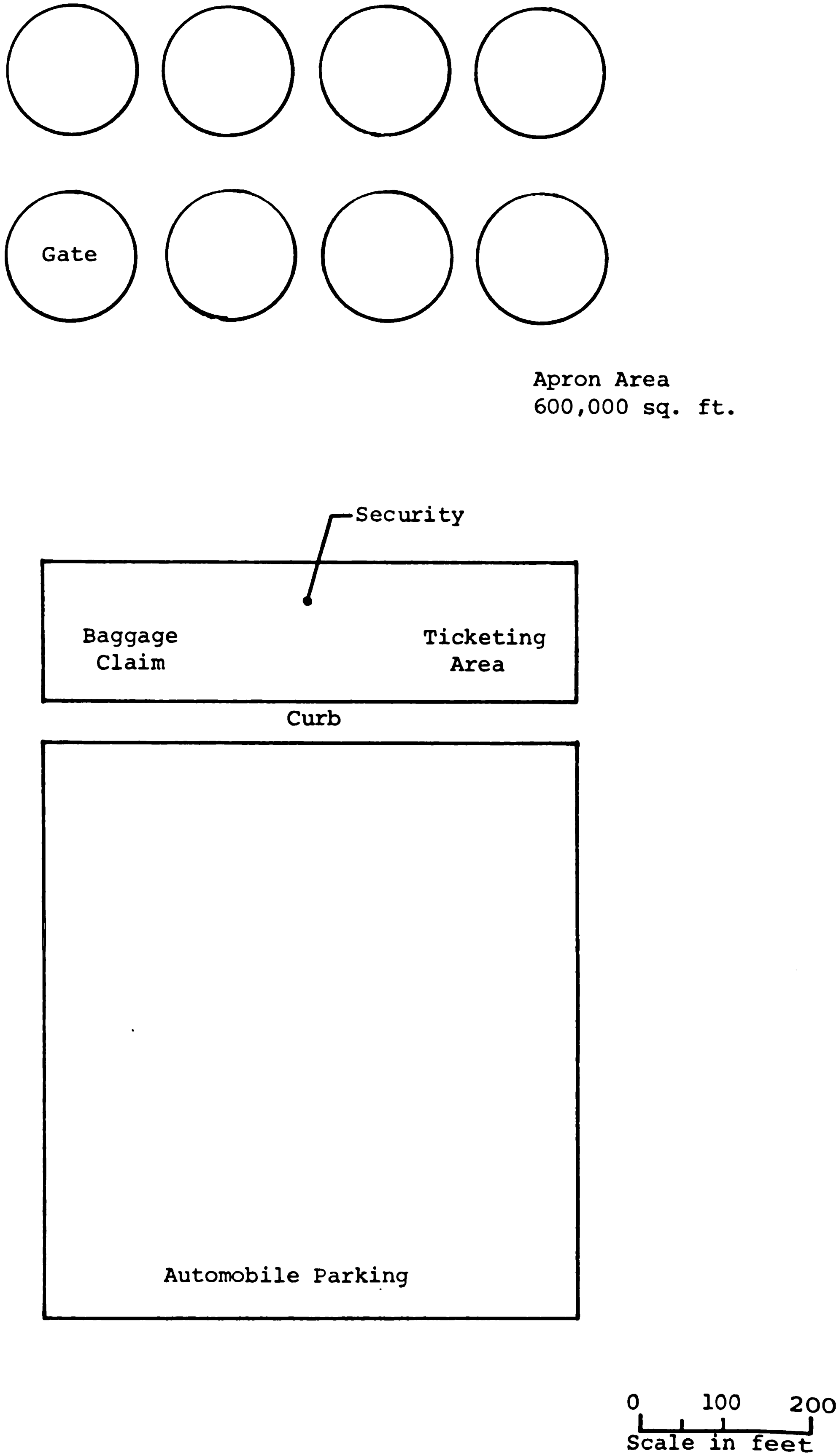


Figure 4.7 Terminal Module, Transporter Concept

modules. Table 4.2 summarizes the terminal area requirements. For the layout of the sixteen gate modules, the following assumptions were made:

- two level terminal
- two level curb
- two level parking garage for automobiles

Other assumptions were the same as for the eight gate modules and the factors considered in the layout were identical. Figures 4.8 and 4.9 show the resulting modules, and each has been prepared to accommodate two million annual enplaned passengers within the processing time design criteria.

4.2.3 Terminal Module Combinations

Modules have been combined in two basic arrangements to form terminal units. Placing modules side-by-side has been designated as arrangement or configuration "A." Configuration "B" describes the terminal unit in which modules have been located on opposite sides of the parking lot.

When modules have been placed side-by-side, the distance between modules is governed by the separation criteria for airfield operations. Linear and transporter modules are placed adjacent to each other, whereas the distance between the taxilane and gate positions, and the size of gate positions has been used to control the distance between the pier and satellite modules. When modules have been placed on opposite sides of the parking

Table 4.2 Area Requirements* for a Sixteen Gate Module (Square Feet of Floor Area)

	Connecting or Transferring Passengers					
	0%	10%	20%	30%	40%	50%
Airline Counters	3,200	3,200	3,200	2,500	2,500	2,500
ATO/Support Space	7,000	7,000	7,000	5,500	5,500	5,500
Outbound Baggage	18,000	16,000	16,000	14,000	12,000	12,000
Baggage Claim	25,500	23,500	21,000	19,200	17,300	15,500
Airline Operations	16,000	16,000	16,000	16,000	16,000	16,000
Departure Lounges	25,600	25,600	25,600	25,600	25,600	25,600
Other Airline Space	2,000	2,000	2,000	2,000	2,000	2,000
Lobby-Ticketing	21,100	21,100	17,800	17,800	14,500	14,500
Lobby-Waiting	14,000	14,000	12,000	12,000	10,000	10,000
Baggage Claim Lobby	13,500	13,500	11,250	11,250	9,000	9,000
Food and Beverage	13,500	13,500	15,000	15,000	16,500	16,500
Other Concessions	24,000	24,000	24,000	24,000	24,000	24,000
Other Rental Space	4,000	4,000	4,000	4,000	4,000	4,000
Other Circulation	30,000	30,000	30,000	30,000	30,000	30,000
	217,400	213,400	204,850	198,850	188,900	187,100
Mechanical Systems	26,090	25,610	24,580	23,860	22,670	22,450
	243,490	239,010	229,439	222,710	211,570	209,550
Building Structure	12,170	11,950	11,470	11,140	10,580	10,480
Total (square feet)	255,660	250,960	240,900	233,850	222,150	220,030
Parking Spaces	2,800	2,650	2,500	2,300	2,050	1,800

* Area requirements for two million annual enplaned passengers.

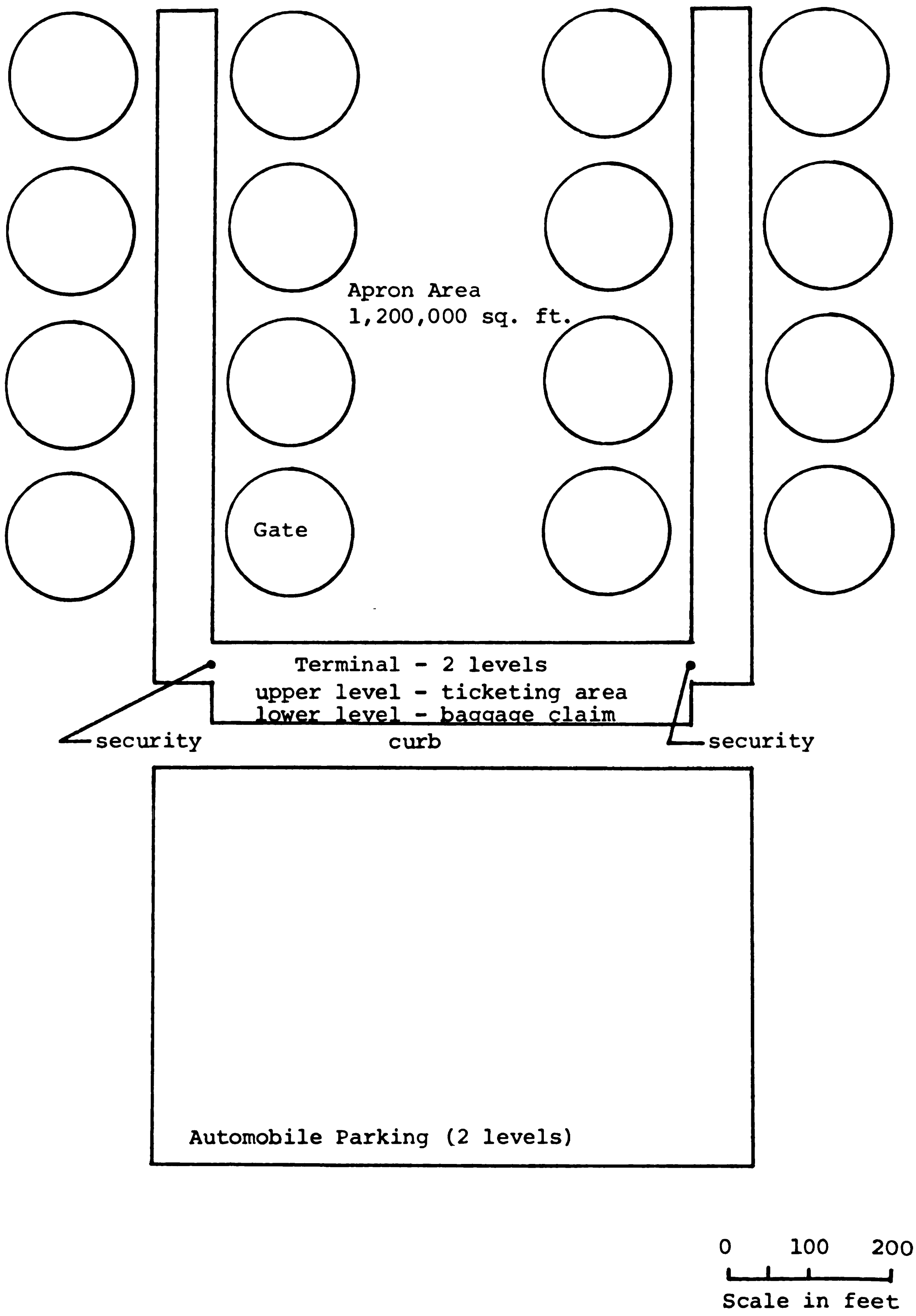


Figure 4.8 Terminal Module, Pier Concept, 16 Gates

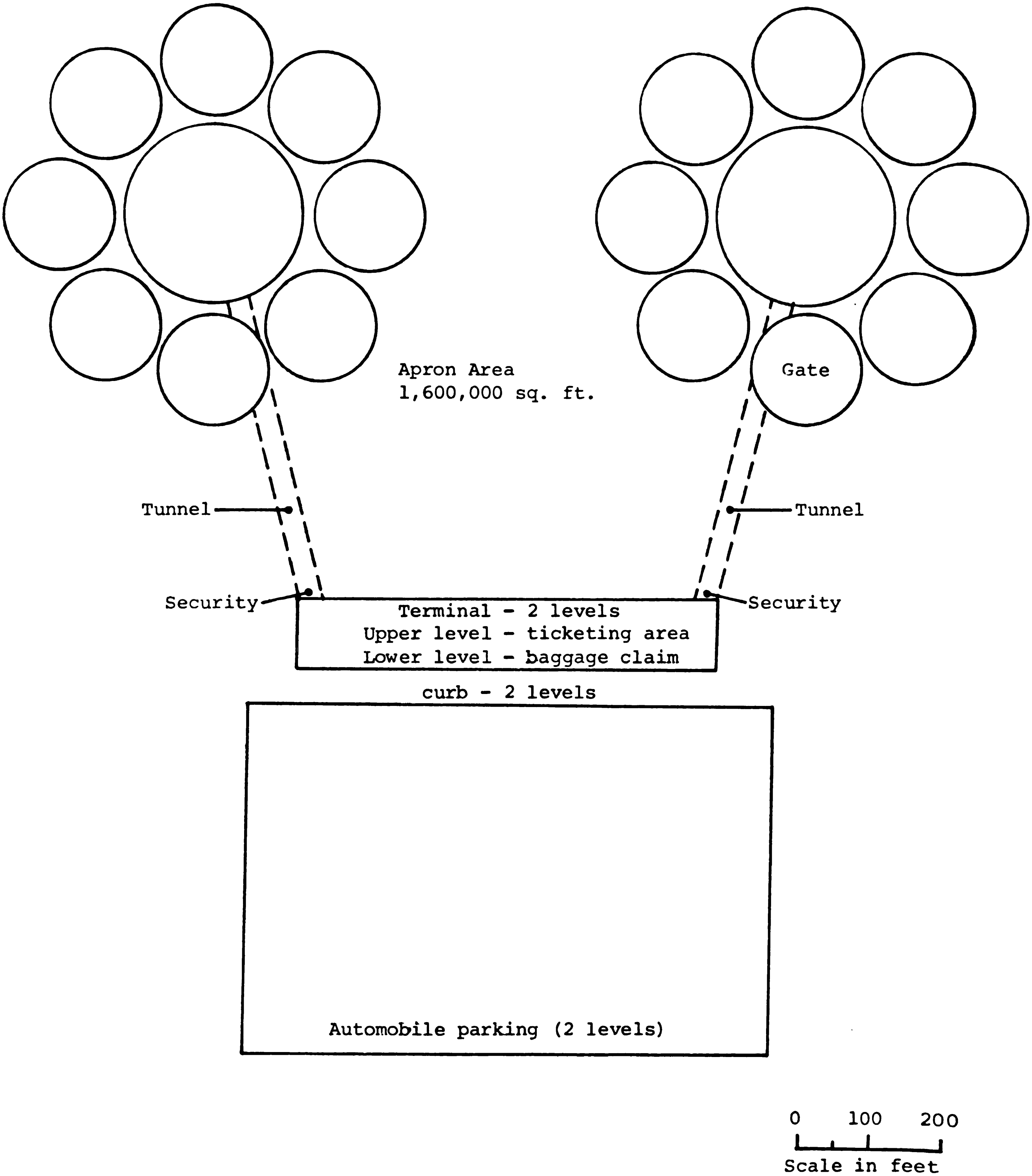


Figure 4.9 Terminal Module, Satellite Concept, 16 Gates

lot, the parking has been placed in a structure to maintain a compactness in the terminal unit. Combinations of up to four modules have been developed for this study and are presented in Figures 4.10 to 4.15. In addition, the number of lanes on the terminal access roads and curbfront are identified for each terminal unit as shown in these figures.

The selection of the appropriate arrangement or configuration of terminals at an airport will be governed by many factors, among which include:

- number of runways and orientation
- ground access system
- curb requirements
- airline operations
- number of connecting or transferring passengers
- site restrictions and limitations

An evaluation of the most appropriate combination of terminals for a specific case is beyond the scope of this study. The terminal units have been developed to assist in identifying guidelines for intra-airport transportation systems and provide terminal alternatives to accommodate a range in air passenger demands as shown in Table 4.3.

4.2.4 Terminal Cost Estimate

One aspect of cost that this study has examined is the percentage increase in the cost of the terminal area by incorporating an intra-airport transportation system. Unit costs have been developed from various sources to estimate

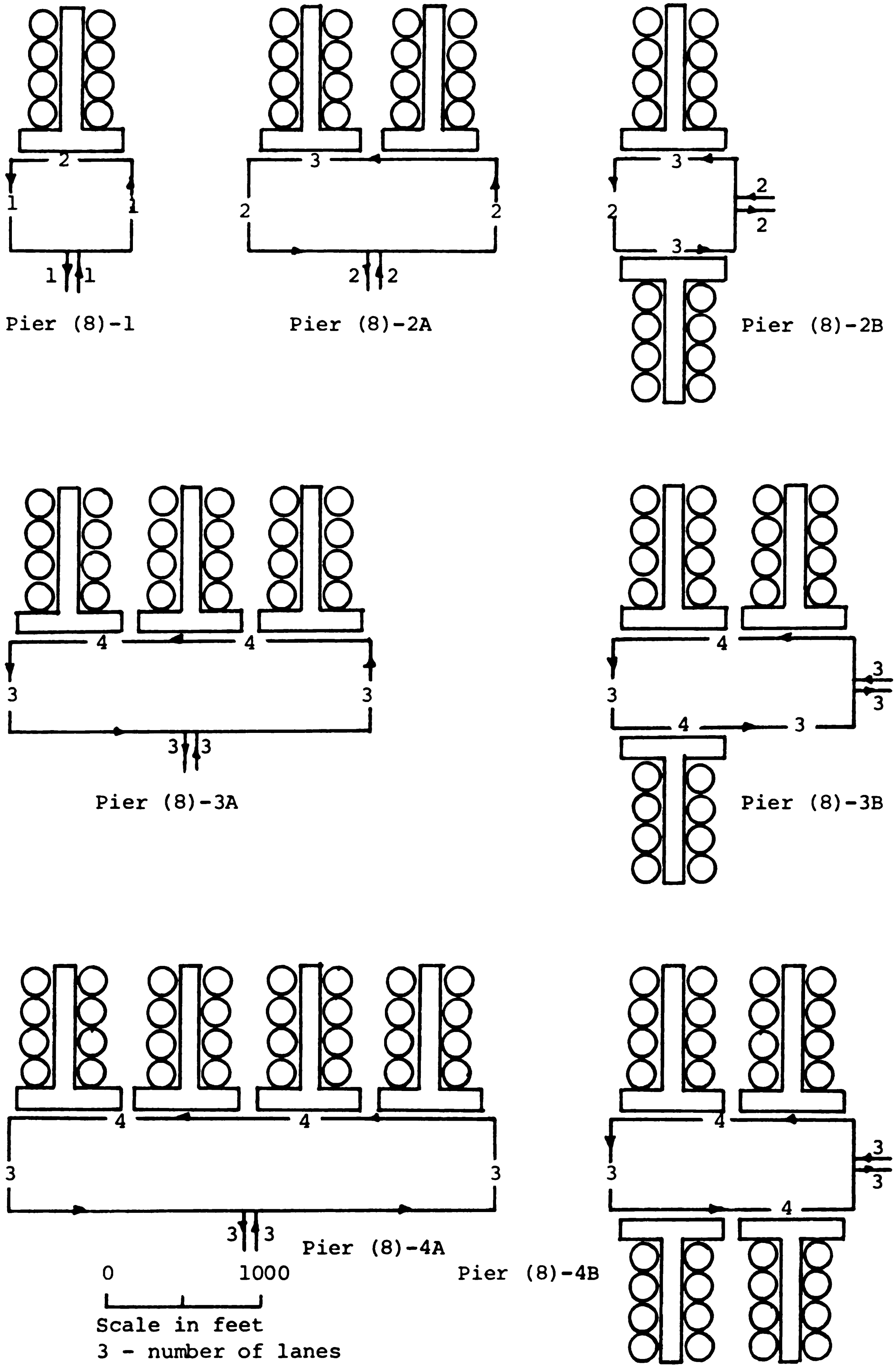


Figure 4.10 Combinations of Pier Modules

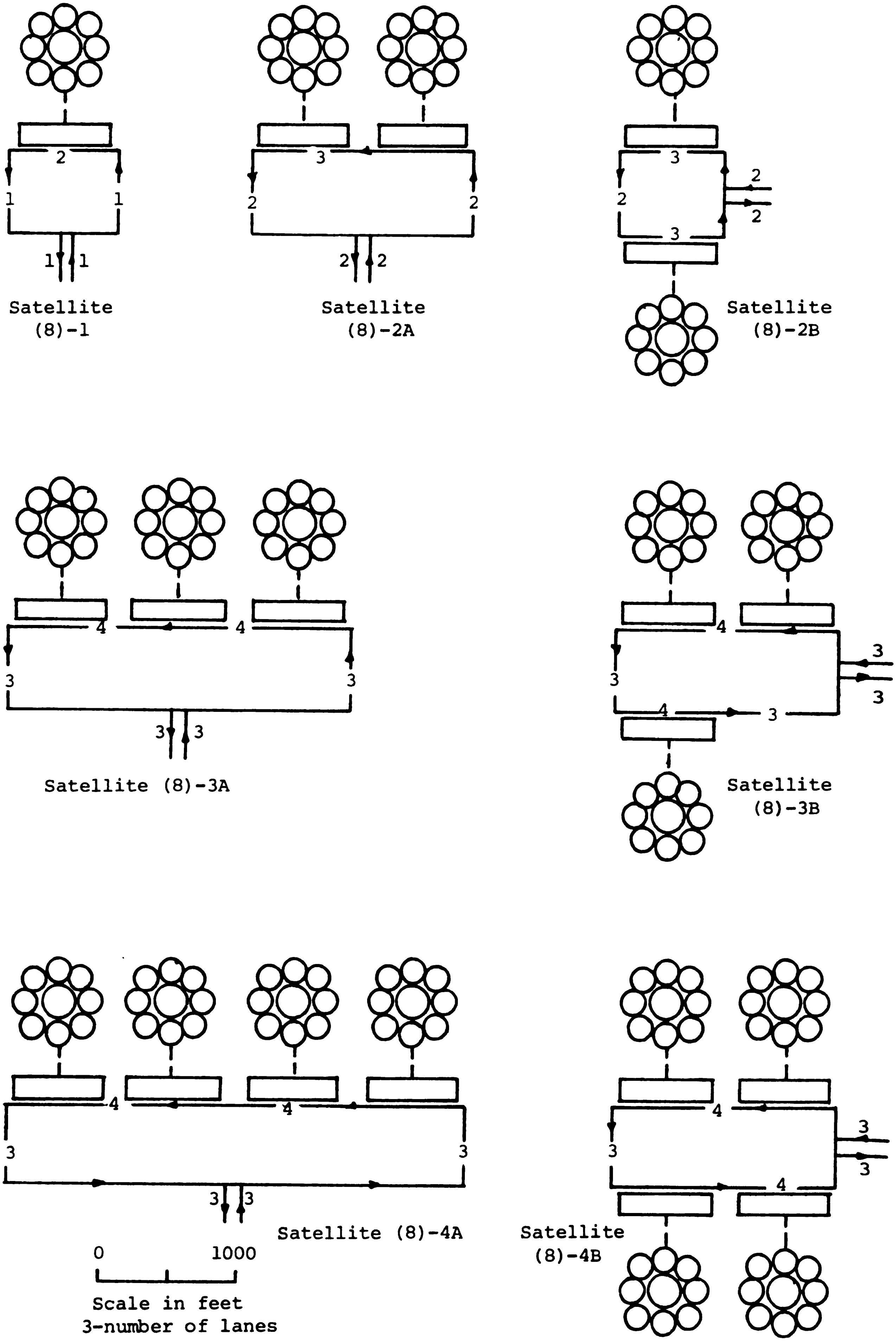


Figure 4.11 Combinations of Satellite Modules

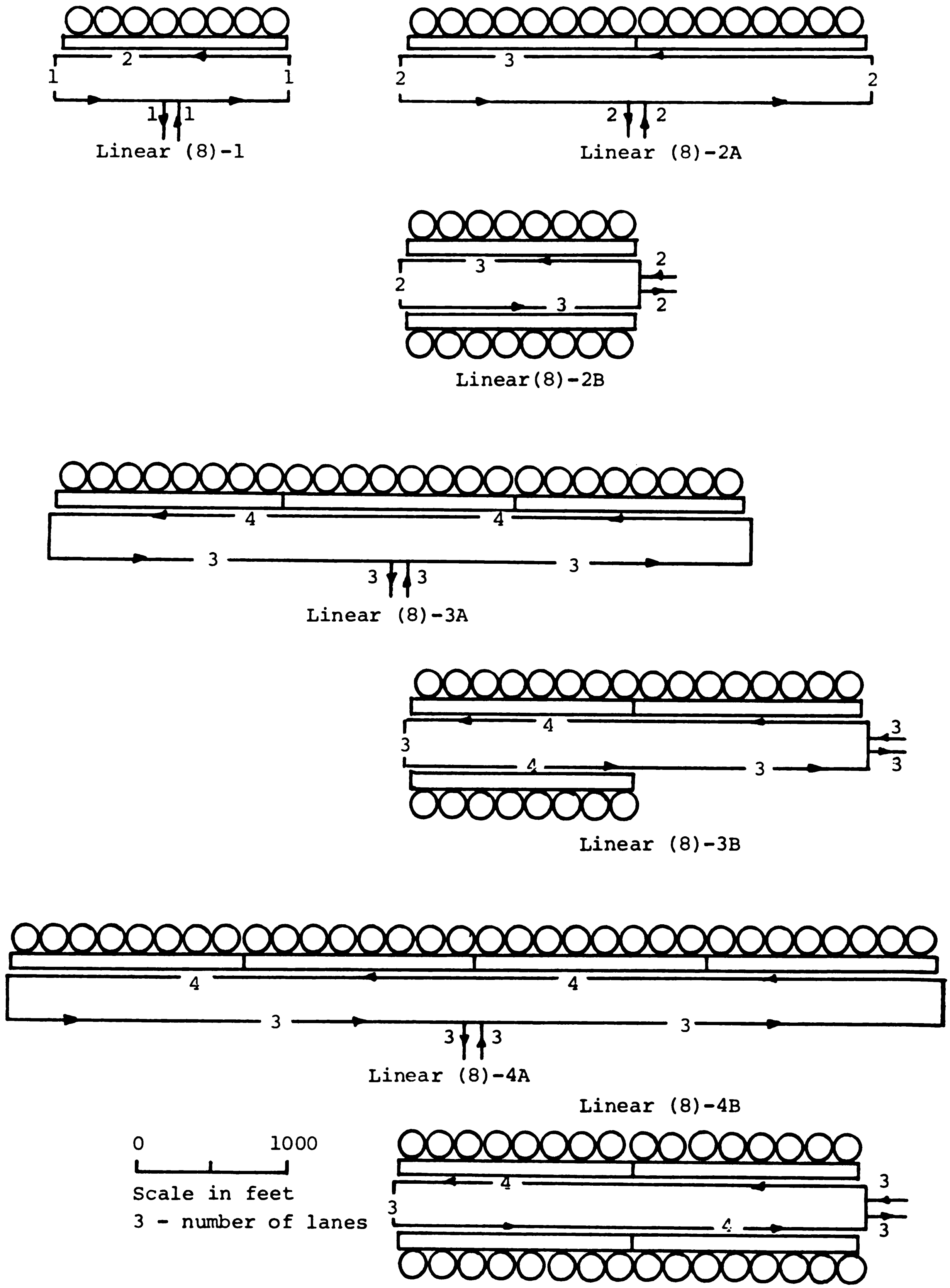


Figure 4.12 Combinations of Linear Modules

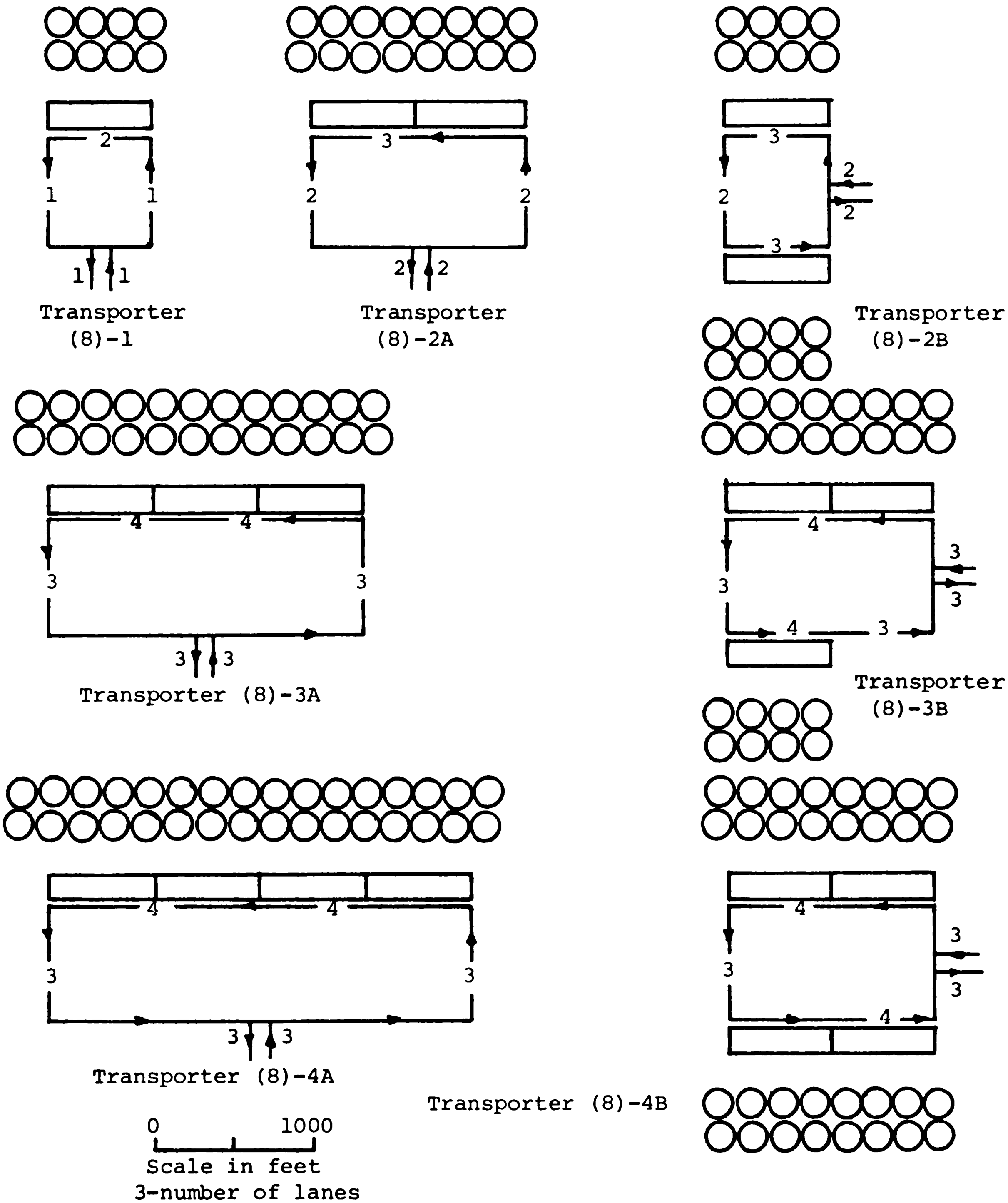


Figure 4.13 Combinations of Transporter Modules

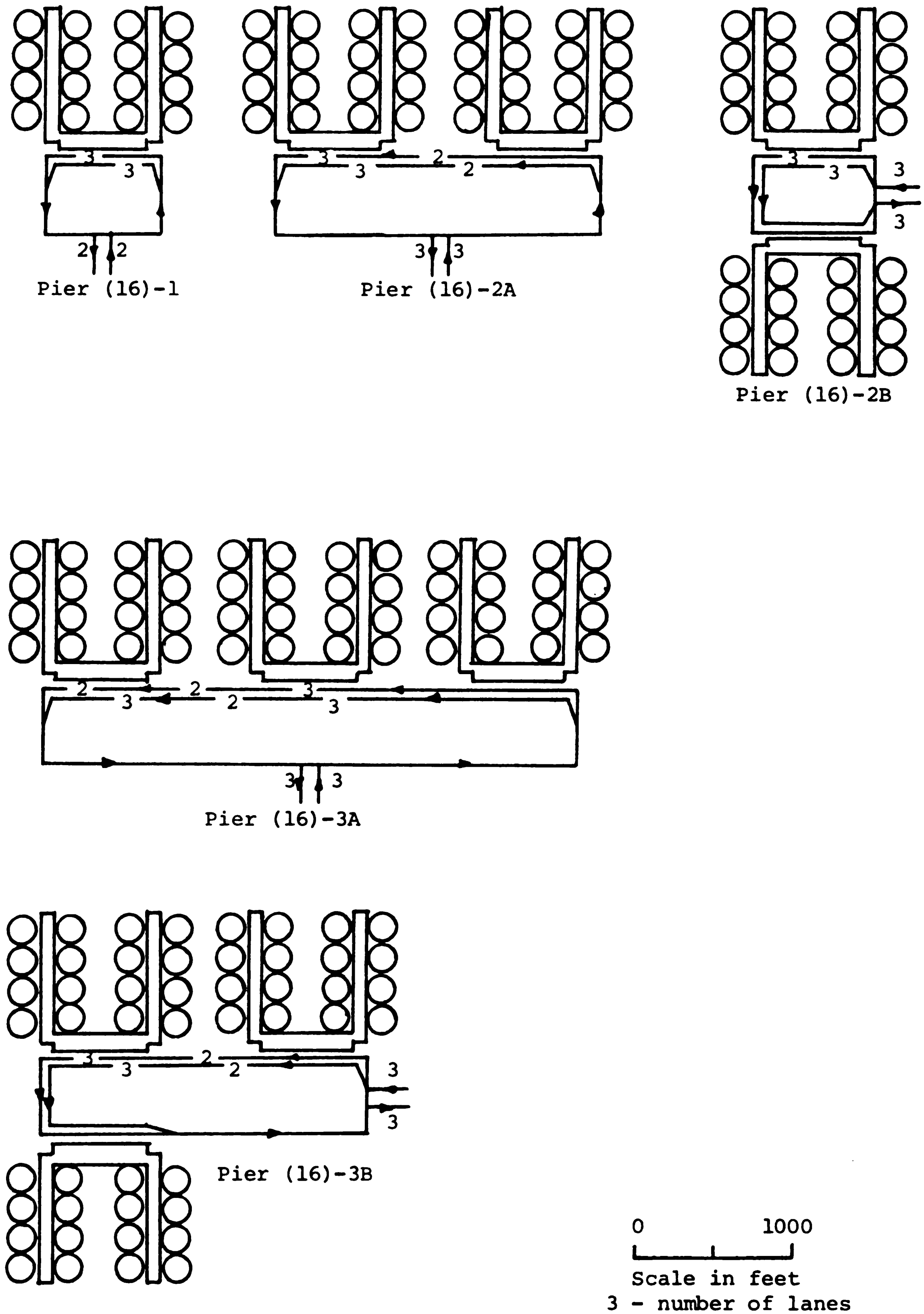
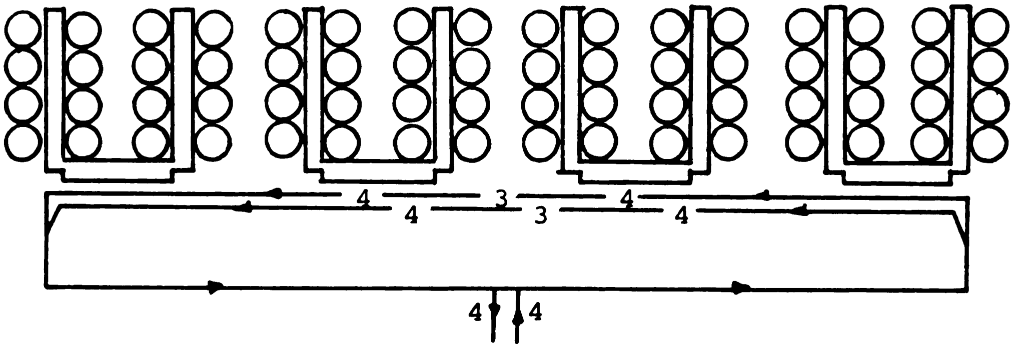
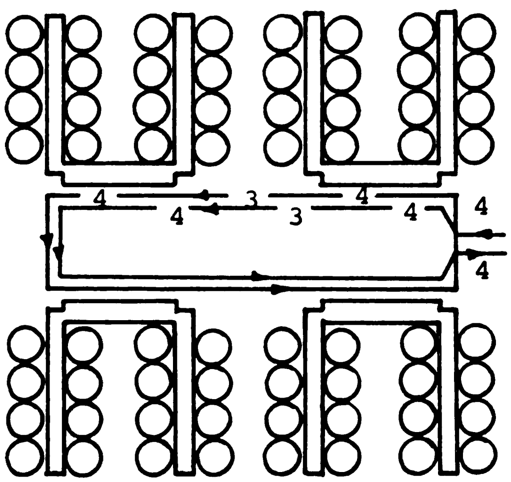


Figure 4.14 Combinations of Pier (16 Gate) Modules



Pier (16)-4A



Pier (16)-4B

0 1000

Scale in feet

3 - number of lanes

Figure 4.14 (cont'd.)

