Airport Landside Notes

Dr. Antonio A. Trani
Professor of Civil and Environmental Engineering
Virginia Tech

Goals of this Section of the Notes

- Understand various terminal design concepts
- Understand the airport terminal design process
- Examine how runway/taxiway/gate geometric design parameters affect the terminal design concept
- Learn simple gate capacity methods
- Estimate Automated People Mover capacity and configurations

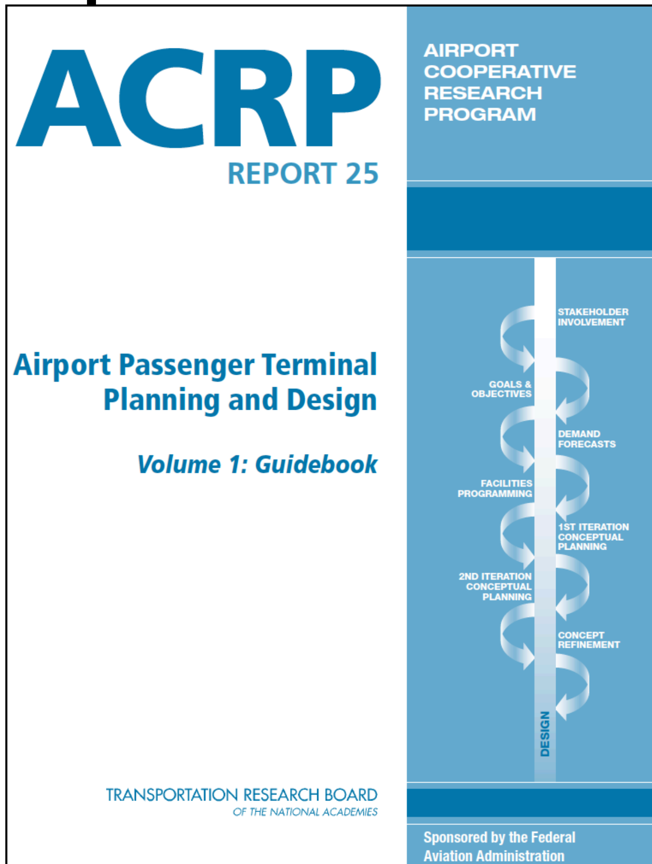
Airport Terminal Design

- Normally carried out by a team of architects and engineers
- Like most design processes, this is an iterative process where many tradeoffs need to be examined

Seoul Incheon Main Terminal (A. Trani)

References for Airport Terminal Design

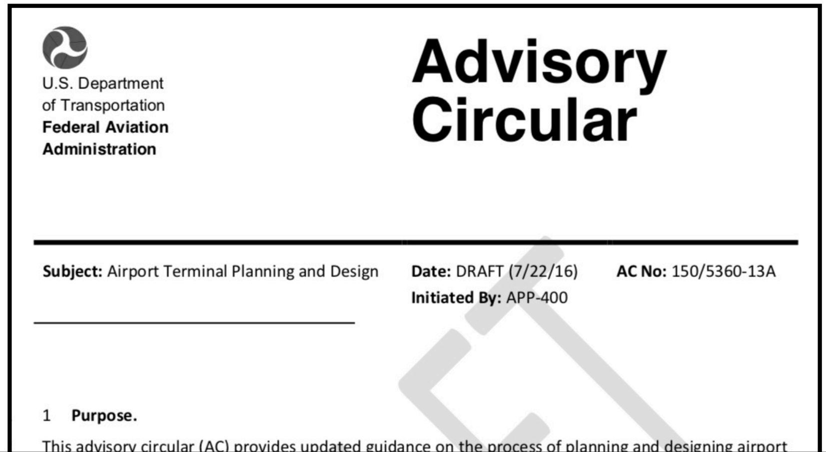
- Airport Cooperative Research Program (ACRP) Report 25 (2 volumes)
- International Air Transport Association (IATA) Airport Development Reference Manual (10th Edition)



VirginiaTech
Invent the Future

More References for Airport Terminal

- FAA Advisory Circular 150/5360-13A
- ACRP Airport Terminal Design Electronic Resource Library (ERL) (https://crp.trb.org/acrp0715/)
- Virginia Tech Air Transportation Systems Lab developed the ACRP ERL with Intermodal Logistics Consulting