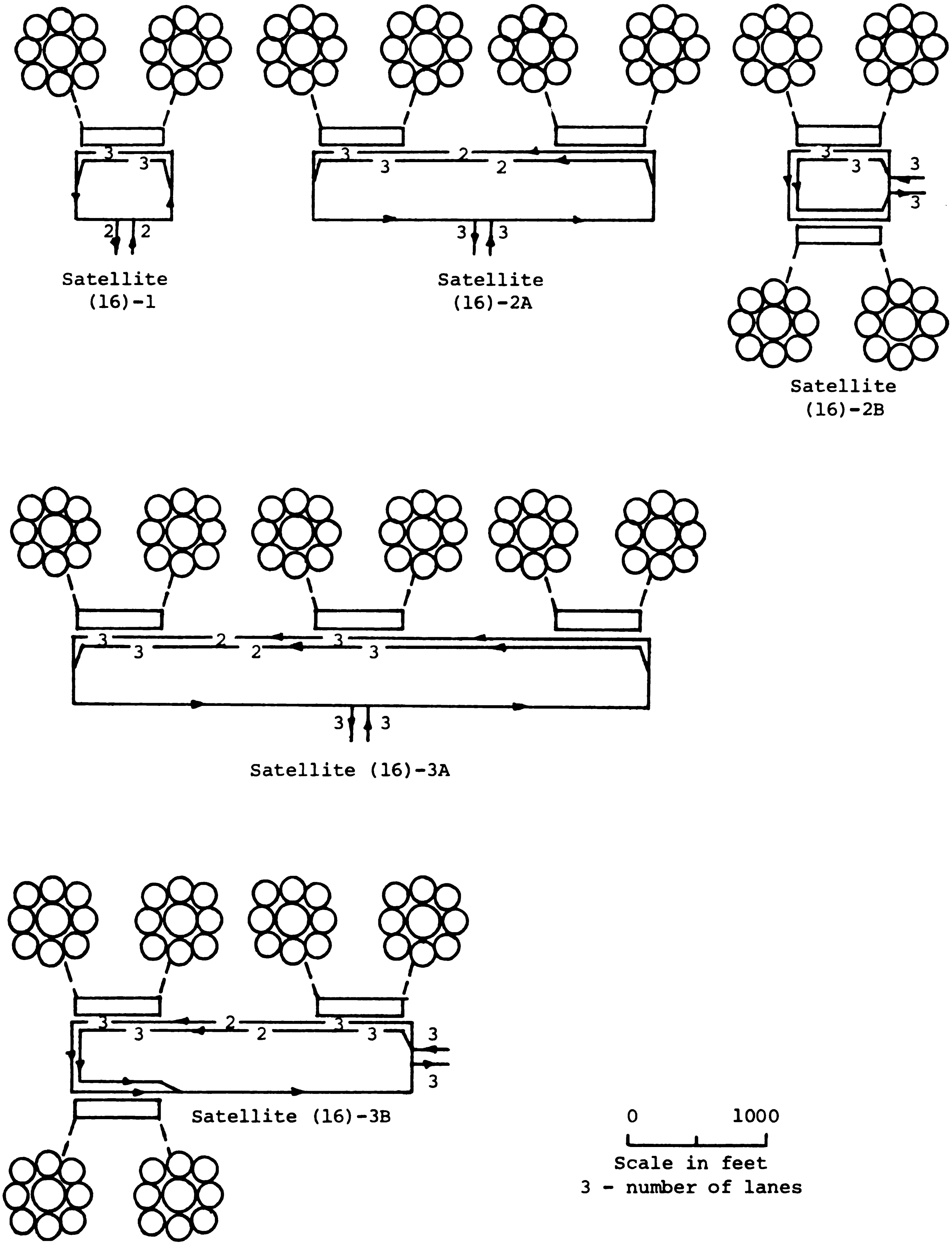
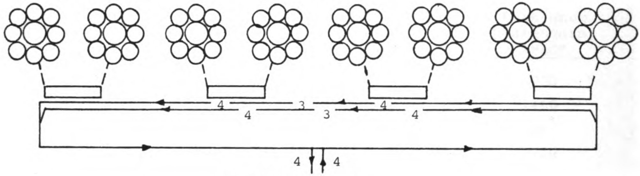
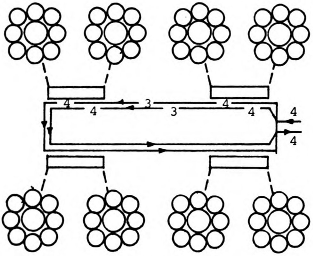


Figure 4.15 Combinations of Satellite (16 Gate) Modules



Satellite (16)-4A



Satellite (16)-4B

0 1000

Scale in feet

3 - number of lanes

Figure 4.15 (Cont'd.)

Table 4.3 Air Passenger Demands Accommodated by Terminal Units

Number of Gates per Module	Number of Modules	Annual Enplaned Passengers	Peak Hour Passengers, PMAD*
8	1	1 million	730
8	2	2 million	1460
8	3	3 million	2190
8	4	4 million	2920
16	1	2 million	1400
16	2	4 million	2800
16	3	6 million	4200
16	4	8 million	5600

* PMAD = Peak Month, Average Day - used for terminal planning and design.

the construction, and operating and maintenance costs for the terminal building, terminal access roads, parking, and apron area. Since the costs have been extracted from several sources and years, all have been adjusted to 1984 dollars using the Consumer Price Index and Engineering News Record Cost Index. Table 4.4 presents the unit costs that have been used for this study. For annual cost calculations, the construction costs of the terminal area have been amortized over a twenty year period with a 10% interest rate.

4.2.5 Walking Distances

As an initial step in identifying potential application of intra-airport transportation systems, walking distances were measured in each terminal unit. Figure 4.16 shows the average walking distances for originating and terminating passengers for each of the six modules that have been developed for this study. These distances have been derived using the networks prepared for the development and testing of the modules with the FAA Airport Landside Model. A typical distribution of passenger movement through the terminal was used. The lowest average walking distances between terminal curb and aircraft gate are observed for the linear and transporter modules, and the longest distances occur with pier and satellite modules.

A comparison of these measured distances to the suggested guidelines of 1000 feet, suggests that

Table 4.4 Unit Costs to Estimate Construction, Operating and Maintenance Costs for Terminal Area (1984 dollars)

	Unit	Unit Cost
CONSTRUCTION		
Terminal Building	per square foot	$106[1]
Parking		
surface lot	per space	$1750[2]
2 level garage	per space	$5300[2]
multi-level garage	per space	$7200[2]
Terminal Access Roads (includes lighting and drainage)		
at grade	per lane mile	$300,000[3]
elevated	per lane mile	$1,200,000[3]
Apron	per square foot	$2[3]
OPERATING AND MAINTENANCE (per year)		
Terminal Area	per enplaned passenger	$1.50[4]

Note: For Transporter terminal concept, must add cost of transporter vehicles
Capital cost of vehicle = $250,000
Operating and maintenance cost = $2.75 per vehicle mile

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[1] Recent studies at Palm Beach Airport, Palm Beach, Florida.

[2] Parking Garage Planning and Operation, ENO Foundation, 1978.

[3] 1982 Dodge Guide to Public Works and Heavy Construction Costs.

[4] Recent in-house studies by Aviation Planning Associates, Cincinnati, Ohio.

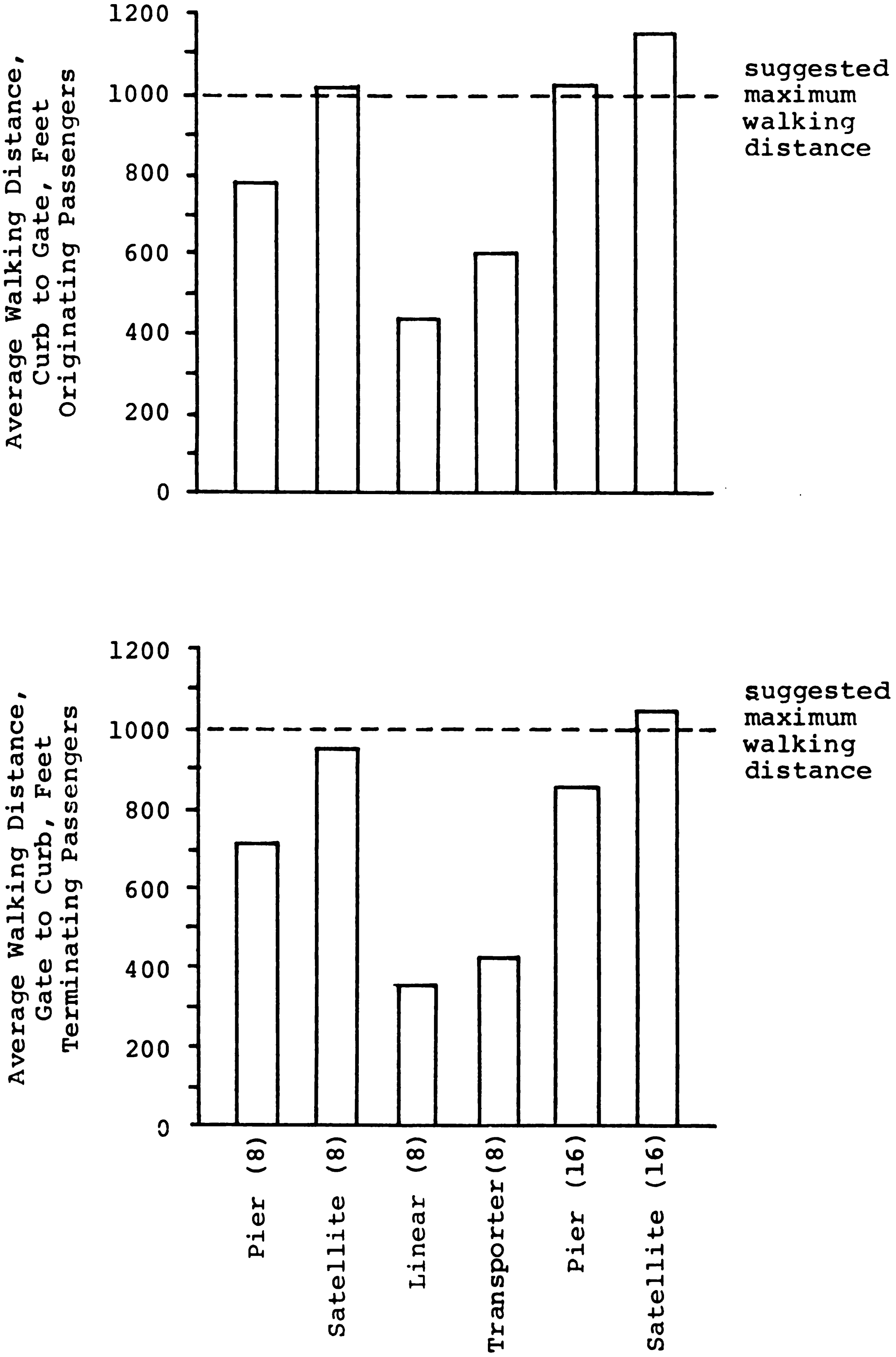

Figure 4.16 Average Walking Distance for Originating and Terminating Passengers

intra-terminal transportation systems be considered for the pier (8 gate) and satellite (8 gate and 16 gate) modules to reduce walking distances. However, the average distances are close to the suggested maximum.

The following assumptions were made to determine the average walking distance for connecting passengers:

- connecting passengers transfer from one module to another module
- there is an equal distribution of connecting passengers between modules
- connecting passengers leave the deplaning gate area and proceed through the central terminal area to the enplaning gate area of another module
- all connecting passengers proceed through security in the module that they will be departing from
- connecting passengers will not use baggage check-in or baggage claim devices

The average walking distances for connecting passengers are shown in Figures 4.17 and 4.18.

In virtually all cases, the walking distances for connecting passengers who transfer between modules is greater than 1000 feet. Intra-airport transportation systems have been incorporated in the terminals to reduce the walking distances for connecting passengers.

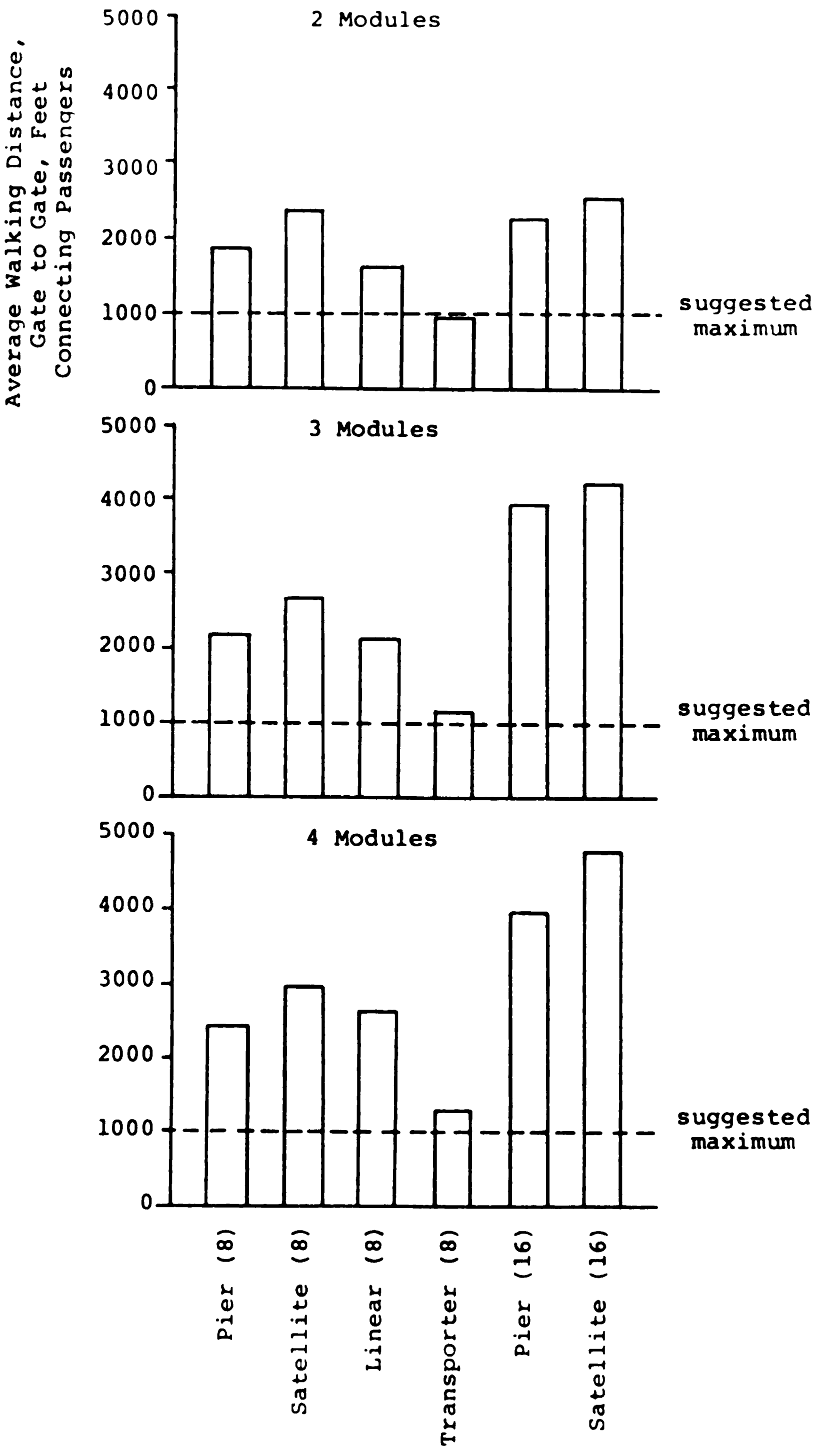

Figure 4.17 Average Walking Distance for Connecting Passengers, Terminal Configuration "A"

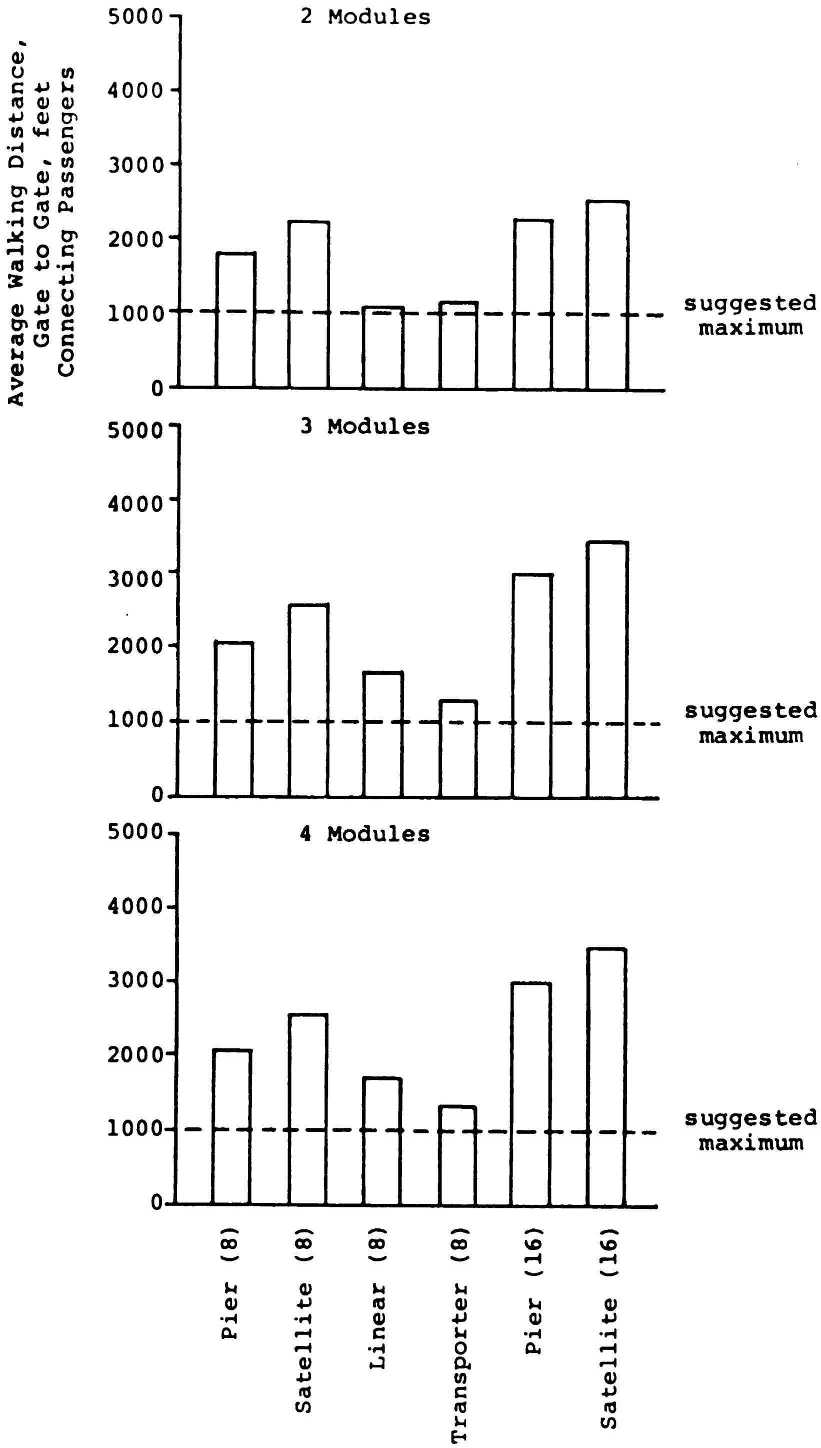

Figure 4.18 Average Walking Distance for Connecting Passengers, Terminal Configuration "B"

4.3 Incorporating Intra-Airport Transportation Systems in Terminal Units

Two route alignment alternatives have been prepared for all terminal units. The "shuttle" alignment is the most direct route between terminal modules, whereas the "loop" alignment basically follows the terminal access road. Figures 4.19 to 4.24 show the two route alternatives for all terminal units.

The following assumptions have been made in incorporating the intra-airport transportation systems in the terminal units.

Moving Walkways

- units to be installed on shuttle alignment
- moving walkway is to be protected from weather, so where modules are placed side-by-side, additional terminal area would be required for pier and satellite concepts
- for configuration "B" concepts, the moving walkway would be incorporated in the parking structure so no additional adjustment to terminal area is required for the shuttle movement across the parking area

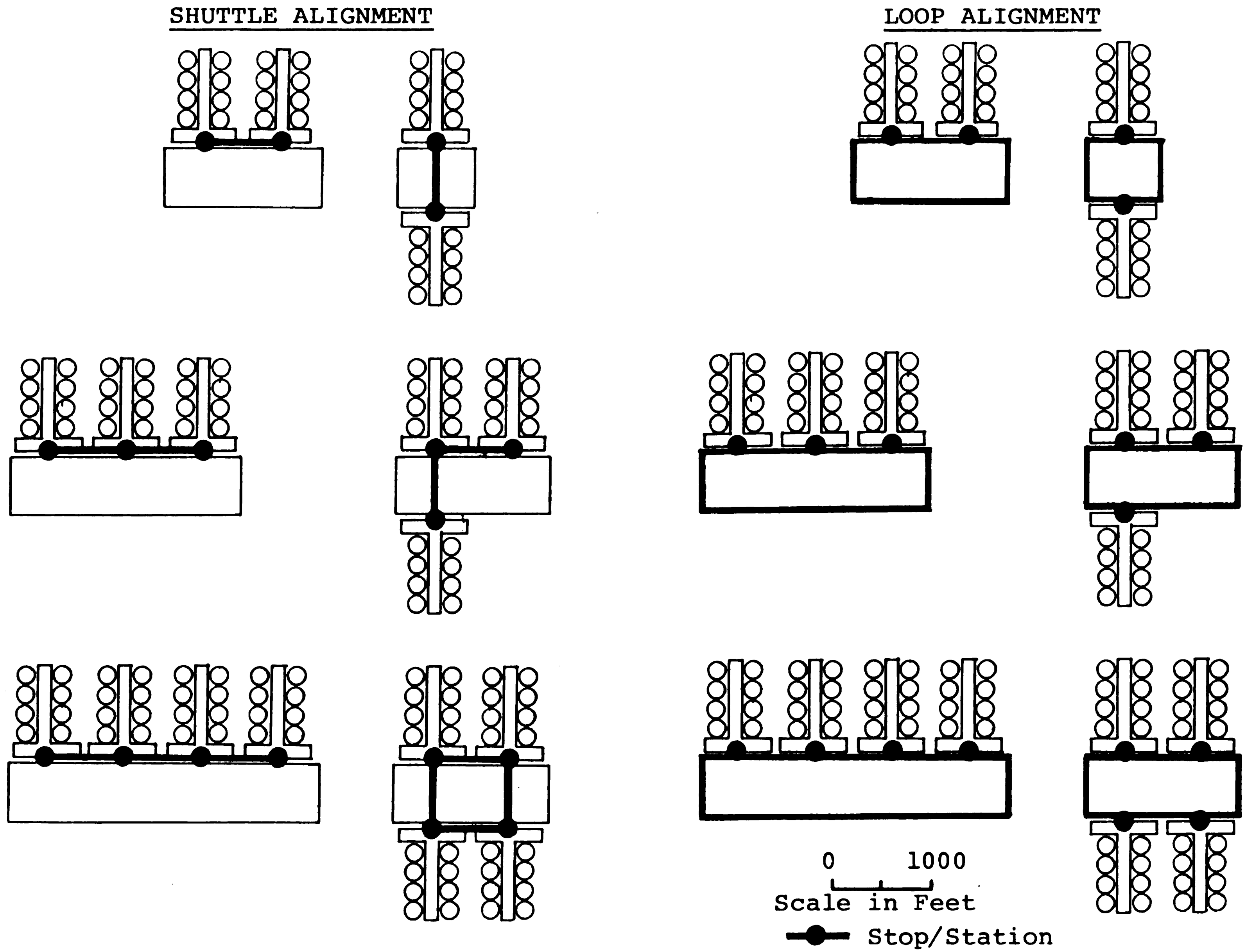

Figure 4.19 Intra-Airport Transportation System Route Alternatives, Pier Terminal Units

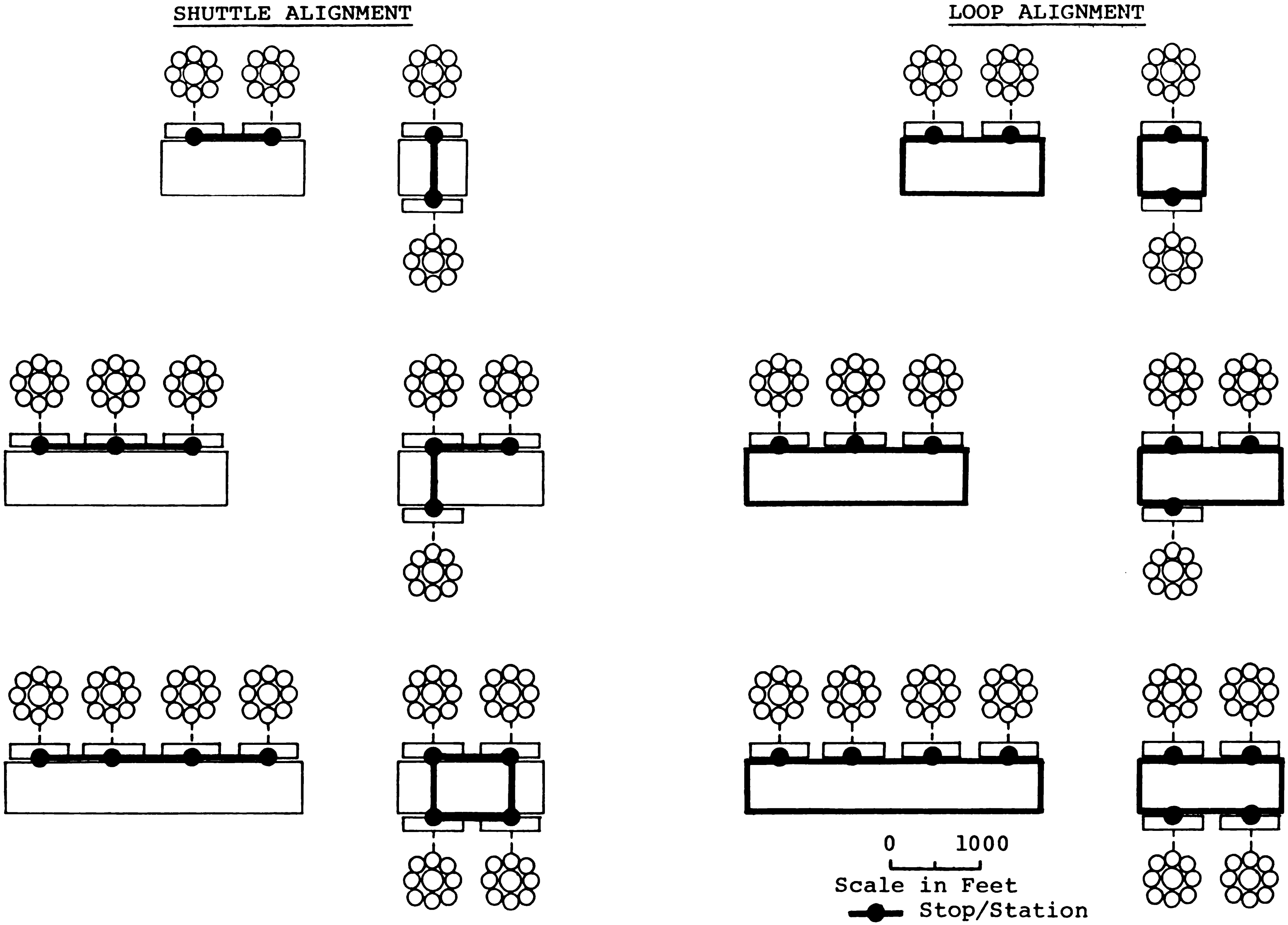

Figure 4.20 Intra-Airport Transportation System Route Alternatives, Satellite Terminal Units

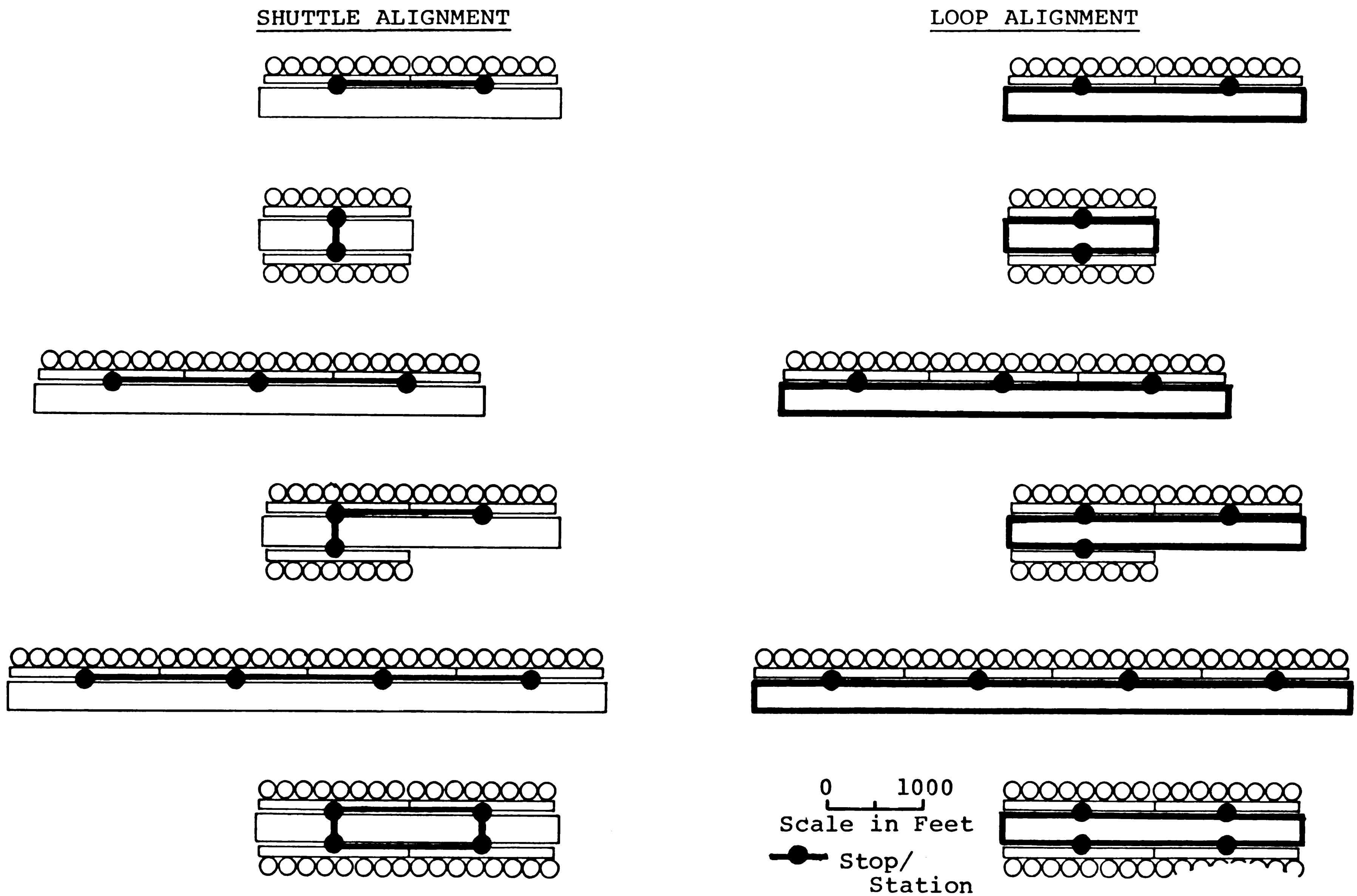

Figure 4.21 Intra-Airport Transportation System Route Alternatives, Linear Terminal Units

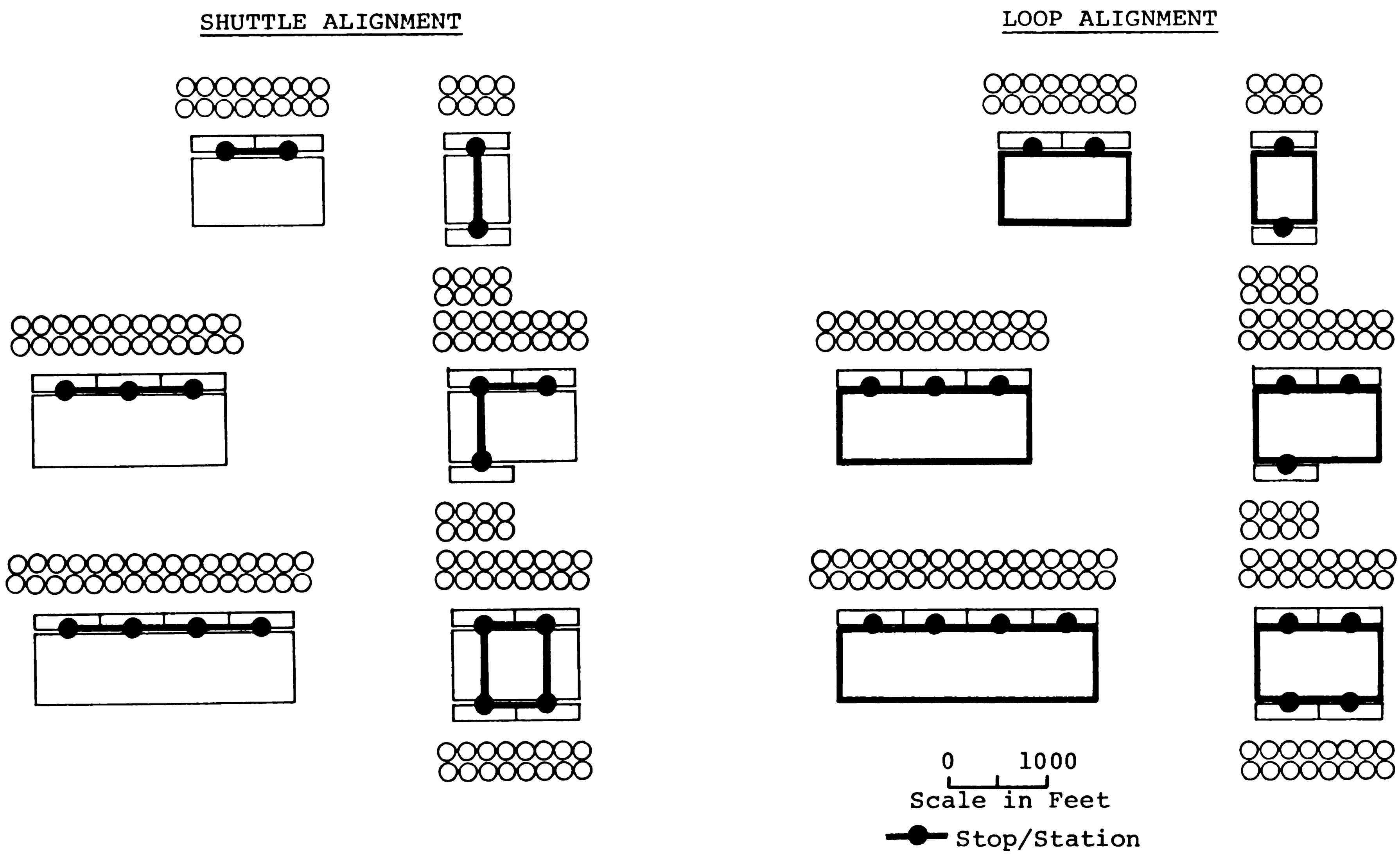

Figure 4.22 Intra-Airport Transportation System Route Alternatives, Transporter Terminal Units

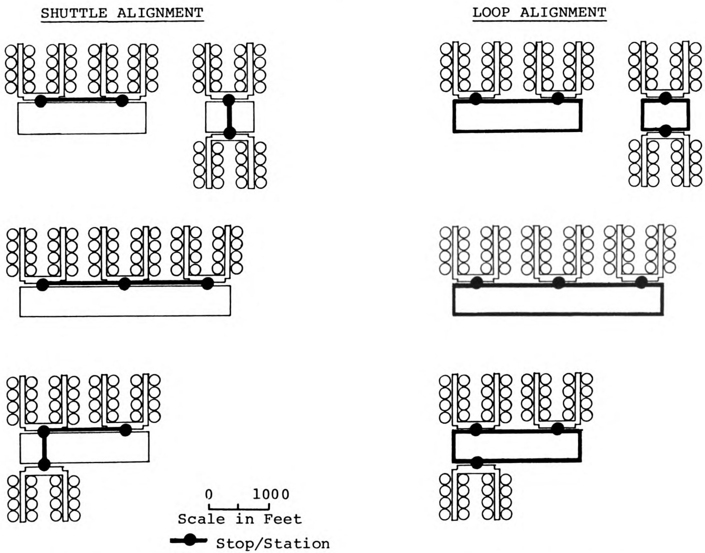

Figure 4.23 Intra-Airport Transportation System Route Alternatives, Pier (16 Gate) Terminal Units

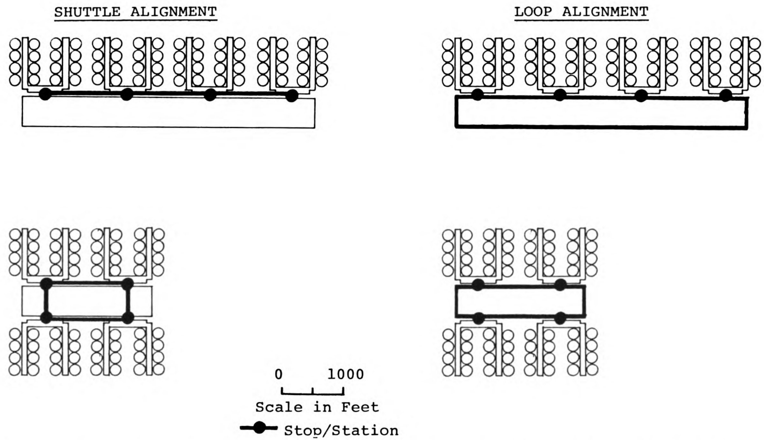

Figure 4.23 (cont'd.) Intra-Airport Transportation System Route Alternatives, Pier (16 Gate) Terminal Units

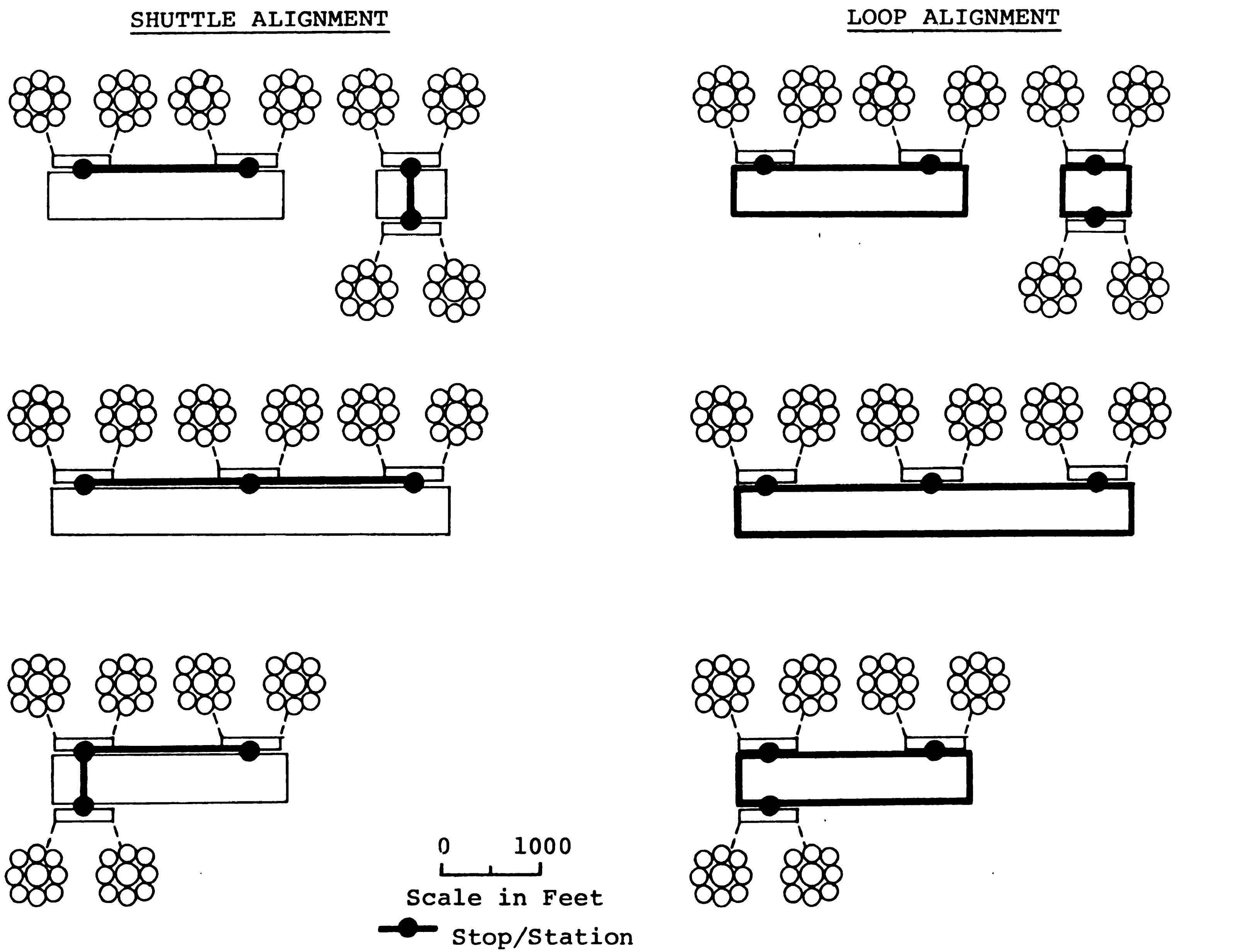

Figure 4.24 Intra-Airport Transportation System Route Alternatives, Satellite (16 Gate) Terminal Units

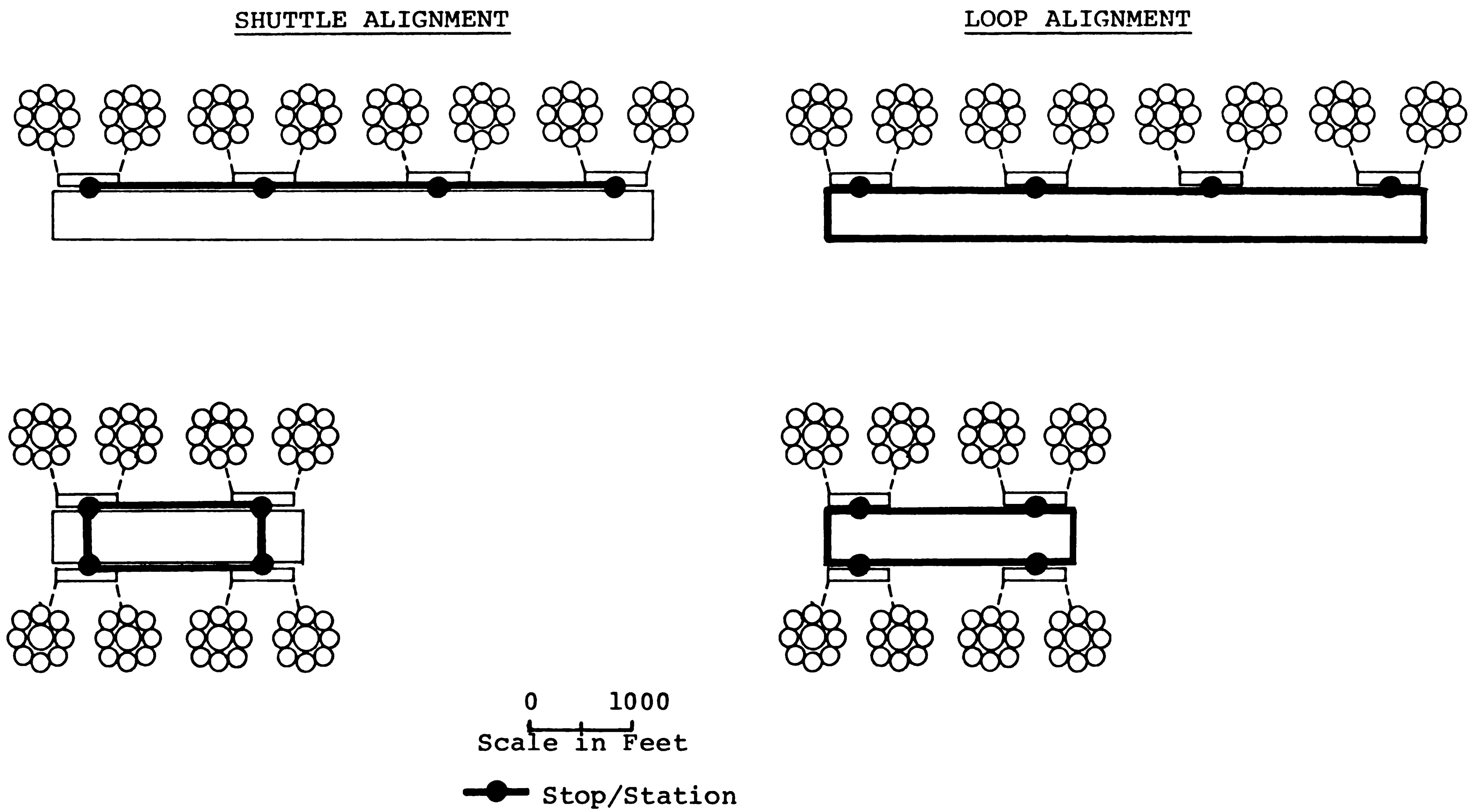

Figure 4.24 (cont'd.) Intra-Airport Transportation System Route Alternatives, Satellite (16 Gate) Terminal Units

- the maximum length of a walkway unit is 600 feet*

Automated Guideway Transit

- can operate on either shuttle or loop alignment

Shuttle - vehicles operate in both directions (i.e. no turnaround facilities required)

- if only one vehicle is required for service, one guideway between stations is sufficient; if two vehicles are required, two parallel guideways are required
- one on-line station for each module.
- for costing, the guideway is an elevated structure

Loop - one on-line station for each module

- vehicles operate in a counter-clockwise direction
- for costing, configuration "B" guideway is an elevated structure; arrangement "A" is elevated adjacent to terminals and at-grade on remainder of route

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* The maximum length is dependent on the maximum loading on the load carrying surface and tractive effort and pull due to the tensioning device. Manufacturers believe the maximum length to be about 600 feet (28), however units can be placed end to end for longer distances. When moving walkways are placed in tunnels or connecting corridors, the maximum length is generally governed by fire regulations.

Buses

- operate on loop alignment on terminal access road
- one stop for each module

4.4 Intra-Airport Transportation System Costs

Unit costs have been identified for capital/ construction and for operating and maintenance of moving walkway, buses, and automated guideway transit systems.

Moving Walkway

The cost of installing a moving walkway unit and operating costs vary widely depending on application and the area installed (28). Several sources (8,28,35) have been reviewed and costs based on a linear foot measure would be appropriate for terminal concept planning. All costs have been adjusted to 1984 dollars using the Consumer Price Index and the Engineering News Record Construction Cost Index.

The cost of installing a moving walkway unit, with a width of 40 inches and an operating speed of 120 ft/min, is $2000 per linear foot. The annual operating and maintenance cost is $80 per linear foot.

Buses

It has been assumed that the capital cost of a bus system for intra-airport service would be the cost of vehicles required for service only. Vehicle maintenance would be done off-site and the system would be operated on a contract basis.

Costs have been identified for two sizes of buses - a conventional or standard urban diesel bus with seating capacity of 50 passengers, and a minibus with seating capacity of 25 passengers. Estimated costs (1984 dollars) of these vehicles used for this study are:

Conventional bus (50 passengers)	-	$125,000
Minibus (25 passengers)	-	80,000

The number of buses required for service is identified using the nomograph presented in Figure 3.3.

Operating costs have been developed on the basis of vehicle miles of travel and include drivers wages, maintenance, fuel, insurance, administration and other variables associated with operation of the service. Several sources (8,15,18,35,37,53) were reviewed to determine approximate operating costs for bus operations on an airport site. The operating costs used in this study are:

Conventional bus	-	$2.75 per vehicle mile
Minibus	-	2.50 per vehicle mile

Vehicle miles travelled in an hour can be derived using the nomograph presented in Figure 3.4. Annual vehicle miles will depend on the hours of service and service frequency throughout the day. For this study it has been assumed that the hourly value determined using the nomograph represents 10 percent of the average daily vehicle miles travelled.

Automated Guideway Transit

Since an AGT system requires the construction of an exclusive guideway and stations, the cost of these fixed facilities must be included as part of the AGT system capital cost estimate.

A procedure was developed in an UMTA study (44) and it has been used as a basis for this study to prepare cost estimates of an AGT system. Although the original procedure was prepared for downtown people mover systems, it incorporated all of the existing AGT airport cost data, and identified adjustments that should be considered when using the procedure for airport application.

Seven components are identified to estimate the capital cost of the system.

(1) Guideways

- all guideway facilities including foundations, supporting structures, running and guidance surfaces, and switching equipment.

(2) Vehicles

- the rolling stock, including on-board command and control equipment

(3) Stations

- passenger loading platforms, access facilities, and vehicle interface equipment

(4) Control and Communications

- wayside and central office control and communications equipment

(5) Power and Utilities

- electric power transformers, feeders, switch gear, and power rails

(6) Maintenance and Support Facilities

- repair shops and equipment such as emergency vehicles

(7) Engineering and Project Management

- all costs of architecture and engineering services, acceptance testing, and overall project management

Data from all operating AGT systems were summarized in the UMTA study to develop unit costs for each of the seven components. These costs have been updated to 1984 dollars using the Consumer Price Index and Engineering News Record Construction Cost Index, and adjusted to include the most recent cost summary of AGT systems (47). Table 4.5 presents the unit cost values that have been used in this study and Figure 4.25 illustrates various station configurations and estimated costs for incorporating AGT in the airport terminal. The nomograph presented in Figure 3.3 is used to determine the number of vehicles required for service. Operating and maintenance costs for AGT have been assumed as $1.75 per vehicle mile based on the UMTA study (44) and other cost summaries. An estimate of vehicle miles travelled is determined using the nomograph presented in Figure 3.4.

Annual capital costs have been calculated assuming the following amortization periods and a 10% interest rate for the intra-airport transportation systems:

moving walkways - 20 years

automated guideway transit - 20 years

Table 4.5 Unit Costs for Estimating AGT System Capital Cost (all costs in millions of 1984 dollars)

Cost Category	Units of Cost	Unit Cost
Guideway		
- elevated	per lane-mile	4.13
- at grade	per lane-mile	1.58
- below grade	per lane-mile	14.22
Station*		
Vehicle	per vehicle	.60
Control and communications	per lane-mile	1.98
Power supply	per lane-mile	1.00
Maintenance support	per vehicle	.14
Project management	% added to sum of above costs	25.20
Contengency	% added to sum of above costs	12.00

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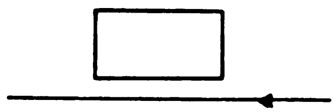
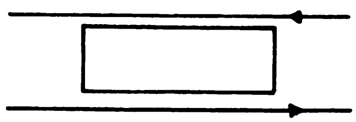
* Depends on configuration, see Figure 4.25.

Source: <u>Planning for Downtown Circulation Systems</u>, Transportation Systems Center for UMTA, U.S.D.O.T., 1983. (Costs upgraded to 1984 values.)

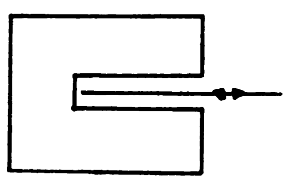
Station	Estimated Cost of Incorporating in Terminal
(A) On-Line, Boarding One Side	$225,000



(B) On-Line, Boarding Two Sides	$300,000



(C) End of Line, One Line	$350,000



(D) End of Line, Two Lines	$500,000

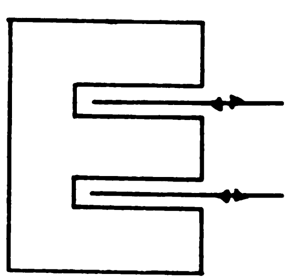


Figure 4.25 AGT Station Configurations

Adapted from: Automated Transit System Planning Guide, Westinghouse Electric Corporation, 1981.

conventional bus - 10 years

minibus - 5 years

Total annual costs are obtained by summing the annual capital and operating and maintenance costs.

4.5 Evaluation

Many factors could be included in an evaluation and the factors will vary from airport to airport to meet specific concerns and characteristics. Two factors have been used in this study to provide a quantitiative comparison that could be used to identify tradeoffs between alternatives. The factors and the comparative measures that have been used include:

Cost

- capital cost
- operating and maintenance costs
- annual cost per user
- additional cost of terminal area per enplaned passenger of incorporating an intra-airport transportation system (will be of interest to airport authorities, airlines and concessionaires as terminal rental fees and charges are set to cover these costs)

Convenience

- reduction in walking distance
- effect on travel time

CHAPTER 5

ANALYSIS

5.1 System Alternatives

Five intra-airport transportation systems have been incorporated in the terminals - moving walkways, automated guideway transit on a shuttle alignment, automated guideway transit on a loop alignment, minibus, and a standard or conventional size bus. The objective of installing a system was to reduce the walking distances for connecting passengers and the routings or alignments of these systems are presented for each concept in Figures 4.19 to 4.24.

Several service parameters were assumed to develop capital and operating and maintenance cost estimates for each system alternative. The assumptions made for each system include:

moving walkways

- operating speed - 120 feet per minute

automated guideway transit

- single vehicle trains
- vehicle capacity - 50 passengers per vehicle
- average speed - 15 miles per hour (1320 feet per minute)
- maximum headway - 5 minutes
- minimum headway - 1 minute

minibus

- vehicle capacity - 25 passengers per vehicle

- average speed - 10 miles per hour (880 feet per minute)

- maximum headway - 5 minutes

- minimum headway - 2 minutes

standard (conventional size) bus

- vehicle capacity - 50 passengers per vehicle

- average speed - 10 miles per hour (880 feet per minute)

- maximum headay - 5 minutes

- minimum headway - 2 minutes

5.2 Capital Cost

Using unit costs and procedures presented in Section 4.4, estimates have been made of the capital/construction cost for each of the intra-airport transportation systems and for connecting passenger levels of 10, 20, 30, 40 and 50% of enplaned passengers. Estimates for a 20% connecting passenger level are graphically shown in Figures 5.1 and 5.2. Figure 5.1 presents costs for all terminal concepts, in two, three and four module combinations, in configuration A. Figure 5.2 presents similar costs for configuration B. The intra-airport transportation systems for which cost estimates have been made include:

minibus

standard (conventional size)

moving walkways

automated guideway transit in a shuttle alignment

automated guideway transit in a loop alignment

As one would expect, the cost of all transportation

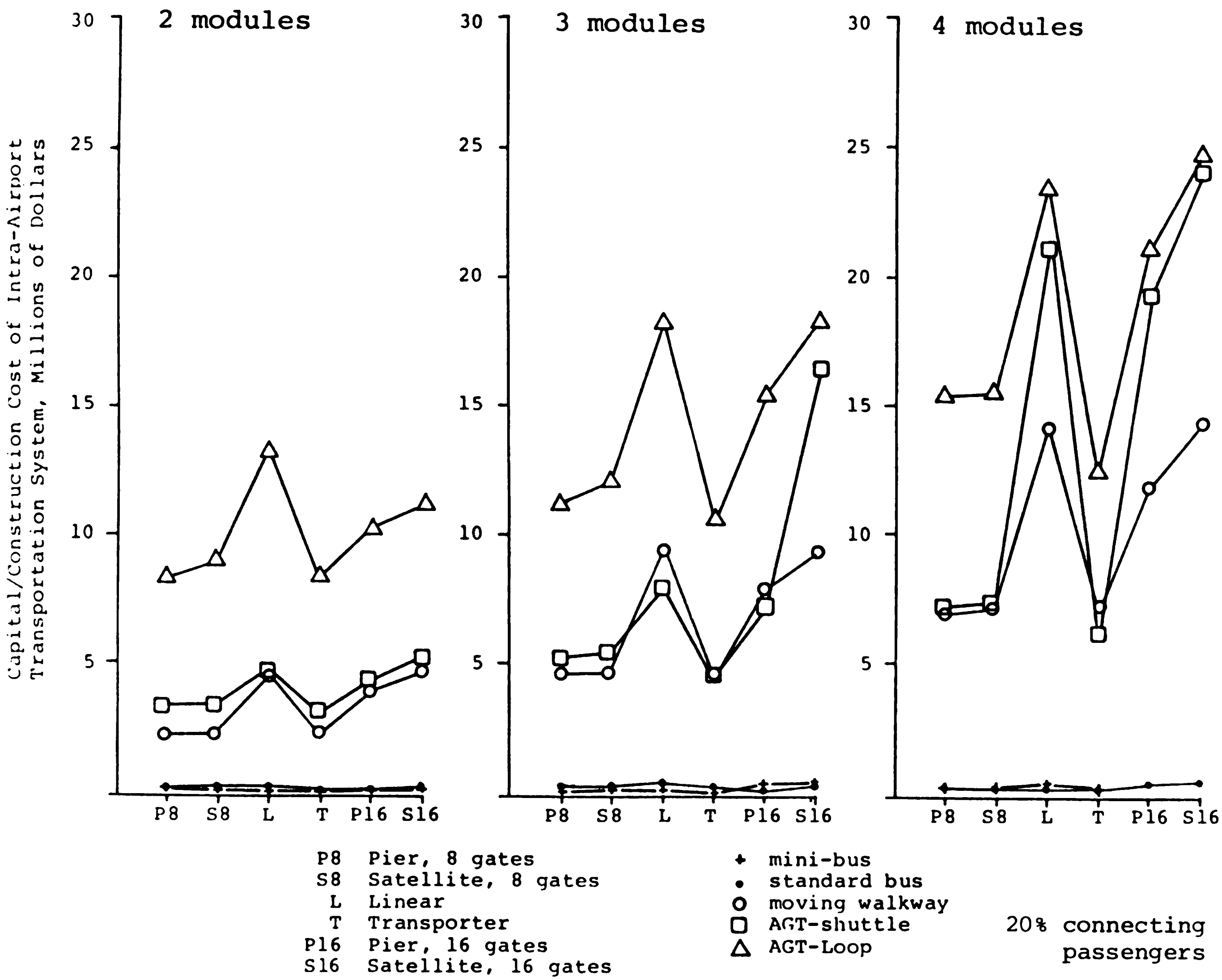


Figure 5.1 Capital/Construction Cost of Intra-Airport Transportation Systems, Terminal Configuration A

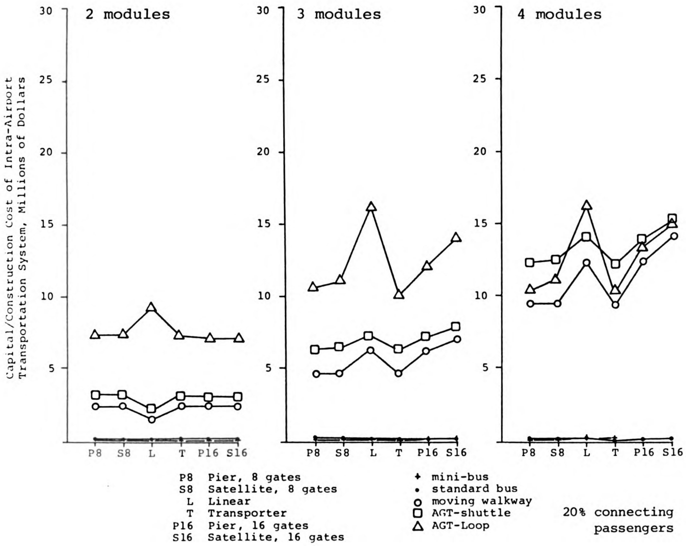


Figure 5.2 Capital/Construction Cost of Intra-Airport Transportation Systems, Terminal Configuration B

system alternatives increases as the number of modules increase. The costs of transportation system alternatives for terminal configuration B are generally less than configuration A due to the compactness inherent in configuration B. This compactness results in shorter walking distances for connecting passengers and shorter guideway requirements for automated guideway transit systems. Because of the fixed guideway and station requirements, automated guideway transit system alternatives are the most expensive, and the bus alternatives are the least expensive.

Similar conclusions result for other levels of connecting passengers and the costs are approximately the same as fixed facilities (moving walkway and guideway for an automated guideway system) are required as a minimum cost for all passenger levels. The vehicle requirements vary with passenger levels. As a result, the capital costs of alternatives for higher connecting passenger levels are a little higher and the capital costs of alternatives for lower connecting passenger levels are lower. However, in many cases the vehicle requirements are the same as the headway service parameter governs.

At low connecting volumes, the minibus is the least expensive alternative, but as demand increases, additional buses are required and at higher demand levels, the standard bus becomes a preferred alternative.

When the demand exceeds 750 pphd (passengers per hour per direction) at the maximum load point, the minibus cannot be used for service as the capacity of minibus service with specified service parameters (25 passengers per vehicle, and 2 minute minimum headway) is exceeded. The capacity of standard size bus service with specified service parameters (50 passengers per vehicle, and 2 minute headway) is 1500 pphd.

Due to the longer length of fixed guideways, and longer length of routes on the terminal access roads, the capital costs of providing intra-airport transportation service for the linear terminal concept are the highest.

5.3 Annual Operating and Maintenance Cost

Another factor considered in assessing the cost of intra-airport transportation system alternatives is the operating and maintenance cost. Estimates of annual operating and maintenance cost have been made for each of the transportation systems at connecting passenger levels of 10, 20, 30, 40 and 50% of enplaned passengers using the unit costs and procedures presented in Section 4.4. Figures 5.3 and 5.4 present these cost estimates in a similar format to that used to show capital/construction costs. The operating and maintenance costs for each of the intra-airport transportation systems for a 20% connecting passenger level for each terminal concept, in two, three and four module combinations, and configuration A, are shown in Figure 5.3. The operating and maintenance costs for the terminals in configuration B, are shown in Figure

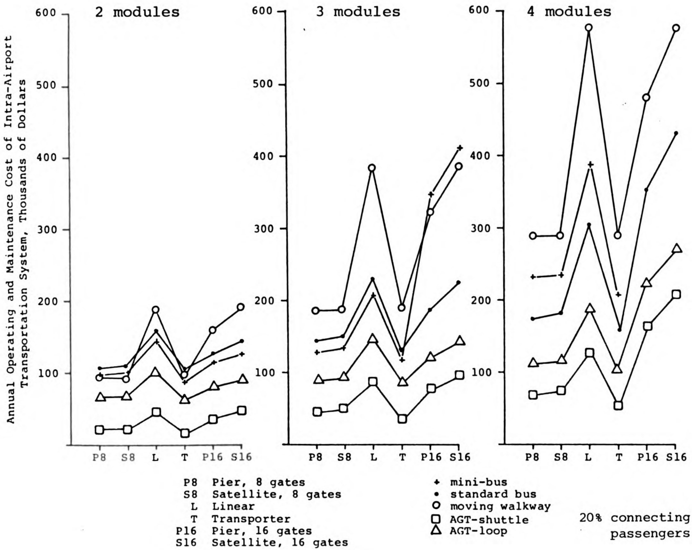


Figure 5.3 Operating and Maintenance Costs of Intra-Airport Transportation Systems, Terminal Configuration A

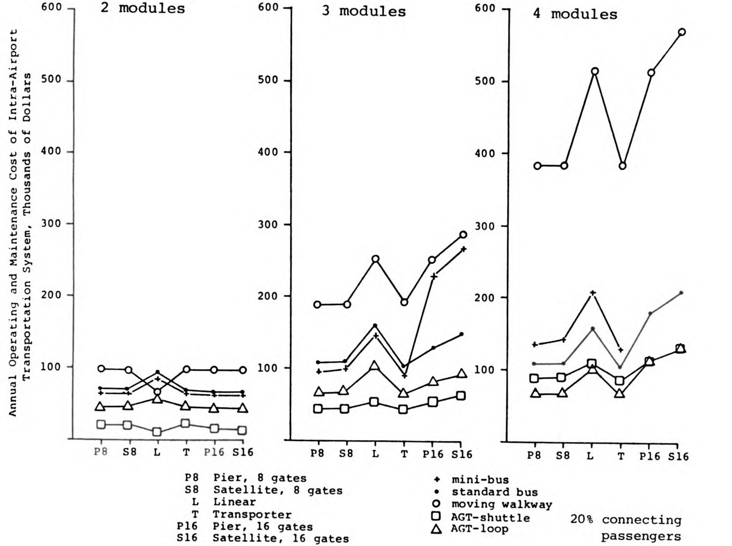


Figure 5.4 Operating and Maintenance Costs of Intra-Airport Transportation Systems, Terminal Configuration B

5.4.

The lowest annual operating and maintenance costs occur with automated guideway transit system alternatives, while moving walkways and bus alternatives experience the highest costs. Similar findings were observed for other connecting pasenger levels.

5.4 Total Annual Cost

Total annual costs have been estimated by amortizing the capital/construction costs and adding the annual operating and maintenance costs. Two approaches have been used to compare annual costs - annual cost per connecting passenger or user of the intra-airport transportation system, and annual cost per enplaned passenger.

5.4.1 Annual Cost per Connecting Passenger

The total annual costs were divided by the annual connecting or transferring passengers for which the system was designed to develop an annual cost of intra-airport transportation system per connecting passenger. Annual costs were developed for 10, 20, 30, 40 and 50% connecting passenger levels. Figure 5.5 presents the costs for the alternative systems for each terminal concept at a 20% connecting passenger level, and terminal configuration A. Figure 5.6 presents the annual cost per connecting passenger for terminal configuration B.

Higher annual costs per connecting passenger are found at the 10% connecting passenger level and lower annual

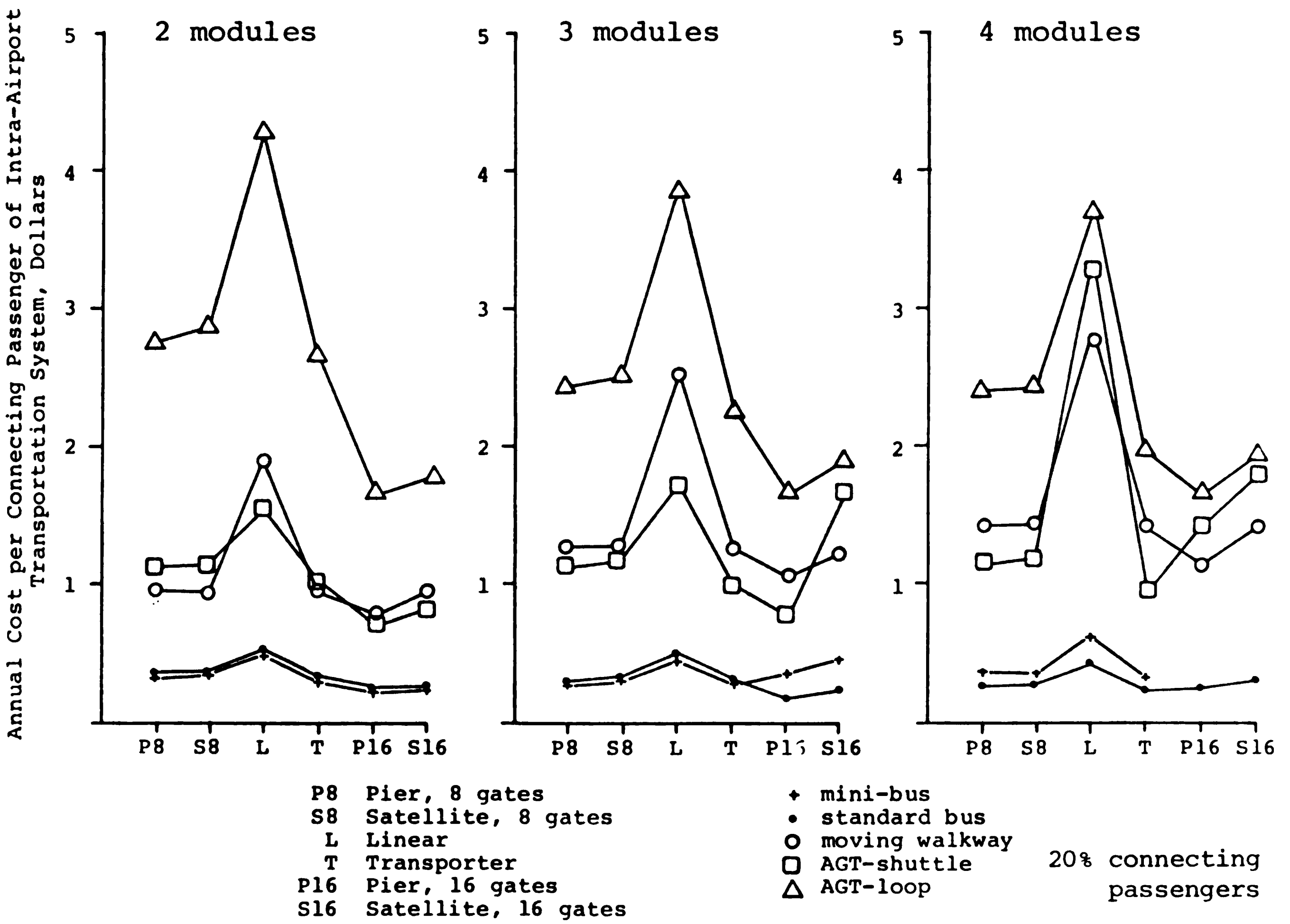


Figure 5.5 Annual Cost per Connecting Passenger of Intra-Airport Transportation Systems, Terminal Configuration A

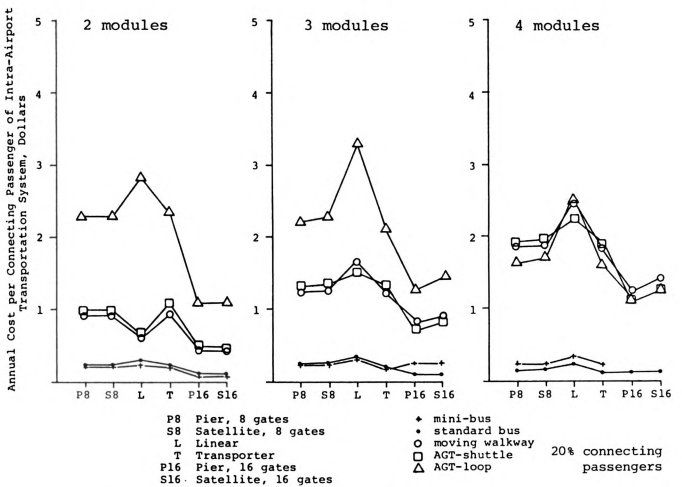


Figure 5.6 Annual Cost per Connecting Passenger of Intra-Airport Transportation Systems, Terminal Configuration B

costs per connecting passenger are found at the 30, 40 and 50% connecting passenger levels. Figure 5.7 shows the annual cost per connecting passenger of the intra-airport transportation system for Pier(8) terminal concepts at various connecting passenger levels to illustrate the reduction in annual cost per connecting passenger as the number of connecting passengers increases. A summary of costs is presented in Table 5.1. Some preliminary observations have been made.

- the annual cost per connecting passenger decreases as the number of connecting passengers increases.
- the bus systems have the lowest annual cost per connecting passenger and automated guideway transit operating on a loop alignment has the highest annual cost per connecting passenger.
- at low connecting passenger levels, the minibus has the lowest annual cost per connecting passenger, however, as passenger levels increase and demand approaches the capacity of the minibus service, the standard bus yields lower annual costs per user.
- the annual cost per connecting passenger of providing intra-airport transportation service for terminal concepts in configuration B are generally less than for configuration A, due to the compactness inherent in configuration B.
- the annual cost per connecting passenger of providing intra-airport transportation service for

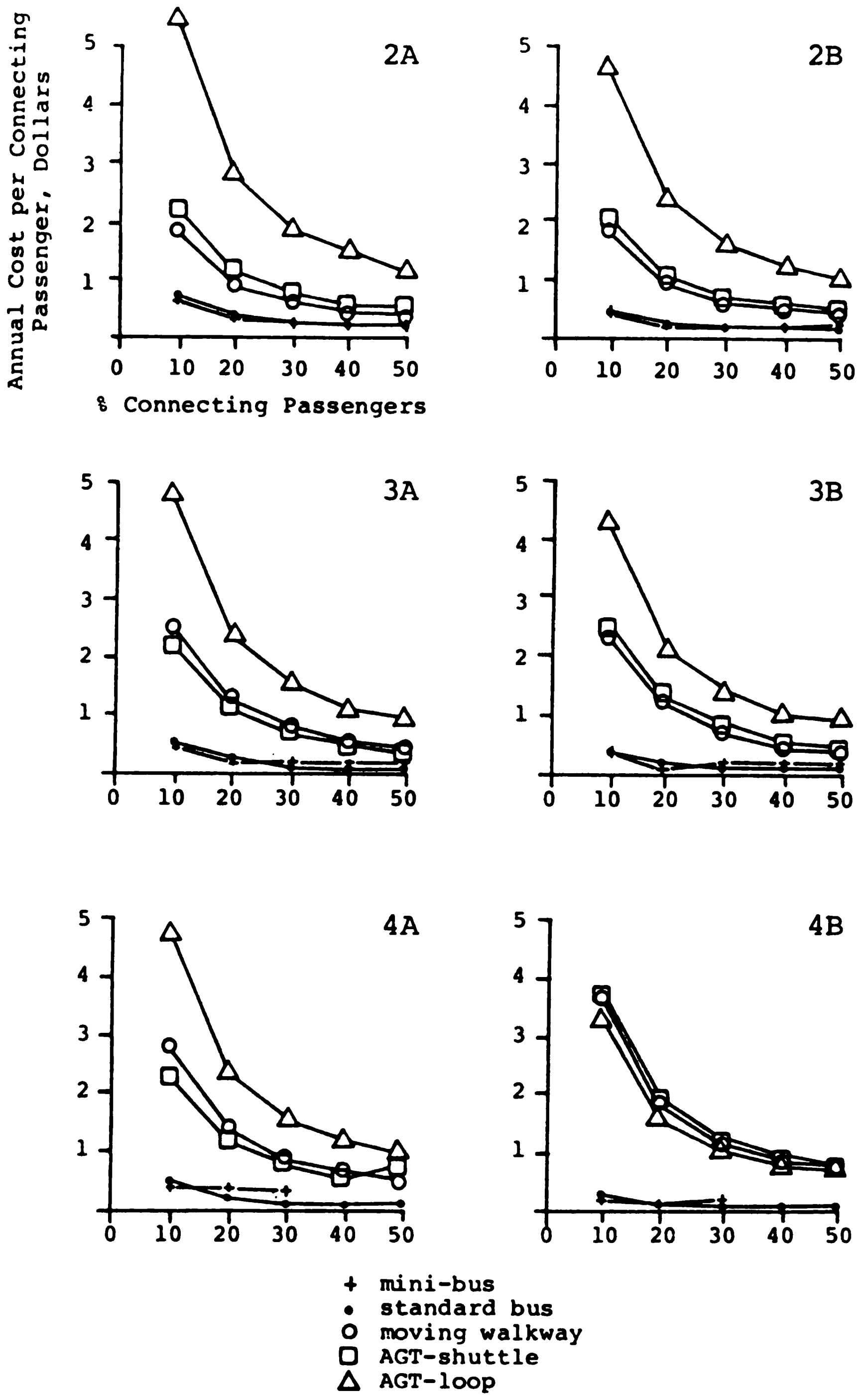


Figure 5.7 Annual Cost per Connecting Passenger of Intra-Airport Transportation Systems, Terminal Concept Pier(8)

Table 5.1 Range* in Annual Costs of Intra-Airport Transportation Systems per Connecting Passenger (dollars)

Terminal Concept	Terminal Configuration	Intra-Airport Transportation System: Minibus	Standard Bus	Moving Walkway	AGT-Shuttle	AGT-Loop
Pier (8)	A	.16-.69	.14- .74	.38-2.83	.44-2.36	1.00-5.55
	B	.10-.46	.09- .49	.38-3.78	.41-3.90	.75-4.64
Satellite (8)	A	.17-.71	.15- .75	.38-2.83	.45-2.40	1.02-5.70
	B	.10-.47	.09- .50	.38-3.78	.41-3.99	.79-4.64
Linear (8)	A	.23-.94	.20-1.01	.76-5.76	.63-6.70	1.58-8.52
	B	.15-.63	.11- .67	.25-5.04	.28-4.49	1.08-6.74
Transporter (8)	A	.16-.56	.12- .60	.38-2.83	.40-2.04	.84-5.30
	B	.10-.43	.09- .45	.38-3.78	.44-3.86	.66-4.64
Pier (16)	A	.17-.56	.10- .42	.31-2.36	.29-3.00	.72-3.31
	B	.09-.26	.05- .28	.19-2.52	.20-2.23	.45-2.59
Satellite (16)	A	.20-.62	.11- .48	.38-2.83	.34-3.73	.73-3.83
	B	.10-.32	.05- .32	.19-2.83	.20-2.46	.45-2.95

* Low end of range is for 4 modules, 50% connecting passengers; upper end of range is for 2 modules, 10% connecting passengers.

16 gate module concepts is less than for 8 gate module concepts.

- the highest annual cost per connecting passenger occurs with the linear concept in configuration A, while pier terminal concept, with 16 gate modules, and in configuration B has the lowest cost.

The intra-airport transportation system with the lowest annual cost per connecting passenger can be identified for a specific number of modules, configuration, and percent of connecting passengers. It was found that the decision point between systems was the same regardless of the terminal concept and configuration. The results are summarized in Table 5.2 (8 gate modules), and Table 5.3 (16 gate modules). For example, with two 8 gate modules, the minibus would be the appropriate system, i.e. lowest annual cost per connecting passenger, up to connecting passenger levels of about 45%, then the standard bus would be selected.

On the basis of annual cost per connecting passenger, automated guideway transit would be appropriate with four 16 gate modules (configuration B) at connecting passenger levels exceeding 30% of the annual enplaned air passenger demand. This represents approximately 2.4 million annual connecting passengers.

Graphs have also been prepared to show the relationship between annual cost per connecting passenger and total annual connecting passengers, for each of the

Table 5.2 Appropriate* Intra-Airport Transportation System for Connecting Passengers (8 Gate Modules)

No. of Modules		2	3	4
Annual Enplaned Air Passengers		2 million	3 million	4 million
% Connecting Passengers	10	mini-bus	mini-bus	mini-bus
	15			std. bus
	20			
	25		std. bus	
	30			
	35			
	40			
	45	std. bus		
	50			

* On basis of annual cost per connecting passenger.

Table 5.3 Appropriate* Intra-Airport Transportation System for Connecting Passengers (16 Gate Modules)

No. of Modules		2	3	4
Annual Enplaned Air Passengers		4 million	6 million	8 million
% Connecting Passengers	10	mini-bus	mini-bus	std. bus
	15	↓	std. bus	↓
	20	↓	↓	↓
	25	std. bus	↓	↓
	30	↓	↓	↓
	35	↓	↓	AGT or moving walkway**
	40	↓	↓	↓
	45	↓	↓	↓
	50	↓	↓	↓

* On basis of annual cost per connecting passenger.

** Moving walkway has lowest annual cost for configuration A; AGT has lowest annual cost for configuration B.

five intra-airport transportation systems. Data for all terminal concepts and configurations have been combined and are presented in Figures 5.8 to 5.12. There is considerable spread in data points for the different transportation systems, however trends do appear. As the number of connecting passengers increase, the annual cost per connecting passenger of an intra-airport transportation system decreases and seems to level off at about 1.5 to 2 million annual connecting passengers.

The annual cost data that has been presented in this section is based on the service parameters described in Section 5.1. There are numerous combinations of these parameters and variations would impact the cost estimates. Possible effects of assuming different parameters are summarized:

Service Parameter	Possible Impact
increase vehicle capacity	- reduce vehicles required for service
	- increase headway required, which will increase waiting time
	- increase cost of an individual vehicle, if increasing vehicle capacity implies larger vehicles
	- could lower operating costs as fewer trips would be required, however a larger vehicle may result in a higher operating cost per vehicle mile
increase average speed	- reduce vehicles required for service
	- could lower operating costs

	depending on performance characteristics of the vehicle
increase maximum headway restriction	- reduce total cost as fewer vehicles and fewer trips would be required to accommodate demand
	- increase waiting time

The cost estimates have been prepared on the basis of minimum separation requirements between modules for the Boeing 767 design aircraft. If the distances between modules were increased, the annual costs per connecting passenger would also increase due to a lengthening of routes. Longer routes would have the following impacts:

- increase vehicle miles of travel
- increase guideway requirements
- increase vehicle requirements

5.4.2 Annual Cost per Enplaned Passenger

The impact on annual cost per enplaned passenger of the terminal area of incorporating an intra-airport transportation system for connecting passengers has also been examined. The annual cost per enplaned passenger is an important guideline used by airport authorities in setting terminal area rentals and fees.

Cost estimates of the terminal area have been made assuming all passenger trips made in the terminal are walking trips. The unit costs used to estimate terminal construction, and operating and maintenance costs were presented in Section 4.2.4. Annual costs were then

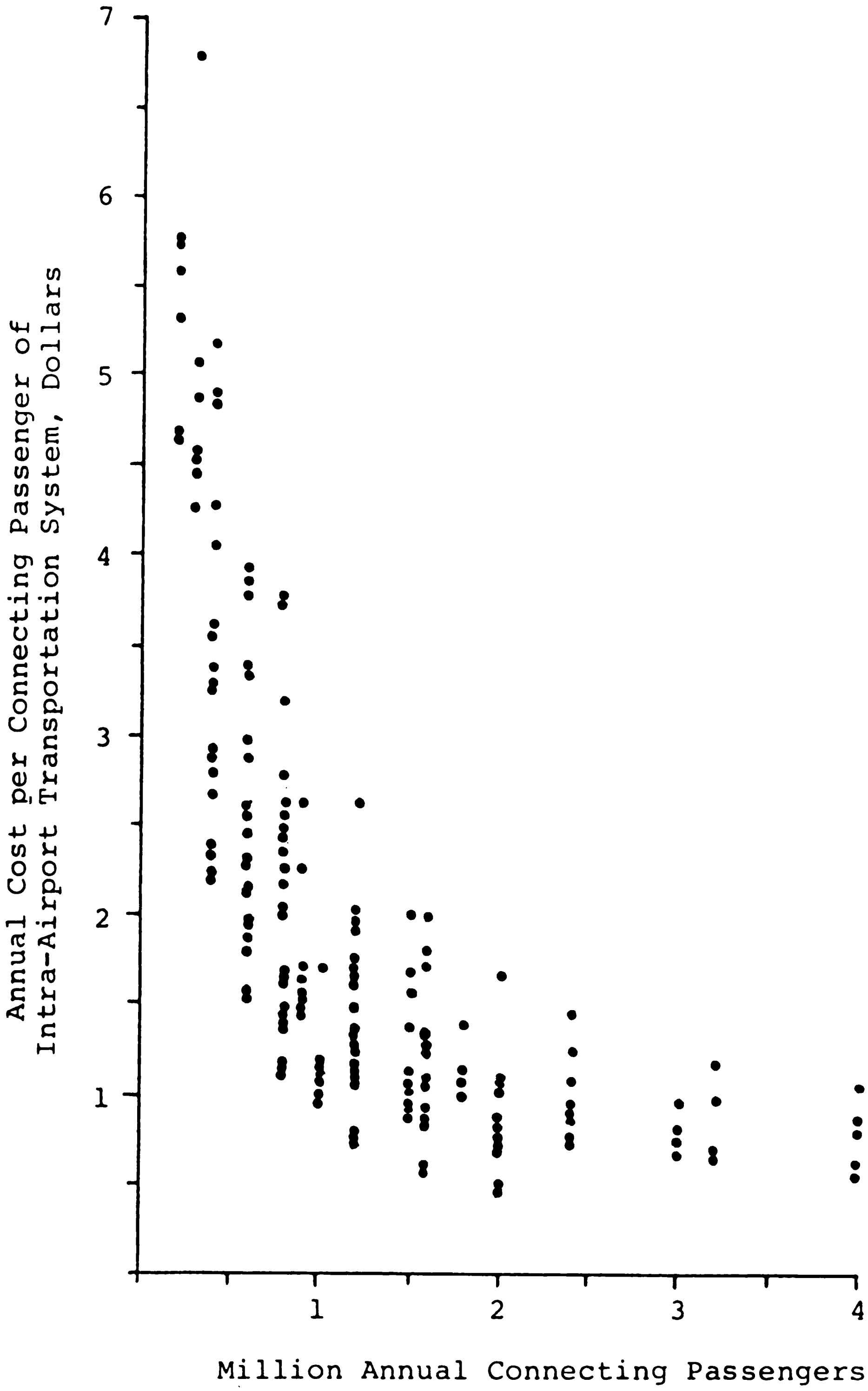


Figure 5.8 Annual Cost per Connecting Passenger of AGT System, Loop Alignment

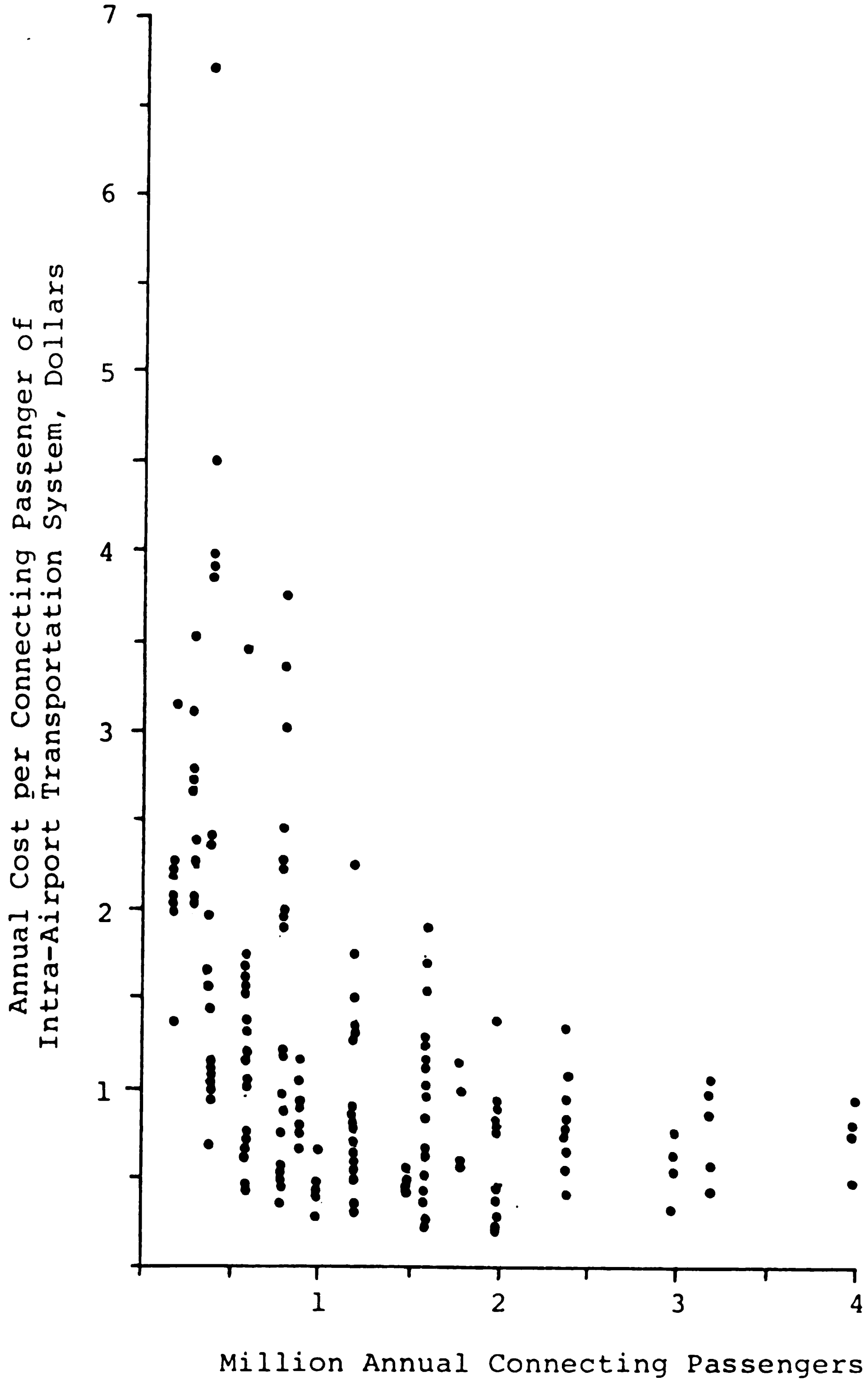


Figure 5.9 Annual Cost per Connecting Passenger of AGT System, Shuttle Alignment

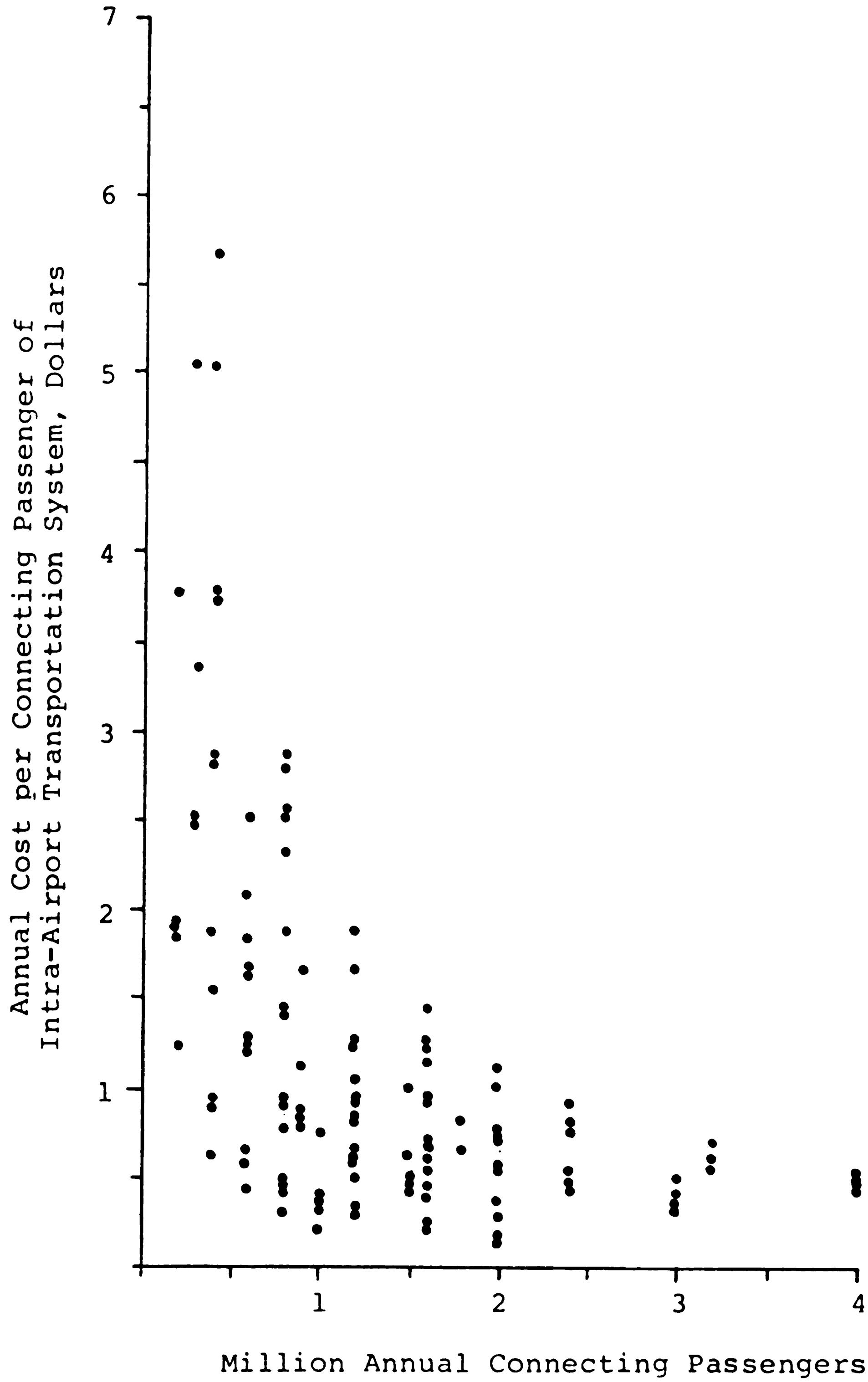


Figure 5.10 Annual Cost per Connecting Passenger of Moving Walkways

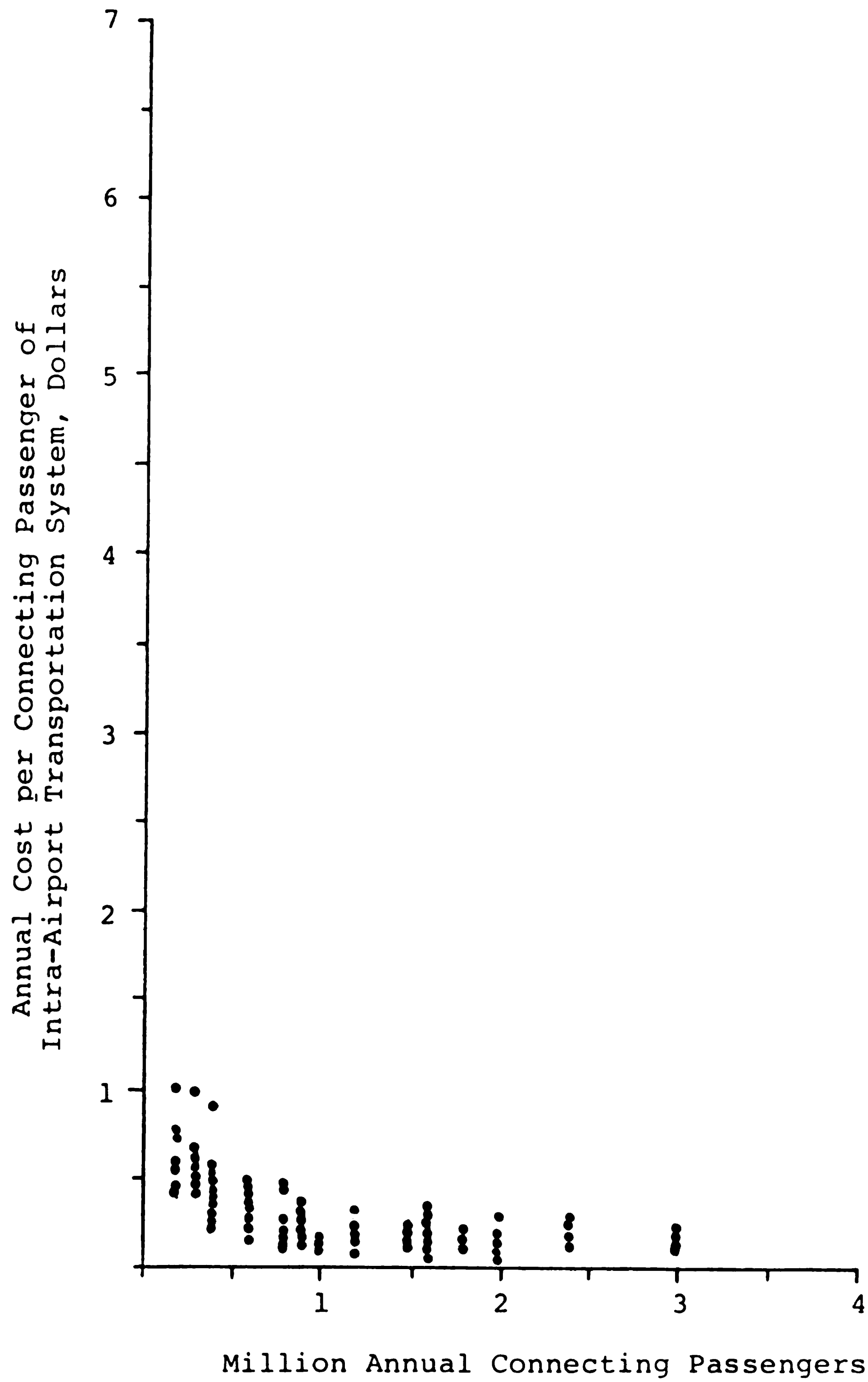


Figure 5.11 Annual Cost per Connecting Passenger of Standard Bus System

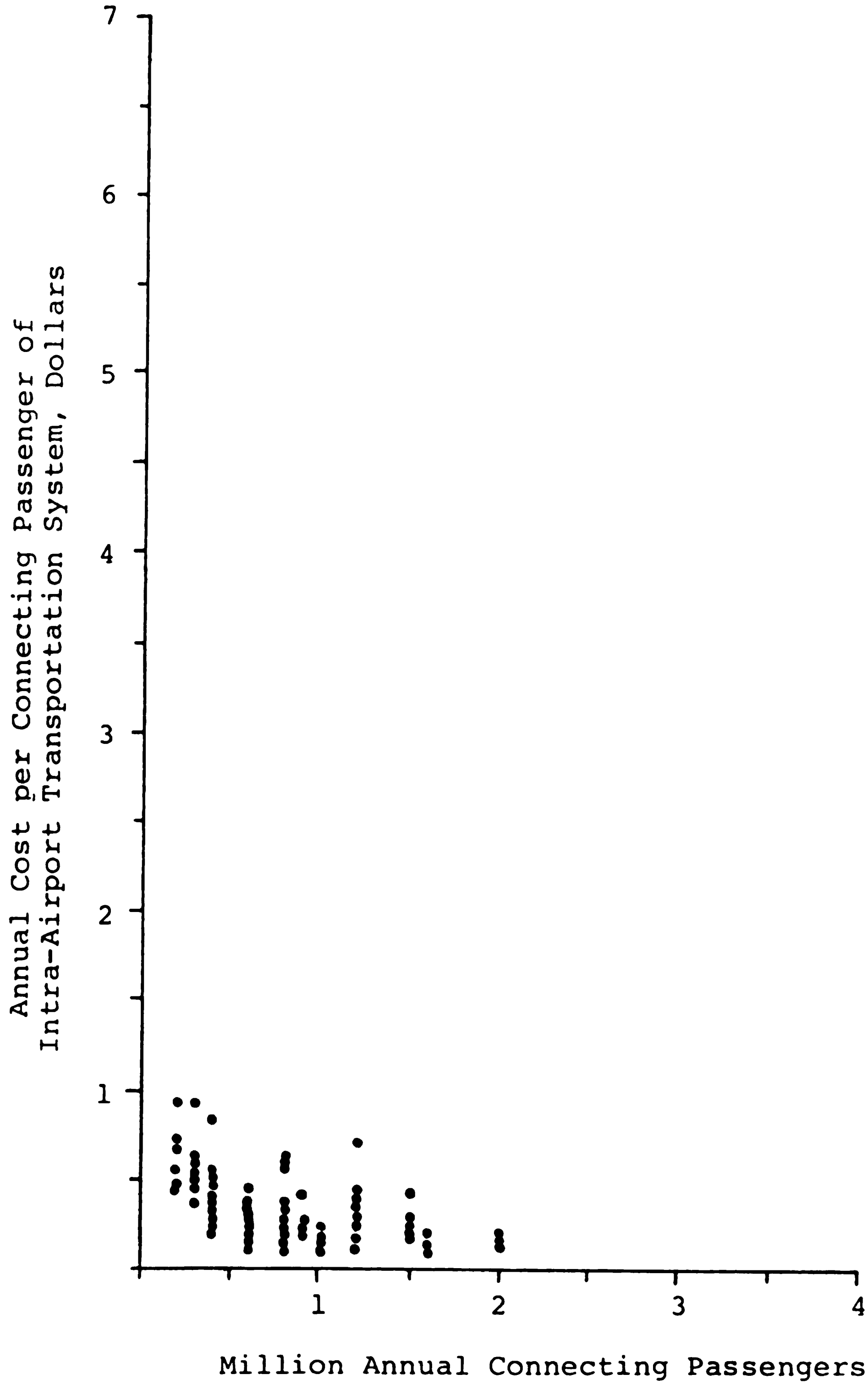


Figure 5.12 Annual Cost per Connecting Passenger of Minibus System

calculated and divided by the total annual enplaned passengers that the terminal serves.

The annual cost per enplaned passenger varies with the terminal concept, number of modules, terminal area configuration, and level of connecting passengers. Ranges in these costs are present in Table 5.4. The lower end in the range is for one module with 50% connecting passengers and the upper end is for two or four modules in configuration B with no connecting passengers. All other combinations of modules, configurations, and levels of connecting passengers fall within the ranges presented. Higher annual costs per enplaned passenger for the Transporter(8) terminal concept reflect the operation of mobile lounges that transfer passengers between the terminal and aircraft that are parked on the apron. The higher annual cost per enplaned passenger for Pier(16) and Satellite(16) terminal concepts reflect the costs of parking structures and a two level curb. Surface parking and a single level curb has been assumed for a single 8-gate module.

The cost of incorporating intra-airport transportation system alternatives was then added to the cost of the terminal area. Annual costs were calculated and divided by the total annual enplaned passengers and these costs are presented in Figures 5.13 and 5.14 for the terminal concepts at a 20% connecting passenger level. The dashed line shows the annual cost per enplaned passenger in which

Table 5.4 Annual Cost* per Enplaned Passenger of Terminal Modules

Module	Range in Annual Cost per Enplaned Passenger**
Pier (8)	$3.34 - 4.54
Satellite (8)	3.35 - 4.56
Linear (8)	3.33 - 4.57
Transporter (8)	3.52 - 4.73
Pier (16)	3.65 - 4.49
Satellite (16)	3.70 - 4.57

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* Estimated cost includes construction, operation and maintenance of terminal building, terminal access roads and parking, and apron area. The contribution of each component to the annual cost is approximately:

construction	- terminal building	-	40%
	- access roads and parking	-	10-20%
	- apron	-	5%
operating and maintenance		-	35-45%

** The lower end of range is for one module with 50% connecting passengers, and the upper end is for two or four modules in Configuration B with no connecting passengers.

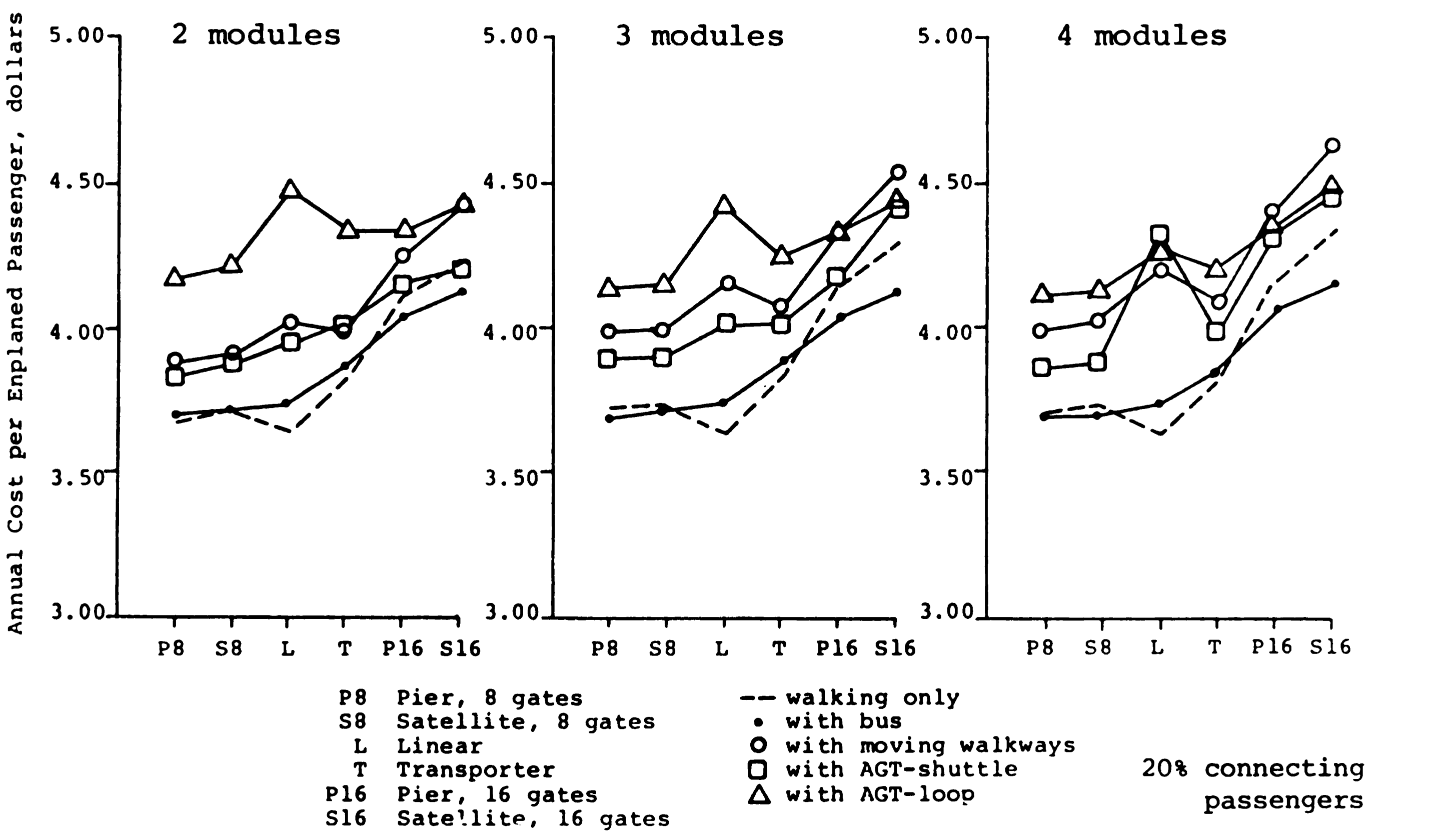


Figure 5.13 Annual Cost per Enplaned Passenger, Terminal Configuration A

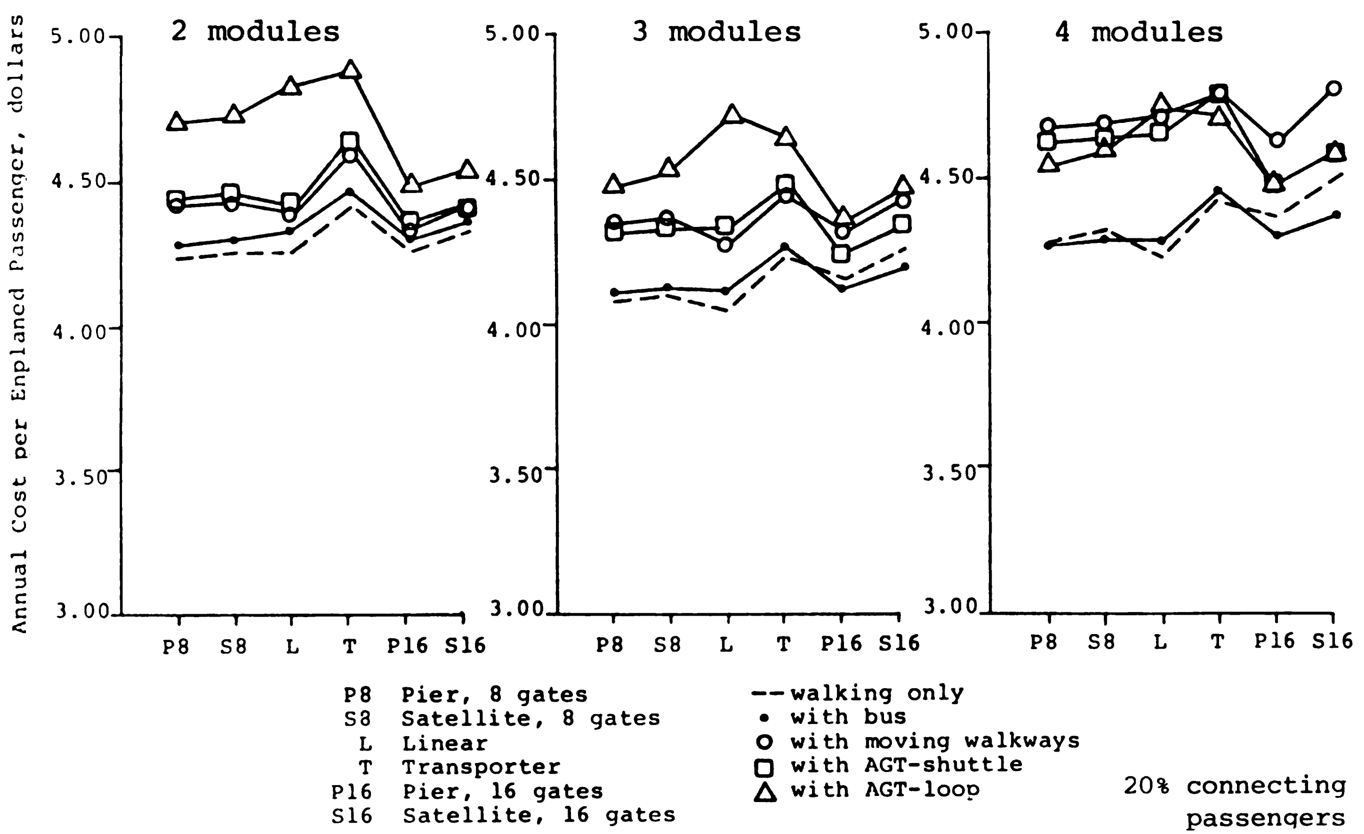


Figure 5.14 Annual Cost per Enplaned Passenger, Terminal Configuration B

all passenger trips in the terminal are walking trips. The solid lines show the annual cost per enplaned passenger of the terminal that includes an intra-airport transportation system to reduce the walking distances for connecting passengers only. The solid lines are generally above the dashed line, however in some cases, the annual cost per enplaned passenger is lower with an intra-airport transportation system. This results when the cost of constructing and maintaining links for walking between modules is greater than providing an intra-airport transportation system and occurs for some Pier and Satellite terminal concepts that have been included in the study.

The average percentage increase or decrease in annual cost per enplaned passenger of the terminal area with the addition of an intra-airport transportation system for connecting passengers is summarized on Table 5.5 for each terminal concept and configuration. For this study, it has been assumed that only one means of transfer would be provided for passengers between modules. As a result, negative values appear on the table for cases where an intra-airport transportation system that transfer passengers between terminal modules would have a lower cost than extending the terminals to provide a walking link. In actual terminal planning, modules that are located close to each other would be linked and passengers may have several choices for movement within the terminal.

Table 5.5 Average Percentage Increase or Decrease in Annual Cost per Enplaned Passenger of Terminal Area with Addition of Intra-Airport Transportation System for Connecting Passengers

		Intra-Airport Transportation System				
Terminal Concept	Terminal Configuration	Minibus	Standard Bus	Moving Walkway	AGT-Shuttle	AGT-Loop
Pier (8)	A	0.2	-0.2	6.6	4.6	12.1
	B	0.6	0.4	6.7	6.4	9.5
Satellite (8)	A	0.1	-0.2	6.2	5.0	12.3
	B	0.5	0.3	6.7	6.4	9.7
Linear (8)	A	3.5	3.0	13.6	13.2	22.7
	B	1.9	1.5	8.0	7.5	14.7
Transporter (8)	A	1.9	1.6	6.5	5.4	12.5
	B	1.2	1.0	6.5	6.9	9.7
Average: 8 Gate Modules		1.3%	0.9%	7.7%	6.9%	12.9%
Pier (16)	A	-1.6	-1.7	5.1	3.2	6.0
	B	-0.6	-0.4	4.1	3.2	4.7
Satellite (16)	A	-3.6	-3.7	5.8	2.3	4.5
	B	-1.4	-1.2	4.4	2.6	4.0
Average: 16 Gate Modules		-1.8%	-1.8%	4.9%	2.8%	4.8%

The following observations are made:

- the smallest impact on the annual cost per enplaned passenger of the terminal area occurs with the use of buses for intra-airport transportation service; the largest impact results with the use of automated guideway transit on a loop alignment.
- smaller increases in annual cost per enplaned passenger occur for terminal concepts with 16 gate modules than with 8 gate modules.
- the smallest impact occurs with the Satellite(16) concept as cost savings result by providing an intra-airport transportation system instead of constructing links for walking between the terminal modules; the largest impact occurs with the Linear(8) terminal concept in configuration A.
- the impact of automated guideway transit in loop alignment is smaller for terminal configuration B.

5.5 Travel Time

The automated guideway transit alternatives have been the most expensive alternatives examined in the study. However, when evaluating intra-airport transportation system, tradeoffs were expected. Because of higher operating speeds, it was anticipated that automated guideway transit would rank high in convenience measures. One measure of convenience that has been considered in this study is travel time.

The average travel time for connecting passengers has been determined for intra-airport transportation system alternatives in each terminal concept. To determine the travel time, it was assumed that connecting passengers would walk from arrival gate to the intra-airport transportation system, board and ride the system, and then alight and walk to their departure gate. A factor has also been included to account for the operating frequency of the intra-airport transportation system. An additional time equal to one half of the headway is added. Figures 5.15 and 5.16 show the average travel times for connecting passengers for each terminal concept at the 20% connecting passenger level.

The average percentage increase or decrease in travel time with an intra-airport transportation system compared to walking only is summarized on Table 5.6. The largest reductions in travel time are obtained by incorporating automated guideway transit on a shuttle alignment. This alignment would be similar to a direct route that a connecting passenger walking from arrival gate to departure gate would follow. Automated guideway transit has been used to replace walking over a portion of the trip. Larger reductions may be achieved for Pier and Satellite terminal concepts by selecting an alignment that would reduce the walking portion even further. Moving walkways could also be used to replace walking on a direct trip, however since the operating speed of moving walkways (120 feet per minute) is less than walking speed, the

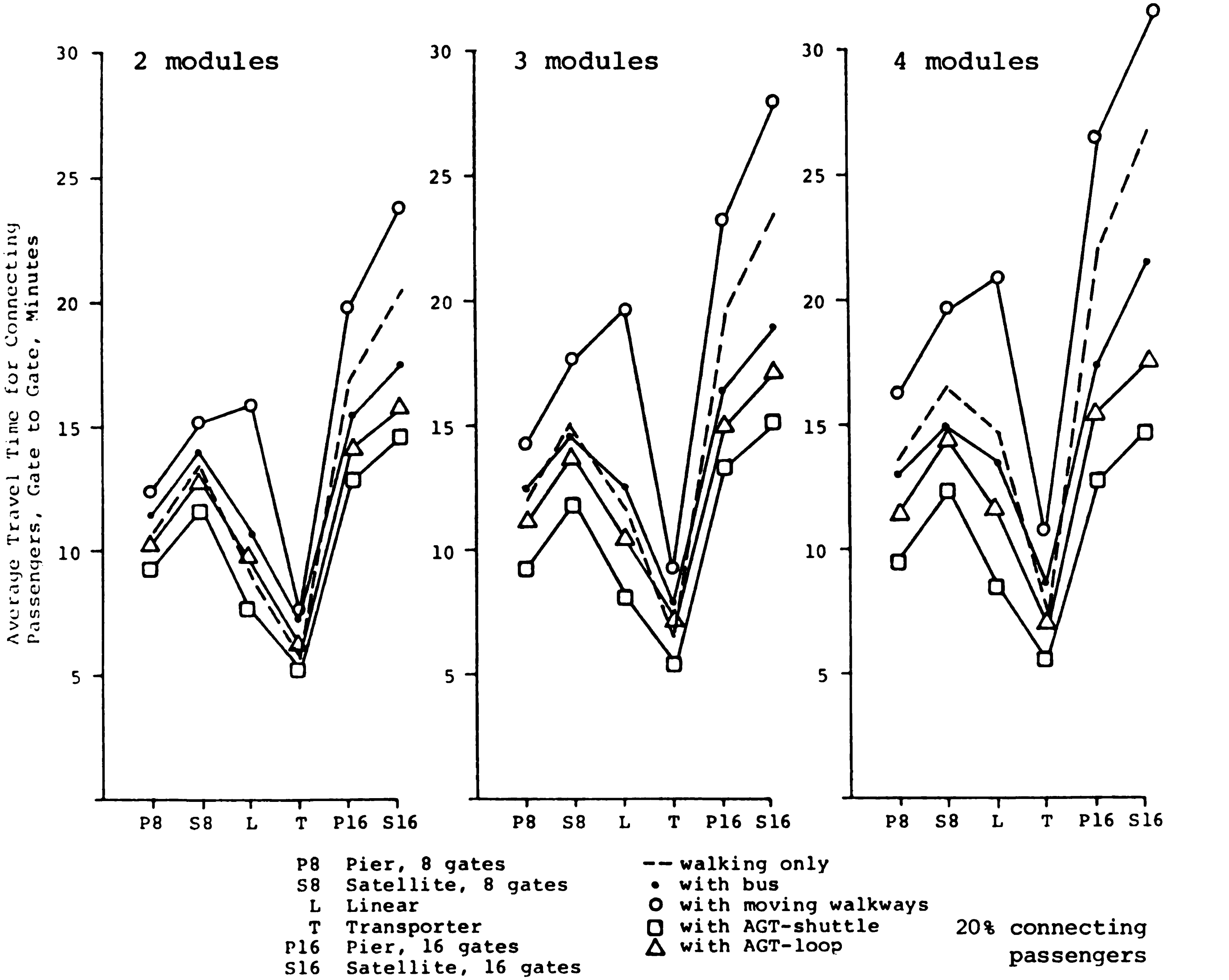


Figure 5.15 Average Travel Time for Connecting Passengers, Terminal Configuration A

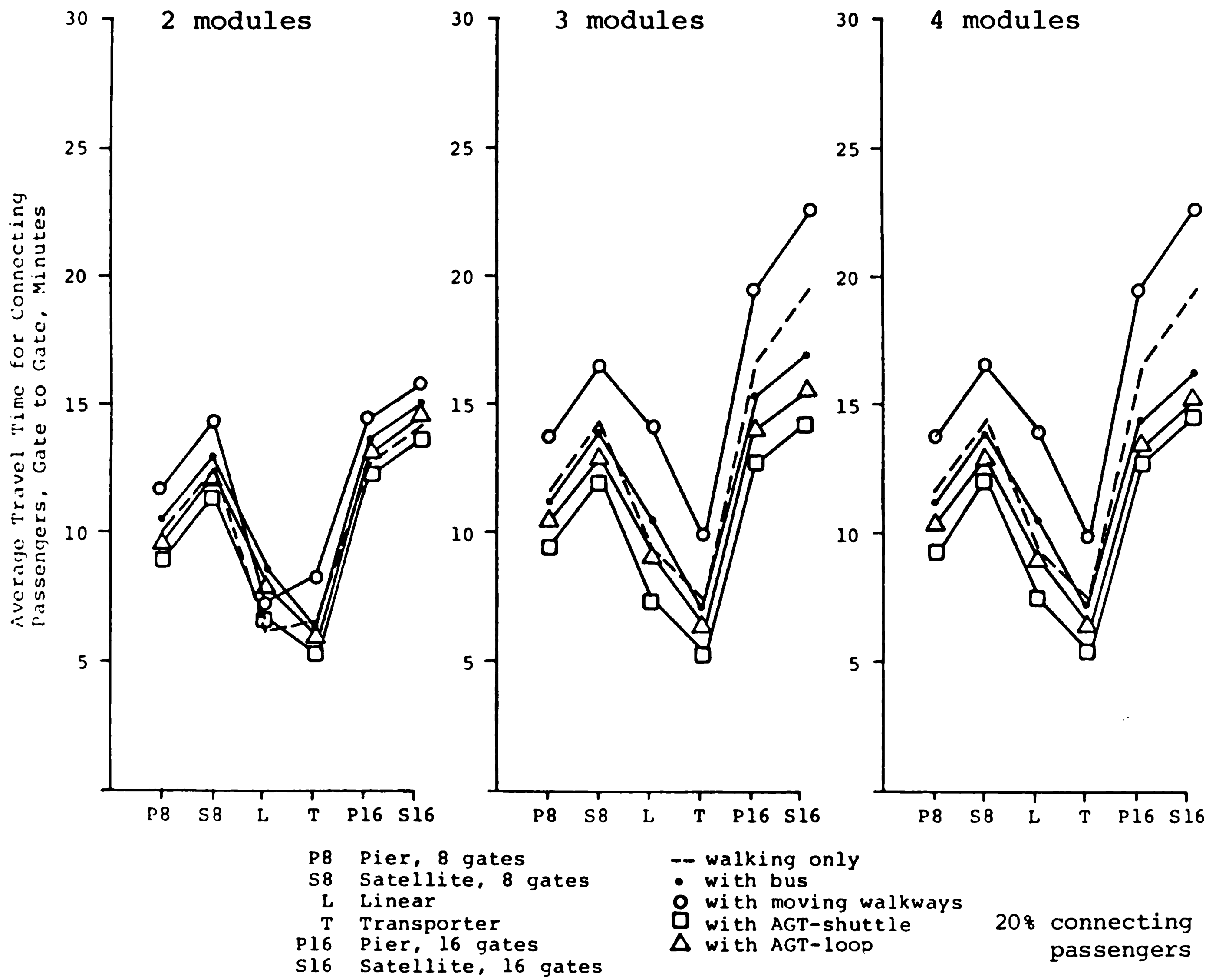


Figure 5.16 Average Travel Time per Connecting Passengers, Terminal Configuration B

Table 5.6 Average Percentage Increase or Decrease * in Travel Time with Intra-Airport Transportatioon System for Connecting Pasengers

			Travel Time** with Intra-Airport Transportation System				
Terminal Concept	Terminal Configuration	Average Travel Time** Walking Only	Minibus	Standard Bus	Moving Walkway	AGT-Shuttle	AGT-Loop
Pier (8)	A	11.9 minutes	- 1%	+ 1%	+18%	-22%	- 9%
	B	11.1	- 5	- 2	+18	-17	- 9
Satellite (8)	A	14.9	- 4	- 2	+16	-20	- 9
	B	13.7	- 3	- 1	+15	-13	-10
Linear (8)	A	11.8	+ 1	+ 4	+62	-31	-12
	B	8.3	+16	+20	+39	-11	+ 6
Transporter (8)	A	6.5	+16	+21	+40	-18	+ 2
	B	7.1	- 9	- 4	+33	-25	-14
Pier (16)	A	19.4	-18	-18	+19	-35	-26
	B	15.4	- 9	- 8	+16	-19	-14
Satellite (16)	A	23.4	-20	-19	+19	-38	-29
	B	17.8	-11	-10	+14	-22	-16

* Compared to walking only.

** Travel time for connecting passenger, arrival gate to departure gate.

travel time from gate to gate with moving walkways actually increases. Since the bus and AGT on loop alignment follow the terminal access road, the routing is not as direct and the reduction in travel time is not as pronounced as the more direct routing of AGT in shuttle alignment.

Although the travel times with moving walkways are longer than walking, moving walkways provide continuous service. The travel times that are presented in Figures 5.15 and 5.16 are for peak period service in which the headways would be shortest to accommodate the higher passenger demands. In off-peak periods, the travel time using moving walkways remains the same, however the travel time using other intra-airport transportation systems would increase to reflect longer headways.

5.6 Walking Distance

The intra-airport transportation systems have been incorporated in the terminals to reduce the walking distances for connecting passengers. Average walking distances for connecting passengers have been determined. These represent the walking distance from arrival gate to intra-airport transportation system, plus the distance from where the passenger alights the transportation system to departure gate. As a result, the total walking distance with an intra-airport transportation system is related to the walking distances within a module and the station/stop location of the transportation system. The number of modules and configuration does not affect this value.

Table 5.7 presents the average walking distance for connecting passengers when the intra-airport transportation system is incorporated. The longest distances occur with the Pier and Satellite concepts.

A comparison of average walking distance for connecting passengers with an intra-airport transportation system, to the average walking distance without a system has also been made to estimate the reduction in walking distance. Figure 5.17 illustrates the average walking distances for each terminal concept in configuration A, and Figure 5.18 presents similar information for configuration B. The largest reductions in walking distances occur as the number of modules is increased.

On review of the resulting average walking distances with the intra-airport transportation system, further reductions would be required for the Pier and Satellite concepts if the objective were to have average walking distances for connecting passengers of below 1000 feet. Two approaches that could be considered are shown in Figure 5.19.

(1) Incorporate a transportation system in the pier of the Pier concept or between the satellite and central landside terminal of the Satellite concept, similar to Tampa airport. In addition to serving connecting passengers, the system would handle originating and terminating passengers. Moving walkways or automated guideway transit could be employed for this purpose.

Table 5.7 Average Walking Distance in Terminal Concepts

Terminal Concept	Average Walking Distance, feet		
	Connecting Passenger with Transport System[1]	Originating Passenger[2]	Terminating Passenger[3]
Pier (8)	1100	788	709
Satellite (8)	1550	1023	945
Linear (8)	700	417	355
Transporter (8)	400	601	413
Pier (16)	1700	1030	868
Satellite (16)	1950	1172	1053

[1] Arrival gate to departure gate

[2] Curb to departure gate

[3] Arrival gate to curb

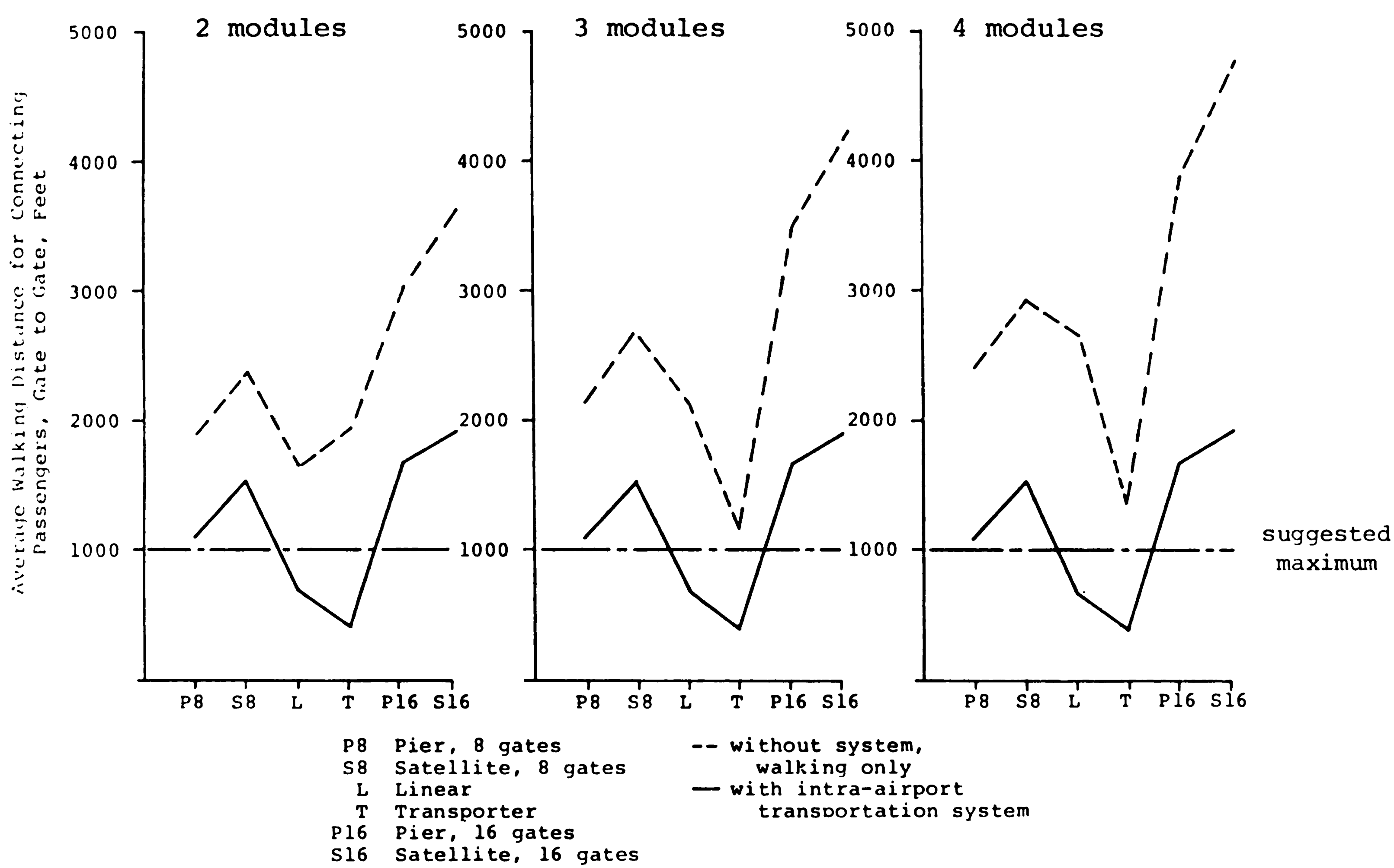
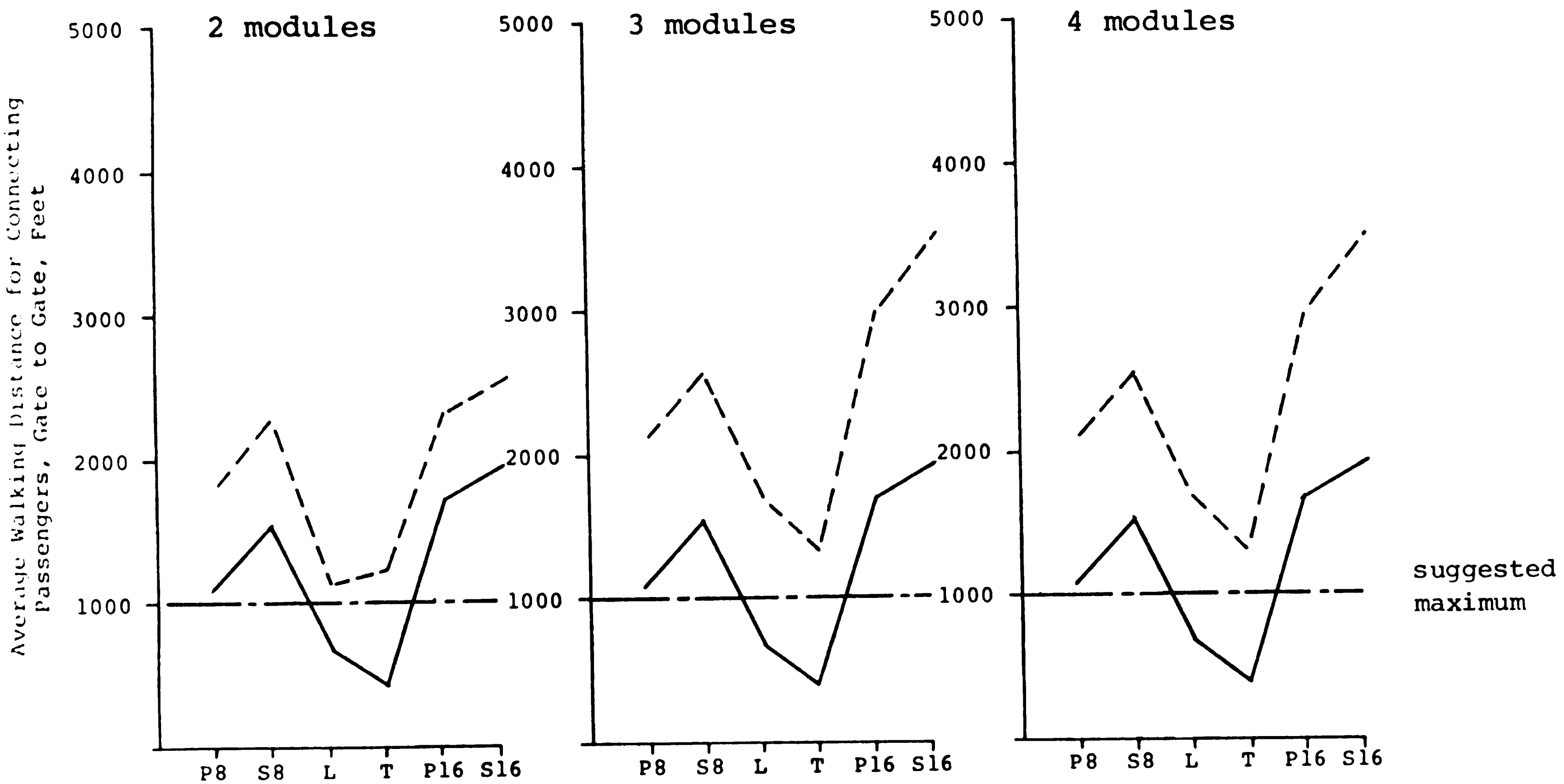


Figure 5.17 Average Walking Distance for Connecting Passengers, Terminal Configuration A

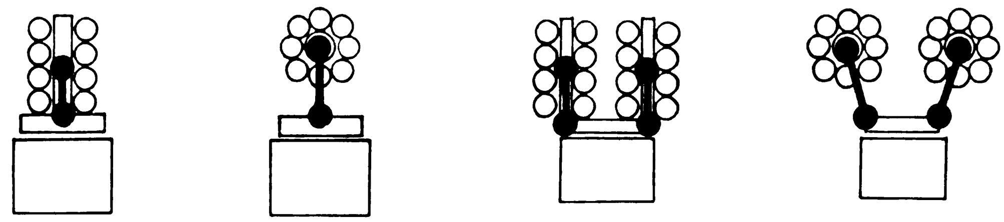


P8 Pier, 8 gates
S8 Satellite, 8 gates
L Linear
T Transporter
P16 Pier, 16 gates
S16 Satellite, 16 gates

-- without system, walking only
— with intra-airport transportation system

Figure 5.18 Average Walking Distance for Connecting Passengers, Terminal Configuration B

(1) Intra-Terminal System



(2) Inter-Terminal System Under Apron

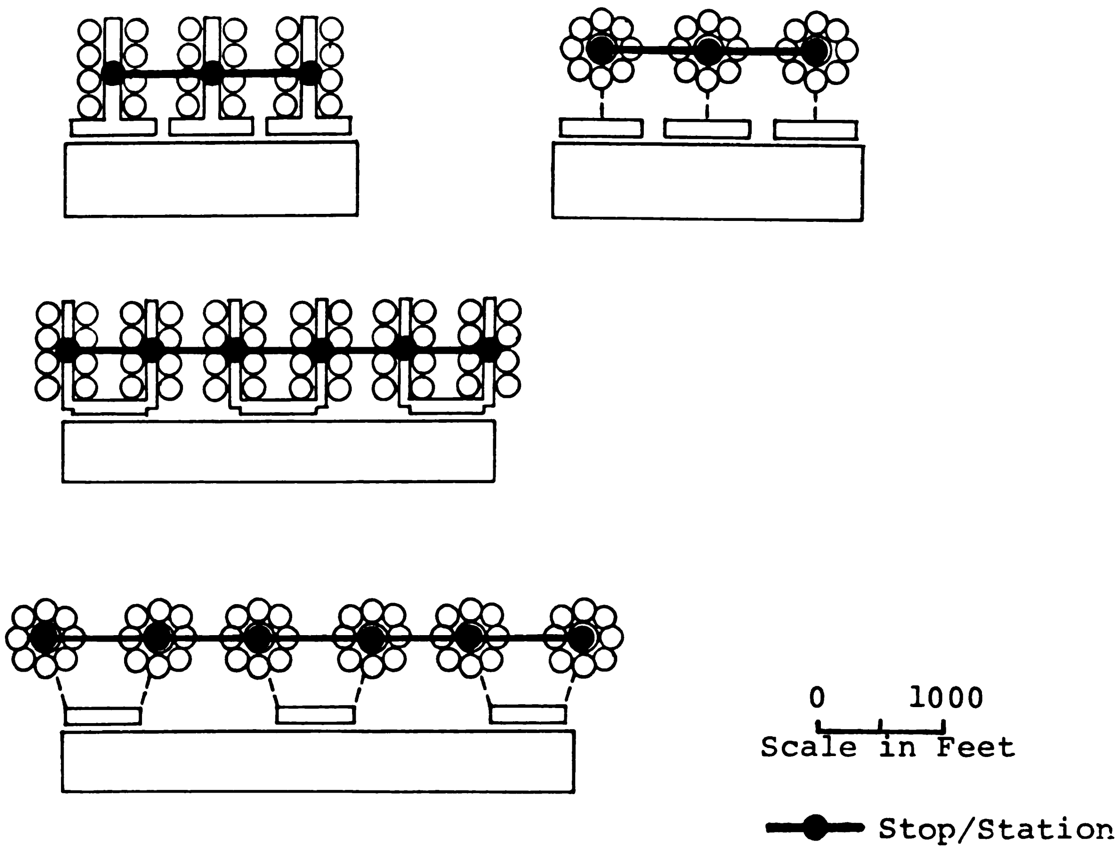


Figure 5.19 Alternative Intra-Airport Transportation System Routes to Reduce Walking Distances for Connecting Passengers in Pier and Satellite Terminal Concepts

(2) Placing the system under the apron to provide a direct link from pier to pier, or satellite to satellite. A similar approach is presently being implemented at the Atlanta-Hartsfield Airport (Figure 2.3). The original concept consisted of a landside terminal and four satellite terminals that are connected by a central underground transportation mall. Moving walkways are now being placed in a tunnel that links the ends of adjacent satellites to eliminate a longer walk to use the central system.

The annual cost per connecting passenger and the effect on walking distance and travel time by placing the automated guideway system under the apron were examined for the Pier and Satellite concepts in configuration A.

5.7 Alternative Alignments for Pier and Satellite Concepts

By placing the intra-airport transportation system in a tunnel under the apron, a direct link would be provided for connecting passenger and average walking distances could be reduced below the suggested guideline of 1000 feet. It was anticipated that the costs of this alternative would be considerably higher than the alternatives initially examined because of tunnel construction.

Estimates of the construction, operating and maintenance costs of using automated guideway transit in a tunnel on a shuttle alignment have been made for Pier and Satellite concepts in configuration A. Total annual costs were prepared and divided by annual connecting passengers so that comparisons could be made to annual cost per connecting passenger values that were presented in Figure 5.5. The annual costs per connecting passenger of an automated guideway transit shuttle in a tunnel for a 20% connecting passenger level are shown in Figure 5.20. For the Pier and Satellite 8-gate modules, the annual cost per connecting passenger falls between the costs of automated guideway transit on shuttle and loop alignments that linked the central terminal areas. However, for the Pier and Satellite 16-gate modules, the annual cost per connecting passenger of placing automated guideway transit in a tunnel to link the modules is higher than all other alternatives originally examined. This results from additional stations and longer guideways than were initially required for the system linking the central terminal areas. A bus system operating on the terminal access road continues to be the lowest annual cost per connecting passenger alternative.

Although the annual cost per connecting passenger of placing the automated guideway transit system in a tunnel is higher than other alternatives, the average walking distances for connecting passengers have been reduced below the suggested guideline of 1000 feet. The average walking distances from gate to gate for connecting passengers with an automated guideway transit shuttle system in a tunnel are shown in Figure 5.21 and the resulting travel times for connecting passengers are presented in Figure 5.22.

It becomes apparent that by using the average walking

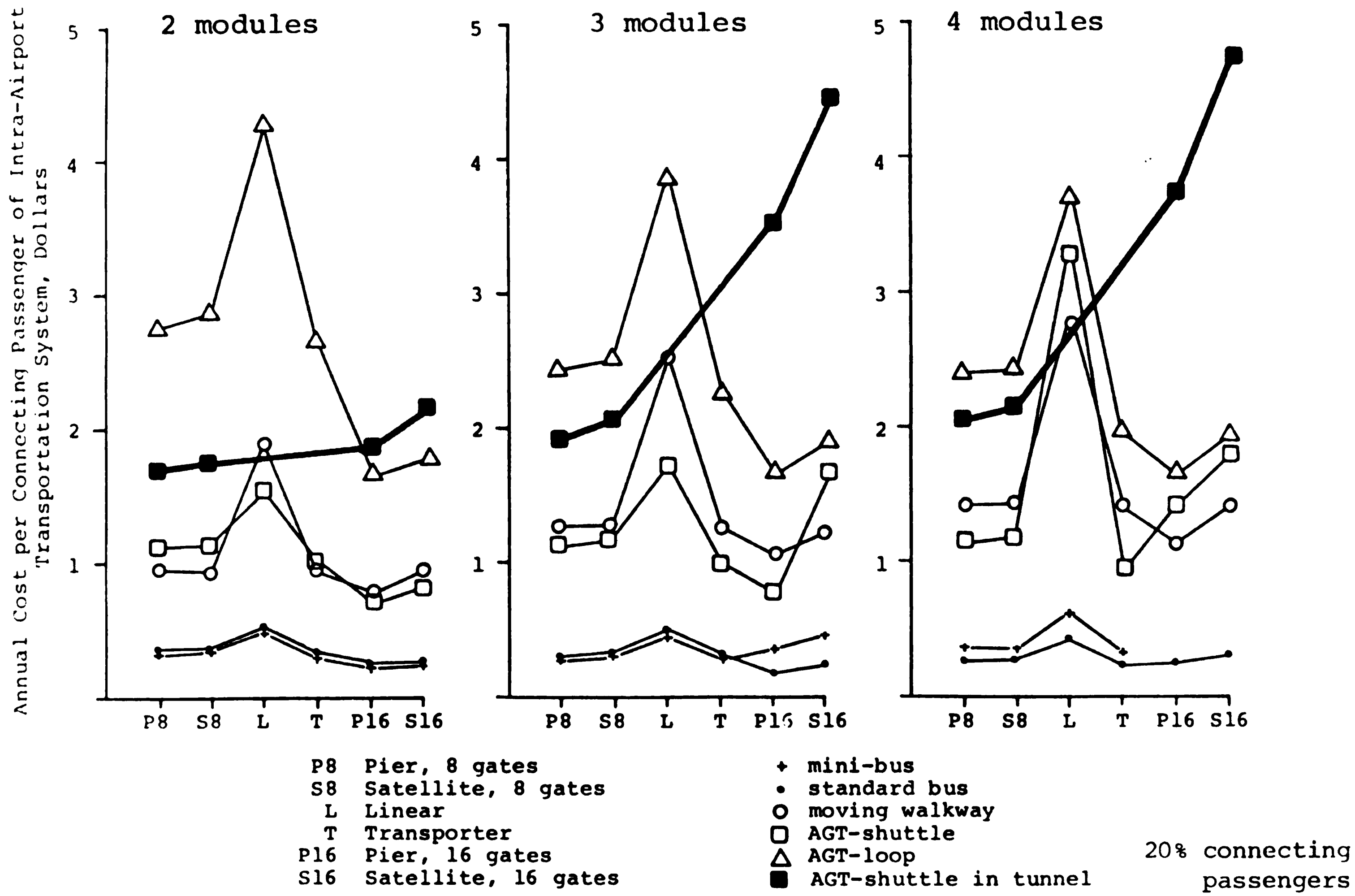


Figure 5.20 Annual Cost per Connecting Passenger of AGT Shuttle in Tunnel, Terminal Configuration A

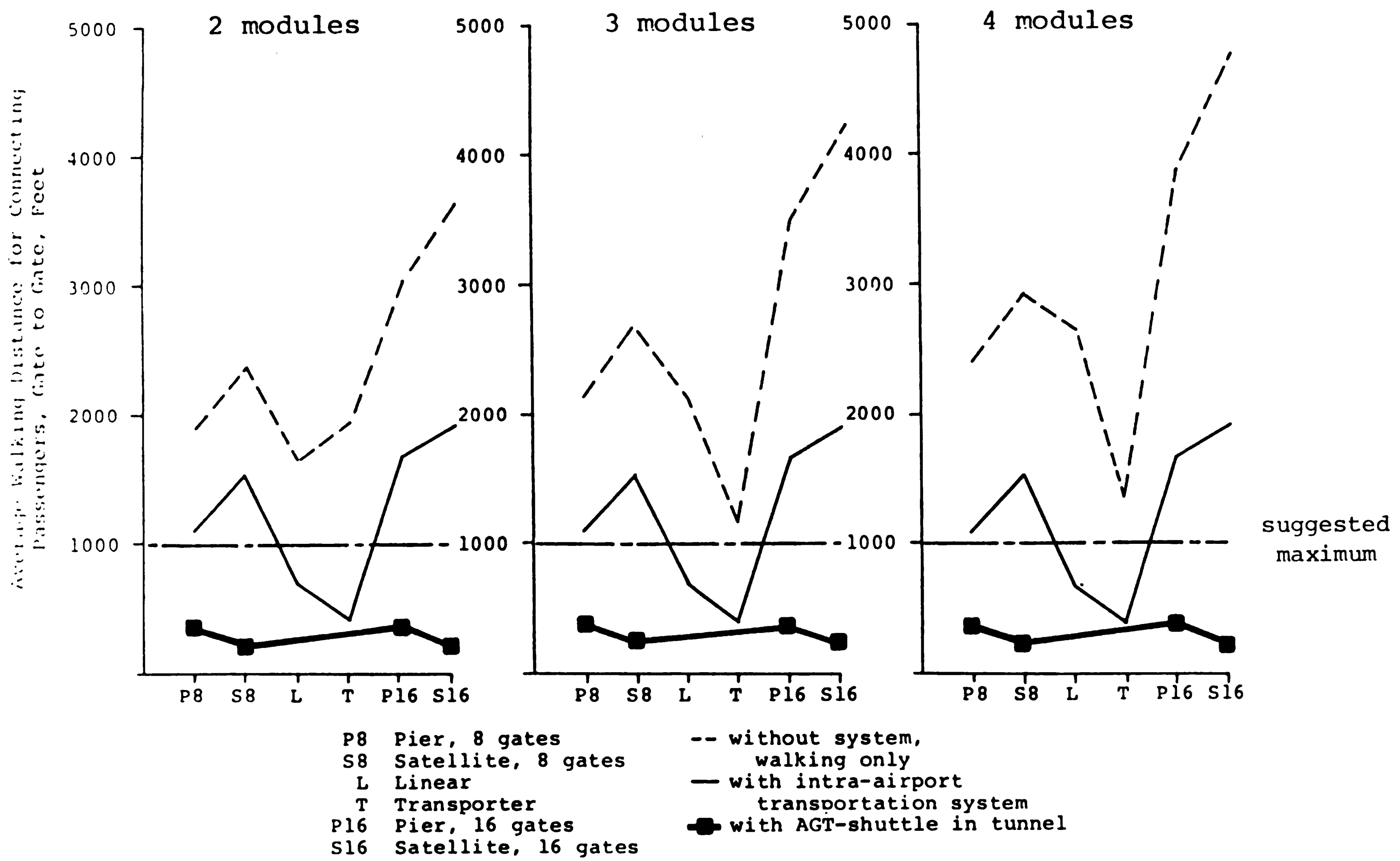


Figure 5.21 Average Walking Distance for Connecting Passengers with AGT Shuttle in Tunnel, Terminal Configuration A

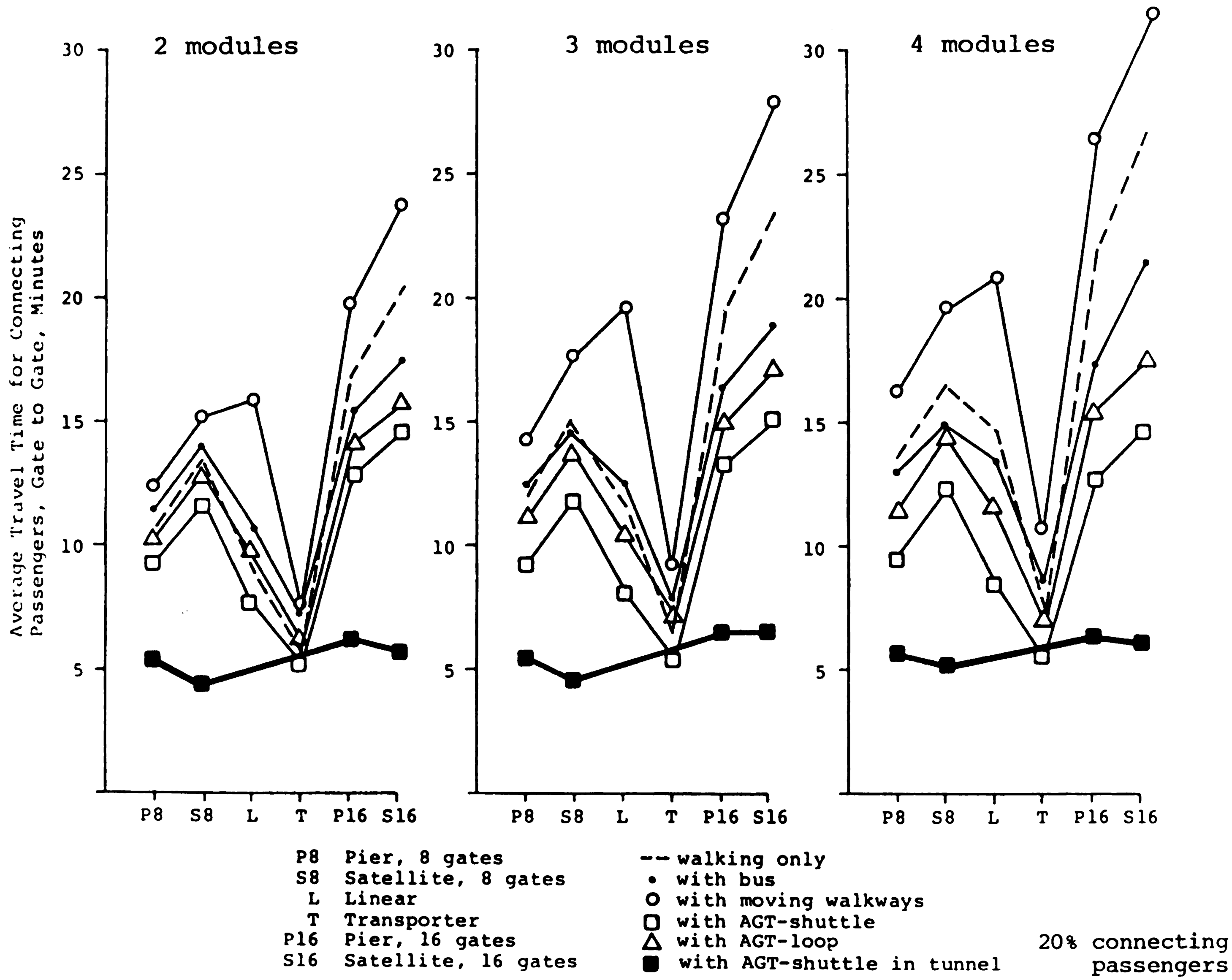


Figure 5.22 Average Travel Time for Connecting Passengers with AGT Shuttle in Tunnel, Terminal Configuration A

distance guideline of 1000 feet, several of the intra-airport transportation systems could not be used for the Pier and Satellite concepts as the average walking distances for connecting passengers between gates and transit stops/stations are above 1000 feet.

Tradeoffs between walking distance and system alternatives and costs result. Travel time is also inherent in the tradeoff and a reduction in walking distance will usually result in a shorter travel time for connecting passengers as walking is generally the slowest portion of the trip.

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 Summary

Consideration and analysis of various intra-airport transportation systems to reduce walking distances and provide for the efficient movement of passengers on the airport site is expected to become an important component in terminal planning studies. A framework for the planning of intra-airport transportation systems has been developed in this study and techniques have been prepared to assist the terminal planner in the conceptual phase of the terminal design process. These include nomographs to determine service characteristics for a system and cost estimating procedures. Modifications have also been made to a Federal Aviation Administration analytical terminal planning model to expand its capabilities to assess the impact of an intra-airport transportation system on other passenger processing facilities.

The FAA Airport Landside Model was originally developed to assist in planning of the landside facilities at an airport and it has become a valuable tool that can be used in the conceptual and schematic design phases. Its use provides the planner with the opportunity to vary parameters in the terminal and assess the impacts. In addition to the modifications to incorporate an intra-airport transportation system, provision has been made to trace connecting pasengers through the terminal area, and additional passenger processing facilities have been included.

Using the framework and techniques, intra-airport transportation systems have been incorporated in "generic" terminals of various concepts and for different passenger demand levels to identify guidelines for the use of these systems.

6.2 Conclusions

The average walking distances for originating and terminating passengers in all of the terminals examined fall within the suggested guideline for maximum walking distance of 1000 feet. However, the average walking distances for connecting passengers exceed the guideline. Minibuses, conventional buses, automated guideway transit operating on a loop alignment, automated guideway transit operating on a shuttle alignment, and moving walkways have each been incorporated in generic terminals to reduce the walking distances for connecting passengers. Route alignments and service characteristics were developed and the total capital/construction cost, annual operating and maintenance cost, total annual cost per connecting passenger, and total annual cost per enplaned passenger were determined for each system, for each terminal concept and configuration, and for several connecting passenger levels. Reductions in travel times were also quantified for each case.

The primary conclusions and findings of applying the methodology developed in this study to the generic terminals include the following:

1. Intra-airport transportation systems operating in linear terminal concepts have the highest total annual cost per connecting passenger, while systems operating in terminals with a more compact arrangement, such as the transporter concept or pier and satellite concepts with 16 gate modules, have the lowest total annual cost per connecting passenger.

The distances travelled and lengths of guideways for an intra-airport transportation system serving connecting passengers in a linear terminal are the longest for the terminal concepts examined and this results in the highest total annual operating cost per connecting passenger.

2. Bus systems have the lowest capital cost and lowest total annual cost per connecting passenger, however these systems have capacity limitations. The capacity of a minibus system is about 750 passengers per hour per direction, and the capacity of a system using conventional or standard size buses is about 1500 passengers per hour per direction.

At lower connecting passenger volumes, the minibus system has the lowest total annual cost per connecting passenger, but as the demand approaches the capacity, a system using standard buses has a lower total annual cost per connecting passenger. The level at which this occurs depends on the terminal configuration but is in the range of 600,000 to 1 million annual connecting passengers.

Since a bus system would share terminal access roads and curbfront with other vehicular traffic, congestion is likely to occur as the demand increases and additional buses are required to accommodate the demand.

3. Moving walkways have higher total annual costs per connecting passenger than bus systems, but can be incorporated within a terminal building to provide a more direct route for connecting passengers than bus systems. The routing of the bus systems would be restricted by the terminal access road layout.

When compared to travel times for connecting passengers walking between gates, the times are increased as moving walkways operate at less than walking speed. However, since moving walkways provide continuous service, no waiting time is required and this is an attractive feature.

4. Automated guideway transit systems have the lowest operating and maintenance costs, but the total annual costs per connecting passenger are high due to the fixed guideway and station requirements. Automated guideway transit provides the greatest potential for reductions in travel times for connecting passengers because of the higher

operating speeds of vehicles on exclusive guideways, and becomes an attractive alternative on a cost basis when the passenger demand exceeds the capacity that can be provided with a bus system. The level at which this occurs depends on the terminal configuration but it is approximately 2.5 to 3 million annual connecting passengers.

Automated guideway transit on a shuttle alignment has a lower total annual cost per connecting passenger than automated guideway transit on a loop alignment for the terminal concepts, configurations and passenger demand levels examined. However, the total annual cost per connecting passengers for the two systems is comparable for configuration B with four terminal modules.

5. A direct or shuttle-type alignment provides the greatest opportunities for shortest travel times and lowest costs.

6. The impact on the annual cost per enplaned passenger of incorporating an intra-airport transportation system for connecting passengers in the terminal area varies with the system, terminal concept, terminal configuration, and the number of connecting pasengers. The largest impact occurs when automated guideway transit operating on a loop alignment is incorporated in a linear terminal concept. The annual cost per enplaned passenger is increased by about 23 percent when compared to the concept without an intra-airport transportation system and

walking is the only means available for connecting passengers.

7. The walking distance guideline becomes an important factor in identifying intra-airport transportation system alternatives for consideration. Alternative systems and route alignments may be eliminated when the walking distances for connecting passengers between gates and system boarding and alighting points exceed the suggested guideline.

For example, the sum of the walking distance from arrival gate to intra-airport transportation system boarding location and alighting point to departure gate exceeds the suggested guidelines of 1000 feet in the pier and satellite terminal concepts examined. Further reduction in walking distances would be required if the objective were to have average walking distances for connecting passengers of below 1000 feet. This would require the introduction of an additional system to reduce the walking distances or placement of the intra-airport transportation system on a different alignment (i.e., in a tunnel under the apron). Bus systems would probably not be considered for these alternative approaches.

8. The selection of an intra-airport transportation system has to be a local decision based upon the desired levels of service and objectives for the individual airport as tradeoffs result between cost, convenience and other

factors. As a result, no attempt has been made in this study to select the appropriate system under various scenarios that include several types of evaluation factors. This study has addressed only the quantitative factors such as walking distance, travel time, and cost.

2.3 Limitations

The framework and techniques developed in this study have general application at airports. The modifications that have been made to the FAA Airport Landside Model provide the planner with a technique to assess the impact of an intra-airport transportation system on passenger processisng facilities within a terminal or between terminals. Further modification would be required so that the model can be used to examine passenger movements between terminals and other activity centers, such as remote parking areas, cargo areas, or adjacent hotels.

Several assumptions have been made in developing the generic terminals and incorporating the intra-airport transportation systems. The systems have been designed to carry connecting passengers only and an equal distribution of connecting passengers between terminals has been assumed. The unit costs represent typical values and do not specifically reflect variations that would occur in different regions of the country. As a result, although the application of the framework and techniques have been demonstrated, care must be taken in extracting cost and convenience values from this study and applying them directly to an actual airport site.

6.4 Future Research Needs

During the course of this study, areas for further research were identified. Work could be undertaken to examine the effects of varying service parameters and route alignments for intra-airport transportation systems. Combinations of transportation systems and guidelines for airport circulation systems could be addressed. In addition, further work would seem necessary to refine capital/construction, and operating and maintenance costing procedures to develop more precise cost estimates of incorporating intra-airport transportation systems on an airport site.

This study has also identified the importance of the walking distance guidelines for planning. Work should be done in this area to clarify guidelines for originating and terminating passengers and develop guidelines for connecting passengers.

Finally, the selection of an intra-airport transportation system has to be a local decision and an evaluation of alternatives involves many considerations and tradeoffs among factors. A framework to assist decision makers in selecting and measuring these factors would be a valuable contribution.

APPENDICES

APPENDIX A

FAA AIRPORT LANDSIDE MODEL - EXAMPLE PROBLEM

The FAA Airport Landside Model* was developed as a tool to assist in the quantitative assessment of the airport landside. It consists of a set of computer routines which analytically model each component of the airport landside and a program and methodology for linking the routines to compute passenger delay and passenger processing time.

For this study, changes have been made to the original model to expand its capabilities. The major changes include the ability to trace the route of connecting passengers and identify time spent by these passengers transferring from gate to gate, and the provision to include an intra-airport transportation system. An example is presented in this Appendix to show the input requirements and output data from the model and illustrate the changes that have been incorporated.

The example consists of two pier modules placed side-by-side and served by one road access system. A people mover system links the two terminals and operates on a loop alignment. The example terminal unit is shown in

---

* The FAA's Airport Landside Model - Analytical Approach to Delay Analysis. Federal Aviation Administration, U.S.D.O.T., Washington, D.C., 1978.

Figure A.1.

There are two basic types of input data. The first is control data that describes overall airport characteristics and includes the following parameters:

- annual passenger enplanements
- number of passengers processed during the peak hour (or design hour)
- number of passenger traffic peaks in a typical day
- number of aircraft operations in the peak hour (or design hour)
- aircraft fleet mix (% widebody aircraft)
- percent of daily passengers processed during peak hour (or design hour)
- average load factor
- percentage of connecting passengers
- origin and destination of connecting passengers within the terminal area (change made for this study)
- percentage of passenger arrivals by auto, taxi, bus, and rail
- average number of bags checked per passenger
- average number of passengers per vehicle using airport roads during the peak hour (or design hour)
- terminal splits
- main roadway capacity (in vehicles per hour)
- number of lanes on main roadway
- percentage of vehicles recirculating
- total number of airport parking spaces
- total airport deplaning curb frontage (feet)
- total airport enplaning curb frontage (feet)

The second is network data that describes

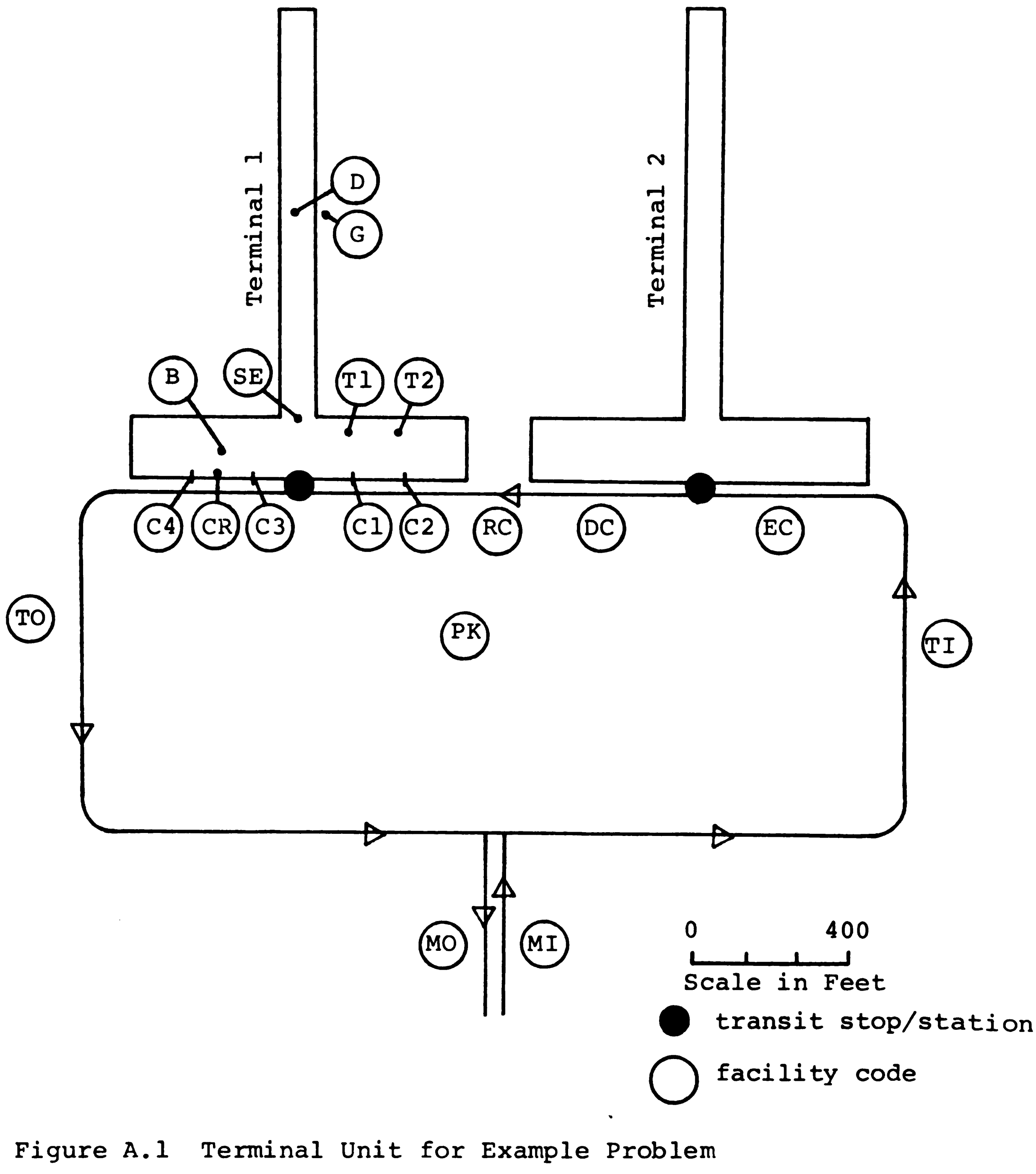
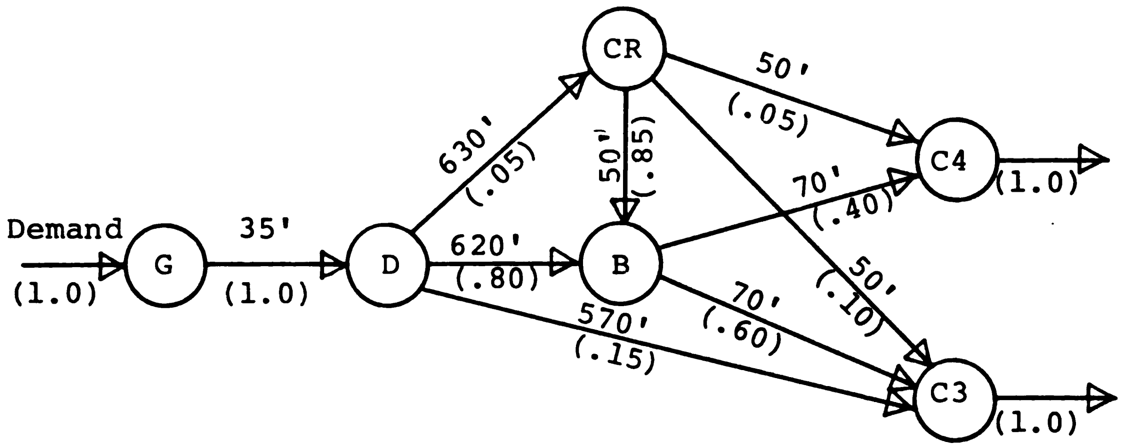


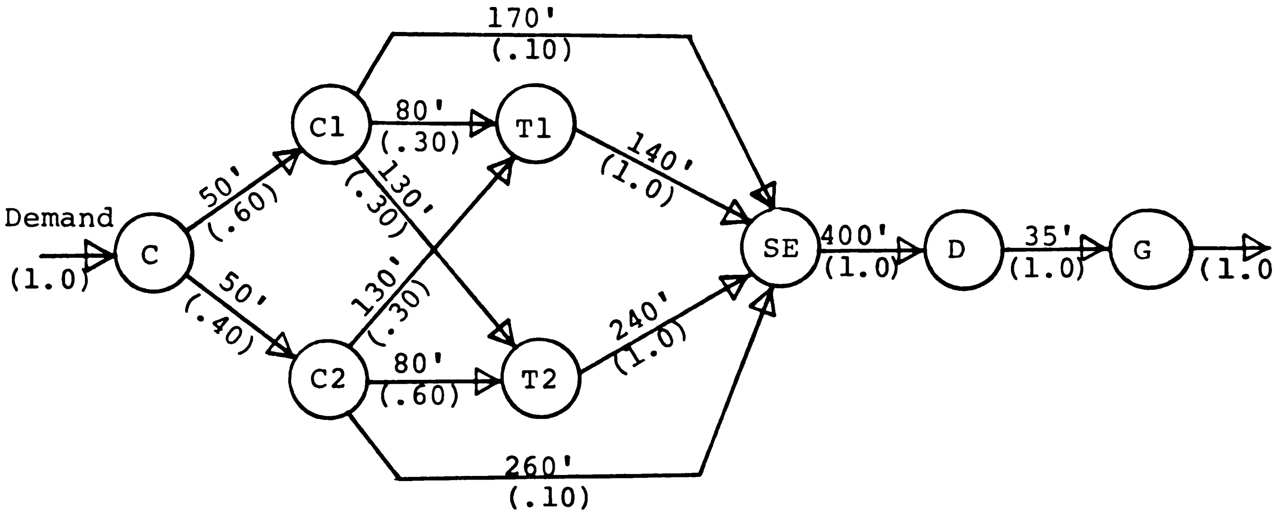
Figure A.1 Terminal Unit for Example Problem passenger flow and passenger servicing characteristics. The passenger flow descriptions include probabilities used by the model to distribute passengers from one processing facility to others. These probabilities are specified in transition probability matrices. The passenger flow descriptions also include the distances (in feet) between the various facilities for each path followed by enplaning, deplaning or connecting passengers. These distances are specified in distance matrices. To assist in the development of these matrices link-node network diagrams are prepared. The nodes represent passenger processing facilities, and the links represent the paths of passengers between these facilities. Figure A.2 presents a network diagram for the deplaning system of either Terminal 1 or Terminal 2. For this example problem, it has been assumed that the two terminals are identical. The distances between processing facilities are shown on the links, and the number in brackets on the links represents the probability of passengers that leave one facility destined to the next. Figure A.3 presents the enplaning system and Figure A.4 presents the connecting systems.

Service characteristics input for each passenger processing facility include the number of units (e.g. number of ticket counters) in service during the peak or design hour, the mean service time, the standard deviation of service time, and applicable queueing model. The two exceptions to this input format for service characteristics



G	Gate
D	Departure Room Area
CR	Rental Car
B	Baggage
C3, C4	Doors

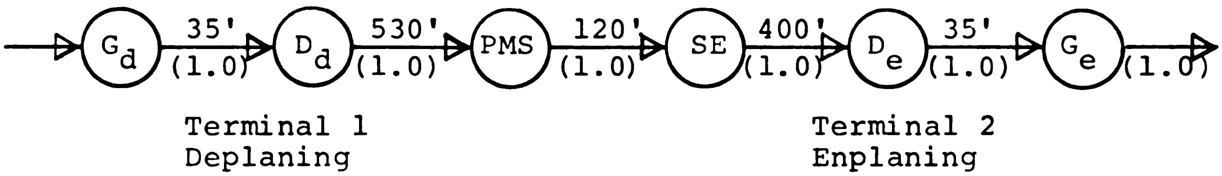
Figure A.2 Deplaning System Network, Terminal 1 and Terminal 2



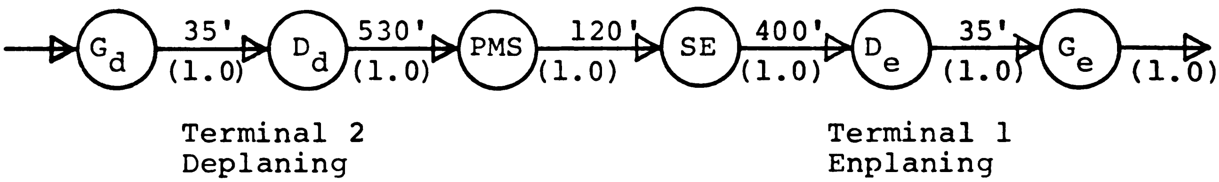
C	Curb
Cl, C2	Doors
Tl	Ticket Counter (express - limited baggage)
T2	Ticket Counter
SE	Security
D	Departure Room
G	Gate

Figure A.3 Enplaning System Network, Terminal 1 and Terminal 2

Terminal 1 to Terminal 2



Terminal 2 to Terminal 1



G_d Gate - deplaning passengers

D_d Departure Room Area - deplaning passengers

PMS People Mover System (Intra-Airport Transportation System)

SE Security

D_e Departure Room - enplaning passengers

G_e Gate - enplaning passengers

Figure A.4 Connecting System Networks

are the baggage claim area and the intra-airport transportation system. For the baggage claim area, the rate at which baggage is placed on the carousel, and the distance from the gate to the baggage claim area are required. The input data for the intra-airport transportation system is the distance between boarding and alighting points (in feet), the average speed (in feet per second), and headway (in seconds).

A roadway model has been incorporated in the FAA Airport Landside Model so network travel and transition probability matrices are not required for the roadway access system. The service characteristics input varies for the parking, curb, and roadway submodels.

For the example problem, the input data is entered in the following order:

Control Data

Network Data

- Deplaning System - Terminal 1
  - Facility Service Characteristics
  - Network Travel Matrix
  - Transition Probability Matrix
- Enplaning System - Terminal 1
- Connection System - Terminal 1 to Terminal 2
- Deplaning System - Terminal 2
- Enplaning System - Terminal 2
- Connecting System - Terminal 2 to Terminal 1
- Road Access System

The input data is shown in Figure A.5.

Figure A.5 Input Data for Example Problem

```
TWO PIER TERMINALS WITH PEOPLE MOVER SYSTEM
B
     1      30
 2000.   1460.    0.10    0.11    0.50
  0.20    0.95    0.04    0.01    0.00    1.50    1.00    0.10    ]-Airport Control Data
     1       2       0
     2
  0.10
  1.00
  0.50    0.50
  0.10    0.10
  0.10    0.10
 2400.       2     .05   3000.    500.    400.
DEPLANING SYSTEM - TERMINAL 1
     6       1                                                    ]-Deplaning System - Terminal 1
     8     10.     10.       1                                      Facility Service Characteristics
     8     10.     10.       1
    12      0.    655.       8
     4    240.     90.       2
     2     10.     10.       1
     2     10.     10.       1
     6       5       7       8       1       1
     0       0     100     100     100     100
    0.     35.      0.      0.      0.      0.
    0.      0.    620.    630.    570.      0.                      ]-Network Travel Matrix
    0.      0.      0.      0.     70.     70.
    0.      0.     50.      0.     50.     50.
    0.      0.      0.      0.      0.      0.
    0.      0.      0.      0.      0.      0.
    0.    1.00      0.      0.      0.      0.                      ]-Transition Probability Matrix
    0.      0.    0.80    0.05    0.15      0.
    0.      0.      0.      0.    0.60    0.40
    0.      0.    0.85      0.    0.10    0.05
    0.      0.      0.      0.      0.      0.
    0.      0.      0.      0.      0.      0.
ENPLANING SYSTEM - TERMINAL 1
     8       2                                                    ]-Enplaning System - Terminal 1
     4     10.     10.       1                                      Facility Service Characteristics
     2     10.     10.       1
     2     10.     10.       1
     6    150.     40.       1
    12    200.     30.       1
     3     40.     10.       2
     8     20.     10.       1
     8     10.      5.       1
     6       1       1       2       2       3       4       5
     0       0       0       0       0     100     100     100
    0.     50.     50.      0.      0.      0.      0.      0.
    0.      0.      0.     80.    130.    170.      0.      0.    ]-Network Travel Matrix
    0.      0.      0.    130.     80.    260.      0.      0.
    0.      0.      0.      0.      0.    140.      0.      0.
    0.      0.      0.      0.      0.    240.      0.      0.
    0.      0.      0.      0.      0.      0.    400.      0.
    0.      0.      0.      0.      0.      0.      0.     35.
    0.      0.      0.      0.      0.      0.      0.      0.
    0.    0.60    0.40      0.      0.      0.      0.      0.    ]-Transition Probability Matrix
    0.      0.      0.    0.30    0.60    0.10      0.      0.
    0.      0.      0.    0.30    0.60    0.10      0.      0.
    0.      0.      0.      0.      0.    1.00      0.      0.
    0.      0.      0.      0.      0.    1.00      0.      0.
    0.      0.      0.      0.      0.      0.    1.00      0.
    0.      0.      0.      0.      0.      0.      0.    1.00
    0.      0.      0.      0.      0.      0.      0.      0.
```

```
CONNECTING SYSTEM - TERMINAL 1 TO TERMINAL 2
   6      3
   8     10.      10.       1
   8     10.      10.       1
3850     15.     600.       9
   3     40.      10.       2
   8     20.      10.       1
   8     10.       5.       1
   6      5       14        3        4        5
   1      1        1        2        2        2
  0.     35.       0.       0.       0.       0.
  0.      0.     530.       0.       0.       0.
  0.      0.       0.     120.       0.       0.
  0.      0.       0.       0.     400.       0.
  0.      0.       0.       0.       0.      35.
  0.      0.       0.       0.       0.       0.
  0.   1.00        0.       0.       0.       0.
  0.      0.    1.00        0.       0.       0.
  0.      0.       0.    1.00        0.       0.
  0.      0.       0.       0.    1.00        0.
  0.      0.       0.       0.       0.    1.00
  0.      0.       0.       0.       0.       0.
DEPLANING SYSTEM - TERMINAL 2
   6      1
   8     10.      10.       1
   8     10.      10.       1
  12      0.     655.       8
   4    240.      90.       2
   2     10.      10.       1
   2     10.      10.       1
   6      5        7        8        1        1
   0      0      100      100      100      100
  0.     35.       0.       0.       0.       0.
  0.      0.     620.     630.     570.       0.
  0.      0.       0.       0.      70.      70.
  0.      0.      50.       0.      50.      50.
  0.      0.       0.       0.       0.       0.
  0.      0.       0.       0.       0.       0.
  0.   1.00        0.       0.       0.       0.
  0.      0.    0.80     0.05     0.15        0.
  0.      0.       0.       0.    0.60     0.40
  0.      0.    0.85        0.    0.10     0.05
  0.      0.       0.       0.       0.       0.
  0.      0.       0.       0.       0.       0.
ENPLANING SYSTEM - TERMINAL 2
   8      2
   4     10.      10.       1
   2     10.      10.       1
   2     10.      10.       1
   6    150.      40.       1
  12    200.      30.       1
   3     40.      10.       2
   8     20.      10.       1
   8     10.       5.       1
   6      1        1        2        2        3        4        5
   0      0        0        0        0      100      100      100
  0.     50.      50.       0.       0.       0.       0.       0.
  0.      0.       0.      80.     130.     170.       0.       0.
  0.      0.       0.     130.      80.     260.       0.       0.
  0.      0.       0.       0.       0.     140.       0.       0.
  0.      0.       0.       0.       0.     240.       0.       0.
  0.      0.       0.       0.       0.       0.     400.       0.
  0.      0.       0.       0.       0.       0.       0.      35.
  0.      0.       0.       0.       0.       0.       0.       0.
```

Connecting System - Terminal 1 to Terminal 2
Facility Service Characteristics

Network Travel Matrix

Transition Probability Matrix

Deplaning System - Terminal 2

Enplaning System - Terminal 2

0.	0.60	0.40	0.	0.	0.	0.	0.
0.	0.	0.	0.30	0.60	0.10	0.	0.
0.	0.	0.	0.30	0.60	0.10	0.	0.
0.	0.	0.	0.	0.	1.00	0.	0.
0.	0.	0.	0.	0.	1.00	0.	0.
0.	0.	0.	0.	0.	0.	1.00	0.
0.	0.	0.	0.	0.	0.	0.	1.00
0.	0.	0.	0.	0.	0.	0.	0.

CONNECTING SYSTEM - TERMINAL 2 TO TERMINAL 1

Connecting System - Terminal 2 to Terminal 1

6	3				
8	10.	10.	1		
8	10.	10.	1		
780	15.	600.	9		
3	40.	10.	2		
8	20.	10.	1		
8	10.	5.	1		
6	5	14	3	4	5
2	2	2	1	1	1
0.	35.	0.	0.	0.	0.
0.	0.	530.	0.	0.	0.
0.	0.	0.	120.	0.	0.
0.	0.	0.	0.	400.	0.
0.	0.	0.	0.	0.	35.
0.	0.	0.	0.	0.	0.
0.	1.00	0.	0.	0.	0.
0.	0.	1.00	0.	0.	0.
0.	0.	0.	1.00	0.	0.
0.	0.	0.	0.	1.00	0.
0.	0.	0.	0.	0.	1.00
0.	0.	0.	0.	0.	0.

ROAD ACCESS SYSTEM

Road Access System

8	0		
2	1250.	25.	3
3	2250.	15.	3
80	240.	60.	7
1	0.	500.	4
1	0.	400.	6
0	4.	2.	5
3	2250.	15.	3
2	1250.	25.	3

The basic output is the total time spent by passengers enplaning, deplaning or connecting. The model does not account for time spent by passengers in optional activities such as visiting restrooms or newstands, or voluntary waiting time experienced by passengers who arrive well in advance of their flight. The total time is calculated as the sum of three components:

(1) Delay time - the time spent by a passenger waiting in queues before being processed.

(2) Service time - the time it takes to service a passenger at all required processing facilities.

(3) Travel time - the time it takes a passenger to travel from facility to facility.

The model presents these times at various levels of aggregation as shown on the output for the example problem (Figure A.6).

The FAA Airport Landside Model program, with the modifications made for this study, is included in this Appendix as Figure A.7.

Figure A.6 Output for Example Problem

```
TWO PIER TERMINALS WITH PEOPLE MOVER SYSTEM


--------------------------------------------------------------------------
      A.  ANNUAL PASSENGER ENPLANEMENTS(000):     2000.
      B.  PEAK HOUR PASSENGERS:                   1460.
      C.  FLEET MIX:                          10 PCT WIDE-BODIES
      D.  AIRPORT ACTIVITY DESCRIPTORS:         1 PEAK 11.0
      E.  CONNECTING PAX:                         20 PCT
      F.  PEAK HOUR AIRCRAFT OPERATIONS:           30
      G.  AVERAGE AIRCRAFT LOAD FACTOR:           50 PCT
                                             AUTO TAXI BUS  RAIL
      H.  PASSENGER MODAL SPLIT:            ( .95, .04, .01, .00)

      ***THE PRIMARY CONTROL PARAMETER FOR THIS RUN IS B***

--------------------------------------------------------------------------


          NUMBER OF TERMINAL UNITS:                 1

          NUMBER OF TERMINAL ZONES:                 2
          PASSENGER SPLIT AT EACH:                 .50
                                                   .50
          AVERAGE NUMBER OF PAX PER VEHICLE:       1.0
          AVERAGE NUMBER OF BAGS PER PAX:          1.5
          TOTAL AIRPORT CURB   FRONTAGE:           900.
          AIRPORT ROADWAY CAPACITY-(VEH/HR):      2400.
          TOTAL NUMBER OF PARKING SPACES:         3000.
```

DEPLANING SYSTEM - TERMINAL 1

STATE	AIRLINE	NUMBER OF SERVERS	ARRIVALS PER SEC	TOTAL SERVICE PER SEC	UTILIZ. FACTOR	PER PAX DELAY (MIN)	LINE LENGTH WAITING (PERSONS)
SPEC		8	.1176	.800	.15	0.	0.
GATE		8	.1176	.800	.15	0.	0.
BAGS		12	.0793	3.600	.02	12.	5.
RENT		4	.0047	.017	.28	0.	0.
CURB		2	.0621	.200	.31	0.	0.
CURB		2	.0319	.200	.16	0.	0.

	PEAK HOUR		ANNUAL
DELAY TIME:	8.4 MIN	3553. PAX-MIN	4476492. MIN
SERVICE TIME:	.7 MIN	281. PAX-MIN	664111. MIN
TRAVEL TIME:	4.0 MIN	1712. PAX-MIN	4044060. MIN
TOTAL TIME:	13.1 MIN	5546. PAX-MIN	9184663. MIN

ENPLANING SYSTEM - TERMINAL 1

STATE	AIRLINE	NUMBER OF SERVERS	ARRIVALS PER SEC	TOTAL SERVICE PER SEC	UTILIZ. FACTOR	PER PAX DELAY (MIN)	LINE LENGTH WAITING (PERSONS)
SPEC		4	.1176	.400	.29	0.	0.
CURB		2	.0706	.200	.35	0.	0.
CURB		2	.0470	.200	.24	0.	0.
TIX		6	.0353	.040	.88	2.	1.
TIX		12	.0706	.060	1.18	12.	4.
XRAY		3	.1411	.075	1.88	7.	20.
SEAT		8	.1411	.400	.35	0.	0.
GATE		8	.1411	.800	.18	0.	0.

	PEAK HOUR		ANNUAL
DELAY TIME:	16.6 MIN	7009. PAX-MIN	8831813. MIN
SERVICE TIME:	4.5 MIN	1898. PAX-MIN	4483333. MIN
TRAVEL TIME:	4.4 MIN	1853. PAX-MIN	4375556. MIN
TOTAL TIME:	25.4 MIN	10760. PAX-MIN	17690702. MIN

CONNECTING SYSTEM - TERMINAL 1 TO TERMINAL 2

STATE	AIRLINE	NUMBER OF SERVERS	ARRIVALS PER SEC	TOTAL SERVICE PER SEC	UTILIZ. FACTOR	PER PAX DELAY (MIN)	LINE LENGTH WAITING (PERSONS)
SPEC		8	.0941	.800	.12	0.	0.
GATE		8	.0941	.800	.12	0.	0.
PMS		1	.1176	.000	.00	5.	0.
XRAY		3	.1411	.075	1.88	7.	20.
SEAT		8	.1411	.400	.35	0.	0.
GATE		8	.1411	.800	.18	0.	0.

	PEAK HOUR		ANNUAL
DELAY TIME:	16.9 MIN	7154. PAX-MIN	9014369. MIN
SERVICE TIME:	2.1 MIN	882. PAX-MIN	2083333. MIN
TRAVEL TIME:	10.5 MIN	4446. PAX-MIN	10500000. MIN
TOTAL TIME:	29.5 MIN	12482. PAX-MIN	21597702. MIN

DEPLANING SYSTEM - TERMINAL 2

STATE	AIRLINE	NUMBER OF SERVERS	ARRIVALS PER SEC	TOTAL SERVICE PER SEC	UTILIZ. FACTOR	PER PAX DELAY (MIN)	LINE LENGTH WAITING (PERSONS)
SPEC		8	.1176	.800	.15	0.	0.
GATE		8	.1176	.800	.15	0.	0.
BAGS		12	.0793	3.600	.02	12.	5.
RENT		4	.0047	.017	.28	0.	0.
CURB		2	.0621	.200	.31	0.	0.
CURB		2	.0319	.200	.16	0.	0.

	PEAK HOUR		ANNUAL
DELAY TIME:	8.4 MIN	3553. PAX-MIN	4476492. MIN
SERVICE TIME:	.7 MIN	281. PAX-MIN	664111. MIN
TRAVEL TIME:	4.0 MIN	1712. PAX-MIN	4044060. MIN
TOTAL TIME:	13.1 MIN	5546. PAX-MIN	9184663. MIN

ENPLANING SYSTEM - TERMINAL 2

STATE	AIRLINE	NUMBER OF SERVERS	ARRIVALS PER SEC	TOTAL SERVICE PER SEC	UTILIZ. FACTOR	PER PAX DELAY (MIN)	LINE LENGTH WAITING (PERSONS)
SPEC		4	.1176	.400	.29	0.	0.
CURB		2	.0706	.200	.35	0.	0.
CURB		2	.0470	.200	.24	0.	0.
TIX		6	.0353	.040	.88	2.	1.
TIX		12	.0706	.060	1.18	12.	4.
XRAY		3	.1411	.075	1.88	7.	20.
SEAT		8	.1411	.400	.35	0.	0.
GATE		8	.1411	.800	.18	0.	0.

	PEAK HOUR		ANNUAL
DELAY TIME:	16.6 MIN	7009. PAX-MIN	8831813. MIN
SERVICE TIME:	4.5 MIN	1898. PAX-MIN	4483333. MIN
TRAVEL TIME:	4.4 MIN	1853. PAX-MIN	4375556. MIN
TOTAL TIME:	25.4 MIN	10760. PAX-MIN	17690702. MIN

CONNECTING SYSTEM - TERMINAL 2 TO TERMINAL 1

STATE	AIRLINE	NUMBER OF SERVERS	ARRIVALS PER SEC	TOTAL SERVICE PER SEC	UTILIZ. FACTOR	PER PAX DELAY (MIN)	LINE LENGTH WAITING (PERSONS)
SPEC		8	.0941	.800	.12	0.	0.
GATE		8	.0941	.800	.12	0.	0.
PMS		1	.1176	.000	.00	5.	0.
XRAY		3	.1411	.075	1.88	7.	20.
SEAT		8	.1411	.400	.35	0.	0.
GATE		8	.1411	.800	.18	0.	0.

	PEAK HOUR		ANNUAL
DELAY TIME:	16.9 MIN	7154. PAX-MIN	9014369. MIN
SERVICE TIME:	2.1 MIN	882. PAX-MIN	2083333. MIN
TRAVEL TIME:	7.1 MIN	3001. PAX-MIN	7088889. MIN
TOTAL TIME:	26.1 MIN	11038. PAX-MIN	18186591. MIN

ROAD ACCESS SYSTEM

	AUTOS	TAXIS	BUSES	RAIL
PASSENGER MODAL SPLIT:	.95	.04	.01	.00
VEHICLE MODAL SPLIT:	.98	.02	.00	.00
PAX PER VEHICLE-BY-TYPE:	.97	1.70	10.00	10.00

DEPLANING CURB FRONTAGE: 500. FT
ENPLANING CURB FRONTAGE: 400. FT

STATE	MODEL	RATE IN (VEH/HR)	TOTAL SERVICE (VEH/HR)	UTILIZATION FACTOR	PER PAX DELAY (MIN)	TOTAL PAX-HR OF DELAY (PEAK HOUR)
RDWY IN	ROAD	1226.	2400.	.5	0.	2.
TMRD IN	ROAD	1217.	3600.	.3	0.	4.
RTL DROP	MGK	120.	1200.	.1	0.	0.
DE-CURB	CURB	117.	260.	.4	0.	0.
EN-CURB	CURB	236.	330.	.7	0.	3.
PARKING	PARK	1024.	1500.	.7	12.	225.
TMRD OUT	ROAD	1217.	3600.	.3	0.	4.
RDWY OUT	ROAD	1226.	2400.	.5	0.	2.

DEPLANING ROADWAY SUMMARY

	PEAK HOUR		ANNUAL
DELAY TIME:	10.9 MIN	158. PAX-HRS	199613. HRS
SERVICE TIME:	2.8 MIN	41. PAX-HRS	94166. HRS
TOTAL TIME:	13.7 MIN	200. PAX-HRS	293779. HRS

ENPLANING ROADWAY SUMMARY

	PEAK HOUR		ANNUAL
DELAY TIME:	7.9 MIN	115. PAX-HRS	144445. HRS
SERVICE TIME:	3.8 MIN	56. PAX-HRS	127322. HRS
TOTAL TIME:	11.7 MIN	170. PAX-HRS	271767. HRS

PEAK HOUR TOTALS FOR TERMINAL UNIT NO. 1(MIN)

	DEPLANING PAX		ENPLANING PAX	
	DELAY	TOTAL	DELAY	TOTAL
TERMINAL	8.4	13.1	16.6	25.4
ROADWAY	10.9	13.7	7.9	11.7
COMBINED	17.1	24.0	22.8	34.8

PEAK HOUR PASSENGERS (MIN)

	DEPLANING PAX		ENPLANING PAX	
	DELAY	TOTAL	DELAY	TOTAL
TERMINAL UNIT NO. 1 -100 PCT	17.1	24.0	22.8	34.8
AIRPORT AVERAGE	17.1	24.0	22.8	34.8

Figure A.7 FAA Airport Landside Model - Program

```
      PROGRAM FAALD(INPUT,OUTPUT,TAPE20=INPUT,TAPE7=OUTPUT,TAPE6)
C     MAIN PROGRAM FOR QUEUEING NETWORK
C     FOR LANDSIDE STUDY
C
C     READS ALL DATA AND OUTPUTS RESULTS
C     CALLS DELAY,FLOW, AND NETWORK COMPUTATION SUBROUTINES
C
      CHARACTER CODE1*4,CODE2*4,CODE3*9,BLNK*1,STAR*1,LCRB*2,
     +E*1,H*1,ICHK*1,NPCP*1,CODE*9,DSTAR*2,CODE4*8
      REAL LAM,MENFAC
      COMMON/VEHCLE/TOTVEH,VHMODE(4),VHLAM1(4,4),VHLAM2(1,4),RENTAL
      COMMON/TSTDAT/APE,FMIX,NPK,ACTPK,NOPS,AVLD,CNCT
      COMMON/RDWAY/RDMAX,NLANES,RECIRC,PRKMAX,CMAX(2)
      COMMON/PXDATA/PAXPER(4),PXMODE(4),VEHPAX
      COMMON /DLAY/N,S(20),DELAY(20),K(20),SSD(20)
      COMMON/CONFIG/NCURB(10),REFLOW(10)
      COMMON/NEW/NUFLAG,MENFAC,SATLIN
      COMMON/AIRL/ CODE4
      DIMENSION TMSPLT(10),PXSPLT(10),LCRB(3),TRVL(20,20),P1(20,20),MCOD
     1E(20),LAM(20),VHLAM(5,4),TRMP1(20,20),DTSAVE(10,3),NAM(20)
     1,ETSAVE(10,3),TITLE(19),CODE2(8),CODE1(14),VLAM(8)   ,TIME(2,2)
     +,CODE3(12),BLNK(1),STAR(1),ICHK(20),DSTAR(1),NUK(20),ISFLAG(20)
     +,ARG(20),CODE4(20),EQ(20),TRSPLT(10,10),NTM(20),TREN(10)
      EQUIVALENCE (TRMP1(1,1),P1(1,1))
      EQUIVALENCE (VLAM(1),LAM(1))
      DATA CODE1/'CURB','TIX','XRAY','SEAT','GATE','SPEC','BAGS',
     1'RENT','FIS','EXPB','STGT','INS','ESCR','PMS '/
      DATA CODE2/' MMK',' MGK','ROAD','CURB','PARK','CURB',' MGK',
     1'BAGS'/
      DATA CODE3/' RDWY IN ',' TMRD IN ',' RTL DROP',' DE-CURB ',
     +' EN-CURB ',' PARKING ',' TMRD OUT',' RDWY OUT',' TERMINAL',
     +' ROADWAY ',' COMBINED',' CMB-CURB'/
      DATA BLNK,STAR,LCRB(2),LCRB(3),E,H/' ','*','DE','EN','E','H'/
      DATA DSTAR/'**'/
      DATA TMSPLT,TIME,ETSAVE,DTSAVE/74*0./
      DATA PAXPER,TERM/1..1.7,10..10..1000./
      DATA VHLAM1/4*1...01..67..5..5..19..33..5..5..8,3*0./
      DATA VHLAM2/0...07,0...065/
      MENFAC=1.
      SATLIN=99.
      KOUT=6
      IN=0
      NAL=0
      KOUNT=0
      DO 1  MM=1,3
      DO 1 NN=1,10
      DTSAVE(NN,MM)=0.
1     ETSAVE(NN,MM)=0.
      CALL CNTRLS(TITLE,PKHRPX,NPCP,BAGPX,NERR)
      IF (NERR.EQ.1) GO TO 72
      CALL APSPEC (NTERM,TMSPLT,NZONE,PXSPLT,NERR,IOFLAG,TRSPLT,TREN)
      IF (NERR.EQ.1) GO TO 72
      CALL PXCALC (CNCT,PKHRPX)
      TOTVEH=TOTVEH*(1.+ RECIRC)
C     ----------PRINT CONTROL DATA AND AIRPORT SPECIFIC DATA
      WRITE(7,96)TITLE
      KOUNT=KOUNT+13
      A=ACTPK*100.
      NALD=IFIX((AVLD+0.005)*100)
      NF=IFIX((FMIX+0.005)*100)
      NNC=IFIX((CNCT+0.005)*100)
      WRITE(7,76)APE,PKHRPX,NF,NPK,A,NNC,NOPS,NALD,    (PXMODE(I),I=1,4)
     1,NPCP
      KOUNT=KOUNT+16
      PPV=1./VEHPAX
      FOOT=CMAX(1)+CMAX(2)
      ROADS=RDMAX
      IF (RDMAX.EQ.0.)ROADS=TERM**2
      WRITE(7,78)NTERM
      WRITE (7,80) NZONE,(PXSPLT(I),I=1,NZONE)
      WRITE (7,82) PPV,BAGPX,FOOT,ROADS,PRKMAX
      KOUNT=KOUNT+14+NZONE
C     ----------CHECK FOR COMPLETION OF TERMINALS' INPUT DATA
2     NT=65-KOUNT
      KOUNT=0
      IN=IN+1
      ITR=NZONE+1
      IF (IN.GT.NTERM) GO TO 66
C     WRITE (7,84) IN
      KOUNT=KOUNT+8
C     ----------READ DATA FOR NEW NETWORK

6     CALL STATES(NRTE,MCODE,TRVL,P1,TITLE,NAM,NERR,NTM)
      JTR=ITR/(NZONE+1)
      IF (NERR)62,8,72
8     IF ((NPCP.EQ.E .OR. NPCP.EQ.H).AND. NRTE.NE.0) GO TO 6
      WRITE (7,90)TITLE
```

```
      KOUNT=KOUNT+5
      NNR=NRTE+1
      PMSTT=O.
      GO TO (10,12,14,14),NNR
C     ----------ROADWAY NETWORKS----------
10    PAXLAM=(1.-CNCT)*TMSPLT(IN)*PKHRPX
      CALL RDFLOW(IN,TMSPLT(IN),VHLAM,RENTAL,TRMP1)
      WRITE(7,100)
      WRITE(7,94) (PXMODE(I),I=1,4),(VHMODE(I),I=1,4)
      WRITE(7,126) (PAXPER(I),I=1,4)
      KOUNT=KOUNT+8
      GO TO 16
C     ----------TERMINAL BUILDING---
12    NAL=NAL+1
      PAXLAM=.58*PKHRPX*PXSPLT(NAL)/3600.
14    CALL FLOW(PAXLAM,P1,LAM)
C     ----------COMPUTE DELAY FOR EACH STATE
16    DO 42 I=1,N
      DELAY(I)=O.
      IF(NRTE.GT.O)ARG(I)=LAM(I)
      ICHK(I)=BLNK(1)
      IMODE=MCODE(I)
      GO TO (18,20,22,26,34,26,36,38,1002),IMODE
C     ----------STANDARD M/M/K QUEUEING MODEL----------
   18 IF(NRTE.NE.1) GO TO 2001
      ARG(I)=ARG(I)*(1-CNCT*REAL(NTM(I))/100.)
      GO TO 2004
 2001 IF(NRTE.NE.2) GO TO 2002
      ARG(I)=ARG(I)*(1.+TREN(JTR)*REAL(NTM(I))/100.)
      GO TO 2004
 2002 IF(NRTE.NE.3) GO TO 2004
      IF(NTM(I).NE.NTM(1)) GO TO 2003
      ARG(I)=ARG(I)*(1.-CNCT)
      GO TO 2004
 2003 ARG(I)=ARG(I)*(1.+TREN(JTR)*(PXSPLT(NTM(1))/PXSPLT(NTM(I))))
 2004 CONTINUE
      CALL MMKS(ARG(I),S(I),K(I),IFLAG,WQ,EL)
      DELAY(I)=WQ
      GO TO 40
C     ----------STANDARD M/G/K QUEUEING MODEL----
   20 IF(NRTE.NE.1) GO TO 2005
      ARG(I)=ARG(I)*(1-CNCT*REAL(NTM(I))/100.)
      GO TO 2008
 2005 IF(NRTE.NE.2) GO TO 2006
      ARG(I)=ARG(I)*(1.+TREN(JTR)*REAL(NTM(I))/100.)
      GO TO 2008
 2006 IF(NRTE.NE.3) GO TO 2008
      IF(NTM(I).NE.NTM(1)) GO TO 2007
      ARG(I)=ARG(I)*(1.-CNCT)
      GO TO 2008
 2007 ARG(I)=ARG(I)*(1.+TREN(JTR)*(PXSPLT(NTM(1))/PXSPLT(NTM(I))))
 2008 CONTINUE
      CALL MGKS(ARG(I),SSD(I),S(I),K(I),IFLAG,WQ,EL)
      DELAY(I)=WQ
      GO TO 40
C     -------ROADWAY DELAY MODEL---
22    ARG(I)=O.
      DO 24 IJ=1,3
24    ARG(I)=ARG(I)+VHLAM(IJ,1)
C     --------CHECK FOR MAIN ROADWAY STATES
      IF (I.EQ.1 .OR. I.EQ.8)ARG(I)=TOTVEH
      VLAM(I)=ARG(I)
      CALL ROAD(ARG(I),SSD(I),S(I),K(I),IFLAG,WQ)
      DELAY(I)=WQ
      GO TO 40
C     -------CURB DELAY MODEL---
26    ARG(I)=O.
      J=MCODE(I)/2
C     -------CHECK FOR COMBINED CURB
      IF (NCURB(IN).EQ.1 .AND. J.EQ.3) GO TO 42
      DO 28 IJ=1,4
28    ARG(I)=ARG(I)+VHLAM(IJ,J)
      VLAM(I)=ARG(I)
      FRONT=SSD(I)
      IF(FRONT.EQ.O.)FRONT=TMSPLT(IN)*CMAX(J-1)
      IF (NCURB(IN).EQ.1) GO TO 30
      WRITE (7,128)LCRB(J),FRONT
      KOUNT=KOUNT+1
      GO TO 32
30    IF (FRONT.EQ.O.)FRONT=TMSPLT(IN)*(CMAX(J)+CMAX(J-1))
      WRITE(7,130) FRONT
      KOUNT=KOUNT+1
32    S(I)=120.*BAGPX
      IF(J .EQ. 3) S(I)= .667*S(I)
      CALL CURB(ARG(I),S(I),K(I),FRONT,SSD(I),IFLAG,WQ)
      DELAY(I)=WQ
      GO TO 40
C     ----------PARKING LOT DELAY MODEL------
34    ARG(I)=VHLAM(1,4)
      VLAM(I)=ARG(I)
      SPAC=(PRKMAX*TMSPLT(IN))
      CALL PARK(ARG(I),SSD(I),SPAC,IFLAG,WQ)
      DELAY(I)=WQ
      GO TO 40
```

```
C       ----------CAR RENTAL RETURN DELAY MODEL----
36      CARS=(RENTAL*VHMODE(1)*TOTVEH)
        ARG(I)=CARS/3600.
        CALL MGKS(ARG(I),SSD(I),S(I),K(I),IFLAG,WQ,EL)
        VLAM(I)=TMSPLT(IN)*CARS
        SSD(I)=(K(I)/S(I))*3600.
        DELAY(I)=WQ
        GO TO 40
C       ----------BAGGAGE CLAIM DELAY MODEL-----
38      TBAGS=PAXLAM*3600.*BAGPX
        IF(NAM(I).EQ.7) ARG(I)=ARG(I)*(1.-CNCT)
        PKBAGS=ARG(I)/(PAXLAM*.6)
        PKBAGS=PKBAGS*TBAGS
        CALL BAGS(PKBAGS,SSD(I),S(I),K(I),BAGPX,IFLAG,WQ)
        DELAY(I)=WQ
        GO TO 40
 1002   CALL PMS(K(I),S(I),SSD(I),PMST,WQ)
        DELAY(I)=WQ
        PMSTT=PMSTT+PMST
C       -------CHECK FOR RHO GREATER THAN 1
40      IF(IFLAG.EQ.O) GO TO 42
42      CONTINUE
        IF(NRTE.GT.O)GO TO 46
C       -------CONVERT DELAY FROM PER VEHICLE TO PER PAX
        CALL CONVRT(VHLAM)
        WRITE(7,86)
        KOUNT=KOUNT+9
        DO 44 I=1,N
        CODE=CODE3(I)
        IF (NCURB(IN).EQ.1 .AND. I.EQ.5)GO TO 44
        IF (NCURB(IN).EQ.1 .AND. I.EQ.4)CODE=CODE3(12)
        MC=MCODE(I)
        RHO=VLAM(I)/SSD(I)
        IF(I.EQ.3)RHO=CARS/SSD(I)
        HRDLAY=(DELAY(I)/3600.)*PAXLAM
        DELAY(I)=DELAY(I)/60.
        WRITE(7,88) CODE,CODE2(MC),VLAM(I),SSD(I),RHO,
       +DELAY(I),HRDLAY
        DELAY(I)=DELAY(I)*60.
        KOUNT=KOUNT+1
44      CONTINUE
        GO TO 58
46      WRITE (7,92)
        KOUNT=KOUNT+7
        DO 48 I=1,N
        IF (NAM(I).EQ.6) DENOM=ARG(I)
C       IF (NAM(I).EQ.6) GO TO 48
        NM=NAM(I)
        MC=MCODE(I)
        IF(NAM(I).NE.14) GO TO 1001
        SK=O.
        RHO=O.
        EQ(I)=O.
        DELAY(I)=DELAY(I)/60.
        GO TO 1003
 1001   SK=K(I)/S(I)
        RHO=ARG(I)/SK
        HRDLAY=DELAY(I)*PAXLAM*60.
        DELAY(I)=DELAY(I)/60.
        EQ(I)=((ARG(I)/K(I))*60.)*DELAY(I)
 1003   WRITE(7,102) CODE1(NM),CODE4(I),K(I),ARG(I),SK,RHO,DELAY(I),
       1EQ(I)
        DELAY(I)=DELAY(I)*60.
49      KOUNT=KOUNT+1
48      CONTINUE
C       -------COMPUTE EXPECTED DELAY,SERVICE,TRAVEL TIMES FOR TERMINAL
        CALL NETIME(P1,TRVL,NRTE,IOFLAG,CD,CS,CT)
        CD=O.
        CS=O.
        DO 51 I=1,N
        CD=CD+(ARG(I)*DELAY(I)/DENOM)
        CS=CS+(ARG(I)*S(I)/DENOM)
51      CONTINUE
        CT=CT+PMSTT
        CD=CD/60.
        CS=CS/60.
        CT=CT/60.
        HCD=CD * (PAXLAM * 3600.)
        HCS=CS*(PAXLAM*3600.)
        HCT=CT*(PAXLAM*3600.)
        YCD=210.*HCD*(5.+NPK)
        YCS=APE*CS*1000.*PXSPLT(NAL)
        YCT=APE*CT*1000.*PXSPLT(NAL)
        TOT=CD+CS+CT
        HTOT=HCD+HCS+HCT
        YTOT=YCD+YCS+YCT
        WRITE(7,110)CD,HCD,YCD,CS,HCS,YCS,CT,HCT,YCT,TOT,HTOT,YTOT
        KOUNT=KOUNT+9
C       -------STORE TIMES FOR THIS TERMINAL ZONE
        GO TO (50,52,54),NRTE
50      DTSAVE(IN,1)=DTSAVE(IN,1)+CD*PXSPLT(NAL)/TMSPLT(IN)
        DTSAVE(IN,2)=DTSAVE(IN,2)+CS*PXSPLT(NAL)/TMSPLT(IN)
        DTSAVE(IN,3)=DTSAVE(IN,3)+CT*PXSPLT(NAL)/TMSPLT(IN)
        GO TO 54
```

```
52    ETSAVE(IN,1)=ETSAVE(IN,1)  +CD * PXSPLT(NAL)/TMSPLT(IN)
      ETSAVE(IN,2)=ETSAVE(IN,2)+CS*PXSPLT(NAL)/TMSPLT(IN)
      ETSAVE(IN,3)=ETSAVE(IN,3)+CT*PXSPLT(NAL)/TMSPLT(IN)
54    NT=66-KOUNT
      KOUNT=0
      ITR=ITR+1
      GO TO 6
C     -------COMPUTE EXPECTED DELAY,SERVICE,TRAVEL TIMES FOR TERMINAL RO
C     ADWA
58    CALL NETIME(TRMP1,TRVL,NRTE,IOFLAG,RD,RS,RT)
      DO 60 I=1,2
      IF (I.EQ.1)WRITE(7,116)
      IF(I.EQ.2) WRITE(7,118)
      KOUNT=KOUNT+3
      TRVL(I,1)=TRVL(I,1)/60.
      TRVL(I,2)=TRVL(I,2)/60.
      RD=TRVL(I,1)
      RS=TRVL(I,2)
      HRD=(RD/60.) * .75 * PAXLAM
      HRS=(RS/60.) * .75*PAXLAM
      YRD=210.*HRD*(5.+NPK)
      YRS=APE*1000.*RS*TMSPLT(IN)/60.
      TOT=RD+RS
      HTOT=HRD+HRS
      YTOT=YRD+YRS
      WRITE (7,112)RD,HRD,YRD,RS,HRS,YRS,TOT,HTOT,YTOT
      KOUNT=KOUNT+6
60    CONTINUE
C     -------TERMINAL UNIT SUMMARY PRINTOUT
62    DO 64 J=1,2
      DTSAVE(IN,3)=DTSAVE(IN,3)+DTSAVE(IN,J)
      ETSAVE (IN,3)=ETSAVE(IN,3)+ETSAVE(IN,J)
      TRVL(J,2)=TRVL(J,2)+TRVL(J,1)
64    CONTINUE
      WRITE (7,108) IN
      KOUNT=KOUNT+10
      CODE=CODE3(9)
      WRITE(7,120)CODE,DTSAVE(IN,1),DTSAVE(IN,3),ETSAVE(IN,1),ETSAVE(IN,
     13)
      CODE=CODE3(10)
      WRITE(7,120)CODE,(TRVL(1,J),J=1,2),(TRVL(2,J),J=1,2)
      DTSAVE(IN,1)=DTSAVE(IN,1)+(1.-CNCT)*TRVL(1,1)
      DTSAVE(IN,3)=DTSAVE(IN,3)+(1.-CNCT)*TRVL(1,2)
      ETSAVE(IN,1)=ETSAVE(IN,1)+(1.-CNCT)*TRVL(2,1)
      ETSAVE(IN,3)=ETSAVE(IN,3)+(1.-CNCT)*TRVL(2,2)
      CODE=CODE3(11)
      WRITE(7,120)CODE,DTSAVE(IN,1),DTSAVE(IN,3),ETSAVE(IN,1),ETSAVE(IN,
     13)
      WRITE(7,122)
      KOUNT=KOUNT+3
      GO TO 2
C     -------AIRPORT SUMMARY PRINTOUT
66    WRITE(7,106)
      KOUNT=KOUNT+11
      TOTPC=0.
      DO 68 I=1,NTERM
      TOTPC=TOTPC+TMSPLT(I)
      TIME(1,1)=TIME(1,1)+DTSAVE(I,1)*TMSPLT(I)
      TIME(2,1)=TIME(2,1)+ETSAVE(I,1)*TMSPLT(I)
      TIME(1,2)=TIME(1,2)+DTSAVE(I,3)*TMSPLT(I)
      TIME(2,2)=TIME(2,2)+ETSAVE(I,3)*TMSPLT(I)
68    CONTINUE
      TIME(1,1)=TIME(1,1)/TOTPC
      TIME(2,1)=TIME(2,1)/TOTPC
      TIME(1,2)=TIME(1,2)/TOTPC
      TIME(2,2)=TIME(2,2)/TOTPC
      DO 70 I=1,NTERM
      IPC=IFIX((TMSPLT(I)+0.005)*100)
70    WRITE(7,104)I,IPC,DTSAVE(I,1),DTSAVE(I,3),ETSAVE(I,1),ETSAVE(I,3)
      WRITE(7,114)((TIME(I,J),J=1,2),I=1,2)
      KOUNT=KOUNT  +5+  NTERM
      STOP
72    WRITE(7,132)
      CALL EXIT
74    FORMAT(I3,F6.2)
76    FORMAT(//80('-')/T11,'A.  ANNUAL PASSENGER ENPLANEMENTS(000): ', T
     152,F8.0/T11,'B.  PEAK HOUR PASSENGERS: ',T52,F8.0/T11,   'C.  FLEE
     1T MIX: ',T50,I2,' PCT WIDE-BODIES'/T11,'D.  AIRPORT ACTIVITY DESCR
     +IPTORS: ',
     +T52,I1,' PEAK ',F4.1/T11, 'E.  CONNECTING PAX: ',T55,I2,' PCT'
     1/T11,'F.  PEAK HOUR AIRCRAFT OPERATIONS:',T55,I3/T11,'G.  AVERAGE
     1AIRCRAFT LOAD FACTOR:',T55   ,I2,' PCT'/T46,'AUTO',' TAXI',' BUS '
     +,' RAIL'
     1,/T11,'H.  PASSENGER MODAL SPLIT:',T45,'(',3(F4.2,','),F4.2,')
     1'//T11,'***THE PRIMARY CONTROL PARAMETER FOR THIS RUN IS ',A1,'***
     1'/80('-')/)
78    FORMAT(///T15,'NUMBER OF TERMINAL UNITS:',T56,I2/)
80    FORMAT(T15,'NUMBER OF TERMINAL ZONES:',T56,I2/    T15,'PASSENGER S
     1PLIT AT EACH:',(T55,F4.2))
82    FORMAT(T15,'AVERAGE NUMBER OF PAX PER VEHICLE:',T56,F3.1/T15,  'AV
     1ERAGE NUMBER OF BAGS PER PAX:',T56,F3.1/T15,'TOTAL AIRPORT CURB
     1FRONTAGE:',T53,F7.0/T15,'AIRPORT ROADWAY CAPACITY-(VEH/HR):', T52,
     1F8.0/T15,'TOTAL NUMBER OF PARKING SPACES:',T53,F7.0//)
84    FORMAT('1',//,80('*')/,1X,'DATA FOR TERMINAL UNIT NO.',I2/80('*')/
     +//)
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86     FORMAT(//80('-')/T3,'STATE',T12,'MODEL',T20,'RATE IN',T30,      'TO
      1TAL',T40,'UTILIZATION',T55,'PER PAX',T66,'TOTAL PAX-HR'/T20,     '
      1(VEH/HR)',T30,'SERVICE',T40,'FACTOR',T55,'DELAY',T66,'OF DELAY'/ T
      130,'(VEH/HR)',T55,'(MIN)',T66,'(PEAK HOUR)'/80('-')//)
88     FORMAT (A9,T13,A4,T19,F7.0,T30,F7.0,T41,F6.1,T53,F8.0,    T66,
      1F8.0)
89     FORMAT(A9,T13,A4,T19,F7.0,T30,F7.0,T42,F5.1,
      +T53,F8.1,T66,F8.2)
90     FORMAT('1',//,1X,19A4,//)
92     FORMAT(1X,'STATE',T9,'AIRLINE',T18,'NUMBER',T27,'ARRIVALS',T38,
      +'T'
      1'OTAL',T48,'UTILIZ.',T59,'PER PAX',T69,'LINE LENGTH'/T18,'OF',  T2
      +7,
      1'PER SEC',T38,'SERVICE',T48,'FACTOR',T59,'DELAY',T69,'WAITING '
      1,/T18,'SERVERS',T38,'PER SEC',T59,'(MIN)',T69,'(PERSONS)'/
      1  80('-')/)
94     FORMAT(/,1X,'PASSENGER MODAL SPLIT:',T30,4(F4.2,6X)/1X,'VEHICLE MO
      1DAL SPLIT:',T30,4(F4.2,6X))
96     FORMAT('1',//,1X,19A4//)
98     FORMAT(A4,':',T28,4(F6.1,4X))
100    FORMAT(T30,'AUTOS',T40,'TAXIS',T50,'BUSES',T60,'RAIL'/    T30,5('-
      1'),T40,5('-'),T50,5('-'),T60,4('-'))
102    FORMAT(T2,A4,T7,A8,T20,I3,T26,F7.4,T37,F7.3,T49,F4.2,T58,
      1F7.0,T71,F8.0)
103    FORMAT(T2,A4,T9,A4,T20,I3,T29,F4.2,T39,F5.2,
      +T49,F4.2,T60,F5.0,T71,F8.1)
104    FORMAT(' TERMINAL UNIT NO.',I2,1X,'-',I3,' PCT',T30,F7.1,T43,F7.1
      +,T55,F7.1,T68,F7.1)
106    FORMAT(///80('-')/' PEAK HOUR PASSENGERS (MIN)'//T32,    'DEPLANING
      1 PAX',T57,'ENPLANING PAX'//T32,'DELAY',T45,'TOTAL',   T57,'DELAY',
      1T70,'TOTAL'/T32,5('-'),T45,5('-'),T57,5('-'),   T70,5('-')/)
108    FORMAT('1',//80('*')/T22,'PEAK HOUR TOTALS FOR TERMINAL UNIT NO.',
      +I2,'(MIN)',
      1//T21,'DEPLANING PAX',T51,'ENPLANING PAX'//T21,'DELAY',     T34,
      1'TOTAL',T51,'DELAY',T64,'TOTAL'/T21,5('-'),T34,5('-'),T51,5('-'),
      1T64,5('-')/)
110    FORMAT(///T30,'PEAK HOUR',T60,'ANNUAL',/,1X,'DELAY TIME:',T20,F7.1
      1,' MIN',T35,F7.0, ' PAX-MIN',T54,F11.0,' MIN'/,1X,'SERVICE TIME:'
      +,T20,
      +F7.1,' MIN',T35, F7.0,' PAX-MIN',T54,F11.0,' MIN'/,1X,'TRAVEL TIME
      +:',T20,
      1F7.1,' MIN', T35,F7.0,' PAX-MIN',T54,F11.0,' MIN'/,1X,'TOTAL TIME:
      1',T20,F7.1,     ' MIN',T35,F7.0,' PAX-MIN',T54,F11.0,' MIN'/)
112    FORMAT (/,T30,'PEAK HOUR',T55,'ANNUAL',/,1X,'DELAY TIME:',T20,
      +F7.1,
      1' MIN',T35,F7.0,' PAX-HRS',T54,F11.0,' HRS'/,1X,'SERVICE TIME:',
      +T20,
      1F7.1,' MIN',T35, F7.0,' PAX-HRS',T54,F11.0,' HRS'/,1X,'TOTAL TIME:
      1',T20,F7.1,' MIN',T35,F7.0,' PAX-HRS',T54,F11.0,' HRS' )
114    FORMAT(//18('-'),T29,7('-'),T42,7('-'),T54,7('-'),T67,7('-')/     '
      1 AIRPORT AVERAGE',T30,F7.1,T43,F7.1,T55,F7.1,T68,F7.1/80('-'))
116    FORMAT(/24('-'),'DEPLANING ROADWAY SUMMARY',31('-')/)
118    FORMAT(/24('-'),'ENPLANING ROADWAY SUMMARY',31('-')/)
120    FORMAT(A9,T18,F7.1,T31,F7.1,T48,F7.1,T61,F7.1)
122    FORMAT(80('*'))
126    FORMAT(1X,'PAX PER VEHICLE-BY-TYPE:',T29,4(F5.2,5X)//)
128    FORMAT(1X,A2,'PLANING CURB FRONTAGE:',T45,F6.0,' FT')
130    FORMAT(' COMBINED CURB FRONTAGE:',T45,F6.0,' FT')
132    FORMAT(' CHECK INPUT DATA FILE FOR CORRECT FORMAT')
       END
       SUBROUTINE APSPEC(NTERM,TMSPLT,NZONE,PXSPLT,NERR,IOFLAG,TRSPLT,
      +TREN)
C      ------READS AIRPORT SPECIFIC DATA------
       COMMON/RDWAY/RDMAX,NLANES,RECIRC,PRKMAX,CMAX(2)
       COMMON/CONFIG/NCURB(10),REFLOW(10)
       DIMENSION TMSPLT(10),PXSPLT(10)
       DIMENSION TRSPLT(10,10),TREN(10)
       NERR=0
       READ(20,2,ERR=10)NTERM,NZONE,IOFLAG
       READ(20,2,ERR=10)(NCURB(I),I=1,NTERM)
       READ(20,4,ERR=10)(REFLOW(I),I=1,NTERM)
       READ(20,4,ERR=10)(TMSPLT(I),I=1,NTERM)
       READ(20,4,ERR=10)(PXSPLT(I),I=1,NZONE)
       READ(20,4,ERR=10)((TRSPLT(I,J),J=1,10),I=1,NZONE)
       IF(NZONE.LT.NTERM) GO TO 13
       DO 11 I=1,NZONE
       TREN(I)=0.
       DO 11 J=1,NZONE
       TREN(I)=TREN(I)+TRSPLT(I,J)*PXSPLT(J)/PXSPLT(I)
    11 CONTINUE
       GO TO 14
    13 DO 12 I=1,NTERM
       TREN(I)=0.
       DO 12 J=1,NTERM
       TREN(I)=TREN(I)+TRSPLT(I,J)*TMSPLT(J)/TMSPLT(I)
    12 CONTINUE
    14 CONTINUE
       READ(20,6,ERR=10)RDMAX,NLANES,RECIRC,PRKMAX,CMAX(1),CMAX(2)
       IF(RECIRC.EQ.0.)RECIRC=.17
       RETURN
10     WRITE(7,8)
       NERR=1
       RETURN
2      FORMAT(10I8)
4      FORMAT(10F8.0)
6      FORMAT(F8.0,I8,8F8.0)
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8     FORMAT(' ERROR OCCURED IN APSPEC -TRYING TO READ DATA FROM INPUT')
      END
      SUBROUTINE BAGS(PKBAGS,T1,S,K,BAGPX,IFLAG,DELAY)
C     -----DELAY AT BAGGAGE CLAIM-----
      DATA BAGRTE,WLKRTE,T2/1.,3.,786./
      IFLAG=0
      S=1./(.2*BAGRTE)
      T=PKBAGS*S/K
      T1=T1/WLKRTE
      XMEAN=(BAGPX*T)/(BAGPX+1)
      DELAY=T2+XMEAN
      DELAY=DELAY-T1
      IF(DELAY.LT.0.)DELAY=0.
      S=S/BAGPX
      RETURN
      END
      SUBROUTINE CONVRT (VHLAM)
C     -----CONVERT FROM VEHICLE TO PAX DELAY-----
      COMMON/VEHCLE/TOTVEH,VHMODE(4),VHLAM1(4,4),VHLAM2(1,4),RENTAL
      COMMON/PXDATA/PAXPER(4),PXMODE(4),VEHPAX
      COMMON /DLAY/N,S(20),DELAY(20),K(20),SSD(20)
      DIMENSION VHLAM(5,4)
      DO 16 J=1,N
      VSUM=0.
      PSUM=0.
      GO TO (2,6,14,10,10,14,6,2),J
2     DO 4 I=1,3
      VSUM=VSUM+VHMODE(I)*TOTVEH
4     PSUM=PSUM+PAXPER(I)*VHMODE(I)*TOTVEH
      DELAY(J)=DELAY(J)*VSUM/PSUM
      PSUM=PSUM+PAXPER(4)*(TOTVEH-VSUM)
      S(J)=S(J)*TOTVEH/PSUM
      GO TO 16
6     DO 8 I=1,3
      VSUM=VSUM+VHLAM(I,1)
8     PSUM=PSUM+PAXPER(I)*VHLAM(I,1)
      DELAY(J)=DELAY(J)*VSUM/PSUM
      PSUM=PSUM+PAXPER(4)*VHLAM(4,1)
      S(J)=S(J)*(VSUM+VHLAM(4,1))/PSUM
      GO TO 16
10    JJ=J-1
      DO 12 I=1,4
      VSUM=VSUM+VHLAM(I,JJ)
12    PSUM=PSUM+PAXPER(I)*VHLAM(I,JJ)
      IF(VSUM.EQ.0.) GO TO 16
      PSUM=PSUM/VSUM
      DELAY(J)=DELAY(J)/PSUM
      S(J)=S(J)/PSUM
      GO TO 16
14    DELAY(J)=DELAY(J)/PAXPER(1)
      S(J)=S(J)/PAXPER(1)
16    CONTINUE
      RETURN
      END
      SUBROUTINE CNTRLS(TITLE,PKHRPX,NPCP,BAGPX,NERR)
C     -----READS IN CONTROL DATA-----
      REAL MENFAC
      DIMENSION ICON(8)
      COMMON/VEHCLE/TOTVEH,VHMODE(4),VHLAM1(4,4),VHLAM2(1,4),RENTAL
      COMMON/TSTDAT/APE,FMIX,NPK,ACTPK,NOPS,AVLD,CNCT
      COMMON/PXDATA/PAXPER(4),PXMODE(4),VEHPAX
      DIMENSION TITLE(19)
      CHARACTER NY*1,NO*1,NPCP*1,ICON*1
      DATA NY,NO/'Y','N'/
      DATA (ICON(I),I=1,8)/'A','B','C','D','E','F','G','H'/
      NERR=0
      READ(20,24,ERR=18)(TITLE(I),I=1,19)
      READ(20,28,ERR=18)NPCP
      READ(20,29,ERR=18)NPK,NOPS
      READ(20,30,ERR=18)APE,PKHRPX,FMIX,ACTPK,AVLD
      READ(20,31,ERR=18)CNCT,(PXMODE(I),I=1,4),BAGPX,VEHPAX,RENTAL
      IF(RENTAL.EQ.0.) RENTAL=0.14
C     -----INITIALIZE DEFAULT DATA-----
      IF(APE.LE.0.  .AND.PKHRPX.LE.0.)NERR=1
      SUM=0.
      DO 1 I=1,4
1     SUM=SUM+PXMODE(I)
      ISUM=SUM
      IF(ISUM.EQ.1)GO TO 78
78    CONTINUE
      IF(BAGPX.EQ.0.)BAGPX=1.5
      IF(CNCT.EQ.0.)CNCT=.2
      IF(FMIX.EQ.0.)FMIX=.1
      IF(NPK.EQ.0)NPK=2
      IF(ACTPK.EQ.0.)ACTPK=0.07
      IF(NOPS.EQ.0)NOPS=70
      IF(AVLD.EQ.0.)AVLD=.5
      IF(VEHPAX.EQ.0.)VEHPAX=1.
C     ------IDENTIFY CONTROL PARAMETER-----
      DO 2 I=1,8
      IF(NPCP.NE.ICON(I)) GO TO 2
      NN=I
      GO TO 4
2     CONTINUE
4     IF(NERR.EQ.1)RETURN
      GO TO(6,16,10,6,16,14,14,16),NN
6     PKHRPX=2*ACTPK*(APE*1000.)/210.
      RETURN
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10      ACTPK=FMIX*.15+.07
        GO TO 6
14      PKHRPX=FMIX*250.+(1.-FMIX)*100.
        PKHRPX=PKHRPX*NOPS*AVLD
16      RETURN
18      WRITE(7,22)
        NERR=1
        RETURN
22      FORMAT ('ERROR OCCURRED IN CONTRL-TRYING TO READ FROM INPUT')
24      FORMAT (20A4)
28      FORMAT(A1)
29      FORMAT(2I8)
30      FORMAT(5F8.0)
31      FORMAT(8F8.0)
        END
        SUBROUTINE CURB(VLAM,S,K,FRONT,SSD,IFLAG,DELAY)
C       -----DELAY AT CURB-----
        COMMON/VEHCLE/TOTVEH,VHMODE(4),VHLAM1(4,4),VHLAM2(1,4),RENTAL
        FRONT=.7*FRONT
        SLOT=(VHMODE(1)+VHMODE(2))/25.
        SLOT=SLOT+VHMODE(3)/50.
        SLOT=SLOT/(1.-VHMODE(4))
        SLOT=SLOT*FRONT
        IF(K.EQ.3)SLOT=SLOT*1.5
        IF(K.GT.3)SLOT=SLOT*1.75
        K=IFIX(SLOT)
        ARG1=VLAM/3600.
        CALL MMKS(ARG1,S,K,IFLAG,DELAY,EL)
        SSD=(K/S)*3600.
        RETURN
        END
        SUBROUTINE FLOW(CAPLAM,P1,LAM)
C       -----SUBROUTINE TO DETERMINE FLOWS IN EACH STATE
C            BY USING CAPLAM=ARRIVAL RATE INTO SYSTEM,AND
C            ONE STEP TRANSITION MATRIX P1 TO OBTAIN SPLITS
C            AMONG STATES-----
        REAL LAM
        COMMON /DLAY/ N,S(20),OUT(20),K(20),SSD(20)
        DIMENSION LAM(20),P1(20,20),HOLD(25)
        DATA HOLD/25*0./
        DATA NOPT/1/
        NLOOP=20
C       -----INITIALIZE LAMBDA'S FOR FORWARD FLOWS-----
        LAM(1)=CAPLAM
        OUT(1)=LAM(1)
C       UTIL=LAM(1)*S(1)/K(1)
C       IF(UTIL.GE.1.  .AND. NOPT.EQ.1)OUT(1)=K(1)/S(1)
        HOLD(1)=OUT(1)
        DO4 J=2,N
        LAM(J)=0.
        KLEE1=J-1
        DO 2 I=1,KLEE1
2       LAM(J)=LAM(J)+P1(I,J)*OUT(I)
        OUT(J)=LAM(J)
C       UTIL=LAM(J)*S(J)/K(J)
C       IF(UTIL.GE.1.  .AND. NOPT.EQ.1)OUT(J)=K(J)/S(J)
        HOLD(J)=OUT(J)
4       CONTINUE
        IN=0
C       -----COMPUTE LAMBDA'S TO INCLUDE FEEDBACK FLOWS-----
6       DO 10 J=1,N
        LAM(J)=0.
        IF(J.EQ.1)LAM(J)=CAPLAM
        DO 8 I=1,N
8       LAM(J)=LAM(J)+P1(I,J)*HOLD(I)
        OUT(J)=LAM(J)
C       UTIL=LAM(J)*S(J)/K(J)
C       IF(UTIL.GE.1.  .AND. NOPT.EQ.1)OUT(J)=K(J)/S(J)
        HOLD(J)=OUT(J)
10      CONTINUE
        IN=IN+1
        IF(IN.LE.NLOOP)GO TO 6
        RETURN
        END
        SUBROUTINE MGKS(LAM,SSD,MEAN,K,IFLAG,WQ,EL)
C       -----COMPUTES A DELAY WITH A GENERAL SEERVICE TIME-----
C            S=MEAN SERVICE TIME,SSD=STANDARD DEVIATION OF
C            SERVICE TIME
        REAL LQ,L,LAM,MEAN,LM,MENFAC
        COMMON/NEW/NUFLAG,MENFAC,SATLIN
        DATA RHOSTR/.98/
1       IFLAG=0
2       LM=LAM*MEAN
        IF(LM/K.LE.RHOSTR) GO TO 4
        IFLAG=1
        XRHO=LM/K
        LM=RHOSTR*K
4       SUM=1.
        TERM=LM
        IF(K.EQ.1) GO TO 8
        KLEE3=K-1
        DO 6 N=1,KLEE3
        SUM=SUM+TERM
        TERM=TERM*LM/(N+1)
6       CONTINUE
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8       SUM=SUM+TERM*K/(K-LM)
        E2=SSD**2/MEAN**2
        WNUM=TERM*E2*K*MEAN/2.
        WQ=WNUM/(SUM*(K-LM)*(K-LM))
        EL=WQ*LAM
        IF(IFLAG.EQ.0) GO TO 10
        WQ=WQ+900.*(XRHO-RHOSTR)/2.
10      RETURN
        END
        SUBROUTINE MMKS(LAM,S,K,IFLAG,WQ,EL)
C       -----POISSON ARRIVAL RATE,EXPONENTIAL INTERARRIVAL
C            TIMES,S=MEAN SERVICE TIME
        REAL LAM,MU,LQ,L,MENFAC
        COMMON/NEW/NUFLAG,MENFAC,SATLIN
        DATA RHOSTR/.98/
1       MU=1./S
3       IFLAG=0
2       RHO=LAM/MU
        IF(RHO/K.LE.RHOSTR)GO TO 4
        IFLAG=1
        XRHO=RHO/K
        RHO=RHOSTR*K
4       P0=1.
        TERM=RHO
        IF(K.EQ.1)GO TO 8
        KLEE1=K-1
        DO 6 N=1,KLEE1
        P0=P0+TERM
        TERM=TERM*RHO/(N+1)
6       CONTINUE
8       P0=P0+TERM/(1.-RHO/K)
        P0=1./P0
        QVAR=TERM*RHO*K/(K-RHO)**2
        WQ=QVAR*P0/LAM
        IF(IFLAG.EQ.0)GO TO 10
        WQ=WQ+900.*(XRHO-RHOSTR)/2.
        EL=QVAR*P0
10      RETURN
        END
        SUBROUTINE MPRINT(N,TOTPIJ,DPC,SPC,TPC,TRVL)
        DIMENSION DPC(20,20),SPC(20,20),TPC(20,20),TRVL(20,20),TOTPIJ(20,2
       +0)
        KOUT=6
        WRITE(7,16)
        DO 2 L=1,N
2       WRITE(7,14)(TOTPIJ(L,M),M=1,N)
        WRITE(7,18)
        DO 4 L=1,N
4       WRITE(7,14)(DPC(L,M),M=1,N)
        WRITE(7,20)
        DO 6 L=1,N
6       WRITE(7,14)(SPC(L,M),M=1,N)
        WRITE(7,22)
        DO 8 L=1,N
8       WRITE(7,14)(TPC(L,M),M=1,N)
        DO 10 I=1,N
        DO 10 J=1,N
        TRVL(I,J)=DPC(I,J)+SPC(I,J)+TRVL(I,J)
10      CONTINUE
        WRITE(7,24)
        DO 12 L=1,N
12      WRITE(7,14)(TRVL(L,M),M=1,N)
        RETURN
14      FORMAT (6(F8.2,4X)/(12X,5(F8.2,4X)))
16      FORMAT('1',1X,'CUMULATIVE TRANSITION MATRIX:'/)
18      FORMAT(//,1X,'CUMULATIVE DELAY MATRIX:'/)
20      FORMAT(//,1X,'CUMULATIVE SERVICE MATRIX:'/)
22      FORMAT(//,1X,'CUMULATIVE TRAVEL TIME MATRIX:'/)
24      FORMAT(///,1X,'TOTAL CUMULATIVE TIME IN SYSTEM(SEC/PAX):'/)
        END
        SUBROUTINE NETIME (P1,TRVL,NRTE,IOFLAG,CD,CS,CT)
C       -----NETWORK PROGRAM FOR CALCULATING EXPECTED VALUES
C            OF DELAY AND TRAVEL TIMES.  INPUTS ARE TRANSITION
C            MATRIX P1 FOR N STATES AND DELAY AND SERVICE TIMES
C            FOR EACH STATE, TRAVEL TIMES BETWEEN STATES.
        COMMON /DLAY/N,SERV(20),DELAY(20),K(20),SSD(20)
        DIMENSION DSAVE(20),SSAVE(20),TSAVE(20),DT(20,20),DPC(20,20)
       +,ST(20,20),SPC(20,20),TOTPIJ(20,20),TRVL(20,20),TT(20,20)
       +,TPC(20,20),P1(20,20),PN(20,20),PSAVE(20)
        DO 2 I=1,N
        DO 2 J=1,N
        PN(I,J)=P1(I,J)
        TOTPIJ(I,J)=P1(I,J)
        DT(I,J)=DELAY(I)+DELAY(J)
        TT(I,J)=TRVL(I,J)
        ST(I,J)=SERV(I)+SERV(J)
        DPC(I,J)=P1(I,J)*DT(I,J)
        SPC(I,J)=P1(I,J)*ST(I,J)
        TPC(I,J)=P1(I,J)*TT(I,J)
2       CONTINUE
C       -----DEGIN LOOP ON N FOR INTERIM MATRICES-----
        KLEE5=N-2
        DO 10 NN=1,KLEE5
        DO 8 I=1,N
        DO 4 J=1,N
        DSAVE(J)=DT(I,J)
        SSAVE(J)=ST(I,J)
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      TSAVE(J)=TT(I,J)
      PSAVE(J)=PN(I,J)
4     CONTINUE
      DO 8 J=1,N
      PN(I,J)=0.
      DT(I,J)=0.
      ST(I,J)=0.
      TT(I,J)=0.
C     -----COMPUTE IJTH ELEMENT OF ALL MATRICES-----
      DO 6 KK=1,N
      PIJ=PSAVE(KK)*P1(KK,J)
      PN(I,J)=PN(I,J)+PIJ
      IF(PIJ.EQ.0.) GO TO 6
      DT(I,J)=DT(I,J)+PIJ*(DSAVE(KK)+DELAY(J))
      ST(I,J)=ST(I,J)+PIJ*(SSAVE(KK)+SERV(J))
      TT(I,J)=TT(I,J)+PIJ*(TSAVE(KK)+TRVL(KK,J))
6     CONTINUE
      IF(PN(I,J).EQ.0.) GO TO 8
      DT(I,J)=DT(I,J)/PN(I,J)
      ST(I,J)=ST(I,J)/PN(I,J)
      TT(I,J)=TT(I,J)/PN(I,J)
8     CONTINUE
C     -----ALL MATRICES COMPUTED FOR STEP N-----
      DO 10 I=1,N
      DO 10 J=1,N
      TOTPIJ(I,J)=TOTPIJ(I,J)+PN(I,J)
      DPC(I,J)=DPC(I,J)+PN(I,J)*DT(I,J)
      SPC(I,J)=SPC(I,J)+PN(I,J)*ST(I,J)
      TPC(I,J)=TPC(I,J)+PN(I,J)*TT(I,J)
10    CONTINUE
      DO 12 I=1,N
      DO 12 J=1,N
      IF(TOTPIJ(I,J).EQ.0.) GO TO 12
      DPC(I,J)=DPC(I,J)/TOTPIJ(I,J)
      SPC(I,J)=SPC(I,J)/TOTPIJ(I,J)
      TPC(I,J)=TPC(I,J)/TOTPIJ(I,J)
12    CONTINUE
      IF(IOFLAG.NE.0) CALL MPRINT(N,TOTPIJ,DPC,SPC,TPC,TRVL)
      IF(NRTE.EQ.0) GO TO 14
      CD=DPC(1,N)
      CS=SPC(1,N)
      CT=TPC(1,N)
      RETURN
14    ECRB=.72*TOTPIJ(1,5)
      EPRK=.45*TOTPIJ(1,6)
      DCRB=.46*TOTPIJ(1,4)
      DPRK=.55*TOTPIJ(1,6)
      ED=(ECRB*DPC(1,5)+EPRK*DPC(1,6))/(ECRB+EPRK)
      ES=(ECRB*SPC(1,5)+EPRK*SPC(1,6))/(ECRB+EPRK)
      DD=(DCRB*DPC(4,8)+DPRK*DPC(6,8))/(DCRB+DPRK)
      DS=(DCRB*SPC(4,8)+DPRK*SPC(6,8))/(DCRB+DPRK)
      TRVL(1,1)=DD
      TRVL(1,2)=DS
      TRVL(2,1)=ED
      TRVL(2,2)=ES
      RETURN
      END
      SUBROUTINE PARK(VLAM,TMEAN,SPACES,IFLAG,DELAY)
C     -----DELAY AT PARKING LOT-----
      IFLAG=0
      AVE=VLAM*TMEAN
      IF(AVE.GT.SPACES)IFLAG=1
      SPEED=12.*5280.
      DELAY=AVE*8.5/SPEED
      DELAY=3600.*(DELAY*AVE/SPACES)
      TMEAN=SPACES/TMEAN
      RETURN
      END
      SUBROUTINE PMS(LENGTH,SPEED,HEADWAY,TRVL,DELAY)
      REAL HEADWAY
      TRVL=REAL(LENGTH)/SPEED
      SPEED=0.
      LENGTH=1
      DELAY=0.5*HEADWAY
      RETURN
      END
      SUBROUTINE PXCALC(CNCT,PKHRPX)
C     -----CALCULATES VEHICLE MODAL SPLIT-----
      COMMON/VEHCLE/TOTVEH,VHMODE(4),VHLAM1(4,4),VHLAM2(1,4),RENTAL
      COMMON/PXDATA/PAXPER(4),PXMODE(4),VEHPAX
      DIMENSION RATIO(4)
      NPFLAG=1
      DO 2 I=1,4
2     RATIO(I)=PXMODE(I)/PAXPER(I)
C     -----COMPUTE 1 DEPENDENT PAX-PER-VEHICLE VARIABLE USING DEFAULTS--
      GO TO (4,6,8,10,12),NPFLAG
4     PAXPER(1)=PXMODE(1)/(VEHPAX-RATIO(2)-RATIO(3)-RATIO(4))
      RATIO(1)=PXMODE(1)/PAXPER(1)
      GO TO 16
C     -----TAXIS-----
6     PAXPER(2)=PXMODE(2)/(VEHPAX-RATIO(1)-RATIO(3)-RATIO(4))
      RATIO(2)=PXMODE(2)/PAXPER(2)
      GO TO 16
C     -----BUSES AND LIMOS-----
8     PAXPER(3)=PXMODE(3)/(VEHPAX-RATIO(1)-RATIO(2)-RATIO(4))
      RATIO(3)=PXMODE(3)/PAXPER(3)
      GO TO 16
```

```
C       -----SUBWAY AND RAIL-----
10      PAXPER(4)=PXMODE(4)/(VEHPAX-RATIO(1)-RATIO(2)-RATIO(3))
        RATIO(4)=PXMODE(4)/PAXPER(4)
        GO TO 16
C       -----VEHICLE-PER-PAX RATE-----
12      DO 14 I=1,4
14      VEHPAX=VEHPAX+RATIO(I)
16      TOTVEH=0.
C       -----NUMBER OF EACH TYPE OF VEHICLE-----
        DO 18 I=1,4
        VHMODE(I)=RATIO(I)*(1.-CNCT)*PKHRPX
18      TOTVEH=TOTVEH+VHMODE(I)
        DO 20 I=1,4
20      VHMODE(I)=VHMODE(I)/TOTVEH
        RETURN
        END
        SUBROUTINE RDFLOW(N,TLAM,VHLAM,RENT,P1)
C       -----COMPUTES ARRIVAL RATES FOR ROADWAY STATES-----
        COMMON/CONFIG/NCURB(10),REFLOW(10)
        COMMON/VEHCLE/TOTVEH,VHMODE(4),VHLAM1(4,4),VHLAM2(1,4),RENTAL
        DIMENSION P1(20,20),PR(8,8),VHLAM(5,4)
        DATA PR/34*0.,1.,16*0.,3*1.,8*0.,1.,0./
        NT=NCURB(N)
        RF=REFLOW(N)
        AUTO=VHMODE(1)
        VHMODE(1)=(1.-RENT)*VHMODE(1)
        DO 4 J=1,4
        DO 2 I=1,4
2       VHLAM(I,J)=VHLAM1(I,J)
4       VHLAM(5,J)=VHLAM2(1,J)
        IF(NT.EQ.2) GO TO 10
C       -----COMBINED EN AND DEPLANING CURB-----
6       DO 8 I=1,4
        VHLAM(I,2)=VHLAM1(I,2)+VHLAM1(I,3)
8       VHLAM(I,3)=0.
C       -----TRANSITION MATRIX, FIRST STEP-----
10      PR(1,2)=TLAM
        PR(1,8)=1.-PR(1,2)
        PR(2,3)=RENT*AUTO
        DO 12 J=4,6
        JJ=J-2
        DO 12 I=1,4
        PR(2,J)=PR(2,J)+VHLAM(I,JJ)*VHMODE(I)
12      CONTINUE
C       ------SECOND MOVES-----
        NC=5
        PR(6,4)=VHLAM(5,2)*VHMODE(1)/PR(2,6)
        PR(6,7)=1.-PR(6,4)
        IF(NT.EQ.1)NC=4
        PR(NC,6)=VHLAM(5,4)*VHMODE(1)/PR(2,NC)
        PR(NC,7)=1.-PR(NC,6)
C       -----CONVERT ARRIVALS FROM PCT TO NO. OF VEHICLES-----
14      TMV=TLAM*TOTVEH
        TMV=(1.+RF)*TMV
        DO 16 I=1,8
        DO 16 J=1,8
        P1(I,J)=PR(I,J)
        IF(I.GE.5 .OR. J.GE.5) GO TO 16
        IF(I.EQ.1)VHLAM(I,J)=VHLAM(I,J)+VHLAM(5,J)
        VHLAM(I,J)=VHLAM(I,J)*VHMODE(I)*TMV
16      CONTINUE
        VHMODE(1)=AUTO
        RETURN
        END
        SUBROUTINE ROAD(VLAM,VO,DIST,LNS,IFLAG,DELAY)
        COMMON/RDWAY/RDMAX,NLANES,RECIRC,PRKMAX,CMAX(2)
C       -----DELAY AT ROAD STATES------
        IFLAG=0
        RATIO=FLOAT(LNS)/NLANES
        RLNS=RATIO*RDMAX/3600.
        IF(RLNS.NE.0.) GO TO 1
        RLNS=LNS*1200.
        RLNS=RLNS/3600.
1       VLAM=VLAM/3600.
        VO=VO*5280./3600.
        IF(1.-VLAM/RLNS)2,4,4
2       IFLAG=1
        VR=1./(1.+VLAM-RLNS)
        VR=VR*.667*VO
        GO TO 6
4       VR=VO*(1.-VLAM/(3*RLNS))
6       DELAY=DIST/VR-DIST/VO
        DIST=DIST/VO
        VLAM=VLAM*3600.
        VO=RLNS*3600.
        RETURN
        END
        SUBROUTINE STATES(NRTE,MCODE,TRVL,P1,TITLE,NAM,NERR,NTM)
C       -----READS DATA FOR NETWORK STATES-----
        COMMON /DLAY/N,S(20),DELAY(20),K(20),SSD(20)
        COMMON/AIRL/CODE4
        DIMENSION TRVL(20,20),P1(20,20),MCODE(20),TITLE(19),NAM(20),
       +CODE4(20),NTM(20)
        CHARACTER CODE4*8
        DATA RATE/3./
        NERR=0
```

```
      READ(20,16)(TITLE(I),I=1,19)
      READ(20,10)N,NRTE
      DO 2 L=1,N
2     READ(20,12)K(L),S(L),SSD(L),MCODE(L),CODE4(L)
      IF(NRTE.GT.0) GO TO 3
      NERR=NRTE
      RETURN
3     DO 4 I=1,N
      DO 4 J=1,N
4     TRVL(I,J)=0.
5     CONTINUE
      IF(N.GT.10) GO TO 177
      READ(20,10)(NAM(I),I=1,N)
      READ(20,10)(NTM(I),I=1,N)
      GO TO 178
177   READ(20,10)(NAM(I),I=1,10)
      READ(20,10)(NAM(I),I=11,N)
      READ(20,10)(NTM(I),I=1,10)
      READ(20,10)(NTM(I),I=11,N)
178   CONTINUE
      DO 6 L=1,N
      IF(N.GT.10) GO TO 277
      READ(20,14)(TRVL(L,J),J=1,N)
      GO TO 278
277   READ(20,14)(TRVL(L,J),J=1,10)
      READ(20,14)(TRVL(L,J),J=11,N)
278   CONTINUE
      DO 6 M=1,N
      TRVL(L,M)=TRVL(L,M)/RATE
6     CONTINUE
      DO 378 L=1,N
      IF(N.GT.10) GO TO 377
8     READ(20,14)(P1(L,M),M=1,N)
      GO TO 378
377   READ(20,14)(P1(L,M),M=1,10)
      READ(20,14)(P1(L,M),M=11,N)
378   CONTINUE
      RETURN
10    FORMAT(10I8)
12    FORMAT(I8,2F8.0,I8,A8)
14    FORMAT(10F8.0)
16    FORMAT(20A4)
20    FORMAT(' ERROR OCCURRED IN STATES--TRYING TO READ FROM INPUT')
22    WRITE(7,20)
      NERR=1
      RETURN
      END
```

APPENDIX B

PROCEDURE USED TO ESTIMATE TERMINAL AREA

The sizing of most terminal elements is based on passenger volumes for a selected design hour. However, when this information is not available, approximations can be developed for preliminary planning purposes by considering the number of aircraft and seating capacities expected to serve the terminal. This technique was developed by the FAA (31), and updated by the Air Transport Association of America (ATA) (1), and has been used for this study. The technique utilizes Equivalent Aircraft (EQA) as a single value to reflect the seating capacities and number of aircraft whose passengers would most directly influence the sizing of a particular component of the terminal. Tables and charts are used for sizing terminal elements based on EQA.

Terminal space requirements have been approximated by combining individual components of the terminal. This appendix summarizes the assumptions made for each component in the development of an area estimate for an eight gate module handling one million annual enplaned air passengers of which approximately 20% are connecting passengers. The applicable tables and charts from the FAA/ATA technique are noted and results are summarized on a worksheet, Figure B.1.

An important factor in the FAA/ATA technique in sizing the components is the Gate EQA. The Gate EQA is developed by multiplying gate positions by equivalent aircraft factors.

Gate EQA for this example:

- 8 gate positions in module
- each gate designed to accommodate a Boeing 767 aircraft

Gate EQA = 16

Another important factor is EQA Inbound. The EQA Inbound is used primarily for sizing baggage claim facilities and represents aircraft arrivals in a peak 20 minute periods.

EQA Inbound, for this example = 8

Area Estimate by Components

1. Airline Counters (Figure 4-5)*

   - assume peak hour gate utilization combines arrivals and departures - use curve B.
   - 80% of enplaning passengers originate flights at airport (20% connecting passengers)
   - Gate EQA = 16
   - from Figure, counter frontage = 200 ft.
   - estimated area = 200 x 10 ft = 2000 sq. ft.

2. ATO (Airline Ticket Office/Support Space (Figure 4-6)

   - space for accounting and safekeeping of receipts, agent supervision, communications, agent lounge

---

* Reference to tables and figures that appear in The Apron and Terminal Building Reference Manual. Ralph Parsons Company. Prepared for Federal Aviation Administration, U.S.D.O.T., Washington, D.C., 1975.

- same assumptions as airline counters
- Gate EQA = 16
- from Figure, area = 4500 sq. ft.

3. Outbound Baggage (Figure 4-16)

   - assume 1.3 average bags per passenger and 60-100% of bag rooms as shown in Figure 4-11
   - Gate EQA = 16
   - from Figure, area = 7000 sq. ft.

4. Baggage Claim Area (Figures 4-22, 4-23, 4-24)

   - assume 1.3 average bags per passenger
   - 80% of deplaning passengers terminate flights at airport (20% connecting passengers)
   - EQA Inbound = 8
   - from Figure 4-22, claiming frontage = 300 feet
   - assume Tee and U-shaped devices alternating at 75 feet with flatbed/direct feed
   - from Figure 4-23, for 300 linear feet of claim display, claiming area = 10,000 sq. ft.
   - from Figure 4-24, for 300 linear feet of claim display, input area = 3600 sq. ft.

5. Airline Operations and Support

   - space for flight operations, flight crew and flight attendants, cabin service and ramp service personnel
   - approximated at 500 sq. ft. per Gate EQA
   - Gate EQA = 16
   - area = 16 x 500 = 8000 sq. ft.

6. Departure Lounges (Table 3-2)

   - some combined use of lounges
   - 60% boarding load factor assumed
   - area per lounge = 1600 sq. ft.
   - total area = 8 x 1600 = 12,800 sq. ft.

7. Other Airline Space

   - area not included under Airline Operations and Support
   - includes air cargo services provided in the terminal (e.g. Priority Parcel), VIP rooms and other special purpose exclusive space
   - assume 1000 sq. ft.

8. Lobby-Ticketing (Figure 4-7)

   - Gate EQA = 16
   - from Figure, area = 9,000 sq. ft. (includes counter area)
   - area for airline counters (item 1) = 2000 sq. ft.
   - area of ticket lobby = 7000 sq. ft.

9. Lobby-Waiting (Figure 4-8)

   - estimated Peak Hour enplanements = 440 passengers
   - assume 1 visitor per peak hour enplaning passenger
   - assume seating for 30% of passengers plus visitors = 30% (440 + 440) = 265
   - from Figure, area = 6000 sq. ft.

10. Lobby-Baggage Claim

   - 3 devices required
   - lobby dimensions/device: length = 75 ft., depth = 30 ft.

- area required = 3 x (75 x 30) = 6750 sq. ft.

11. Food and Beverage Services (Figure 4-25)

- annual enplaned passengers = 1 million

- assume 20% average daily use factor for coffee shop and restaurant

- from Figure, area = 10,000 sq. ft.

12. Other Concessions and Terminal Services (Figure 4-26)

- space for services such as:

  news and tobacco; gift and apparel; rental auto counters; insurance; public telephones; vending machines; washrooms; airport management; police and security; medical aid; building maintenance and storage

- annual enplaned passengers = 1 million

- from Figure, area = 12,000 sq. ft.

13. Other Rental Space

- space not directly related to air passenger activities, e.g. U.S. weather service

- assume 2000 sq. ft.

14. Other Circulation

- primarily the corridor to gate area

- assume 15,000 sq. ft.

15. Building Mechanical Systems (HVAC)

- assume 12% of gross total space

16. Building Structure

- for building columns and walls, allow 5% of the total gross area approximated for functions on lines 1 through 15.

Public Parking Spaces (Figure 5-9)

- 80% of enplaning passengers originate flights at airport (20% connecting passengers)

- annual originating passengers = 800,000
- from Figure, parking spaces required = <u>1500</u>

AIRPORT MASTER PLANNING WORKSHEET
FOR TERMINAL BUILDING SPACE STATION CODE ______

LINE				
	YEAR			
	ENPLANEMENTS (Domestic Sched. Service)	(8 gates)		
1.	AIRLINE COUNTERS L.F. GROSS AREA S.F.	200 2,000		
2.	ATO/SUPPORT SPACE S.F. (Adjoining Counters)	4,500		
3.	OUTBOUND BAGGAGE GROSS AREA S.F.	7,000		
4.	BAG CLAIM: DISPLAY L.F. . CLAIMING AREA S.F. . INPUT AREA S.F.	300 10,000 3,600		
5.	AIRLINE OPS.& SUPPORT S.F.	8,000		
6.	DEPARTURE LOUNGES S.F.	12,800		
7.	OTHER AIRLINE SPACE S.F.	1,000		
	SUB-TOTAL #1 THRU #7 S.F.	48,900		
8.	LOBBY-TICKETING S.F. (Excluding Line #1 Above)	7,000		
9.	LOBBY-WAITING: # SEATS GROSS AREA S.F.	6,000		
10.	LOBBY-BAG CLAIM GROSS AREA S.F.	6,750		
11.	FOOD & BEV. SERV. S.F.	10,000		
12.	OTHER CONCESSIONS & TERMINAL SERV. S.F.	12,000		
13.	OTHER RENTAL SPACE S.F.	2,000		
14.	OTHER CIRCULATION: VERT. : IN CONNECTOR : MISC.	15,000		
	SUB-TOTAL #8 THRU #14 S.F.	58 ,750		
	SUB-TOTAL #1 THRU #7 S.F.	48,900		
	TOTAL #1 THRU #14 S.F.	107,650		
15.	HVAC (Allowance @___%)	12,900		
	SUB-TOTAL #1 THRU #15 S.F.	120,550		
16.	STRUCTURE (Allow. @___%)	6,000		
17.	TOTAL BASE AREA S.F.	126,550		
18.	SPACES NOT IN FAA REPORT			
	TOTAL GROSS AREA S.F.	126,550		

Figure B.1 Airport Master Planning Worksheet

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