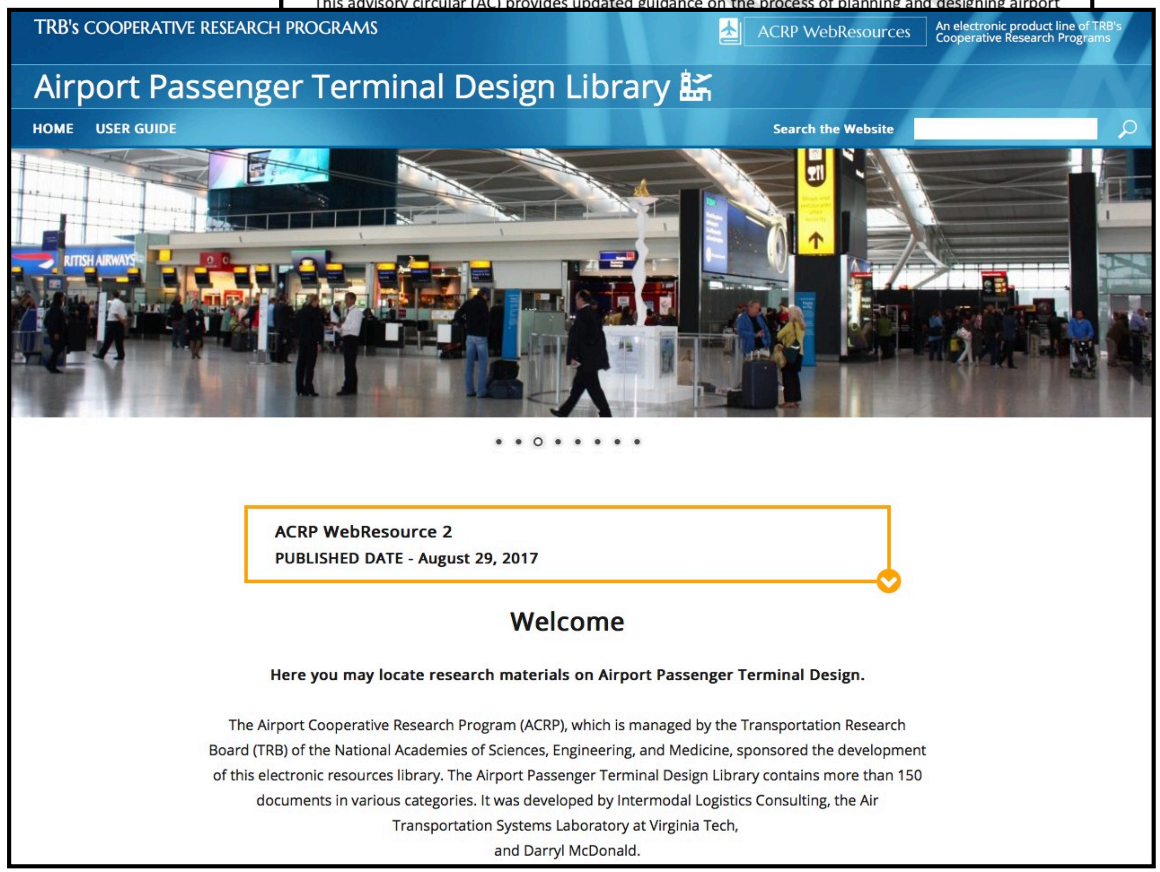

U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

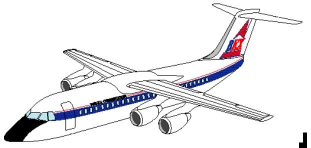
Subject: Airport Terminal Planning and Design
Date: DRAFT (7/22/16)
Initiated By: APP-400
AC No: 150/5360-13A

1 **Purpose.**

This advisory circular (AC) provides updated guidance on the process of planning and designing airport

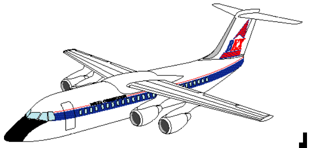


Material Presented in this Section



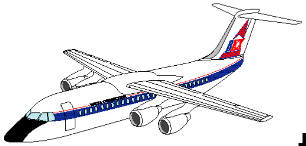
- Brief description of terminal concepts
  - + horizontal distribution
  - + vertical distribution
  - + landside components
- Future directions and impacts
- Some analytic techniques to model and simulate terminals

Purpose of the Discussion



- To review and understand the basic airport terminal concepts
- To discuss modeling techniques applicable to primary and secondary flows inside the airport terminal
- Discussion of challenges in airport terminal modeling
  - Passenger behavior modeling
  - Shopping activities inside airport terminals
  - Security implications

Basic review of Terminal Concepts

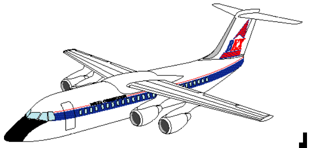


Goals in the ***design of airport terminals***:

- Walking distances (keep them short)
- Pleasing environment (helps the traveler)
- Services (well located and available)
- Security (minimize threat potential)
- Cost effective (typically includes concessions)
- Aesthetics (good waiting environment)

Sometimes these goals contradict each other (i.e., like the cost effectiveness vs. aesthetics)

Airport Terminal Concepts

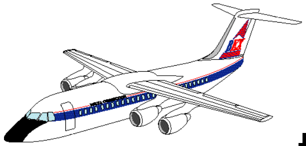


Horizontal Distribution

1) Linear
2) Pier-Finger
3) Satellite
4)Transporter

- Combinations of these are possible
- In fact, most airport terminals evolve over time from one concept to another one (i.e., linear to pier and then to satellite or transporter)
- Landside configurations have either centralized or decentralized services

Airport Terminal Concepts (cont.)

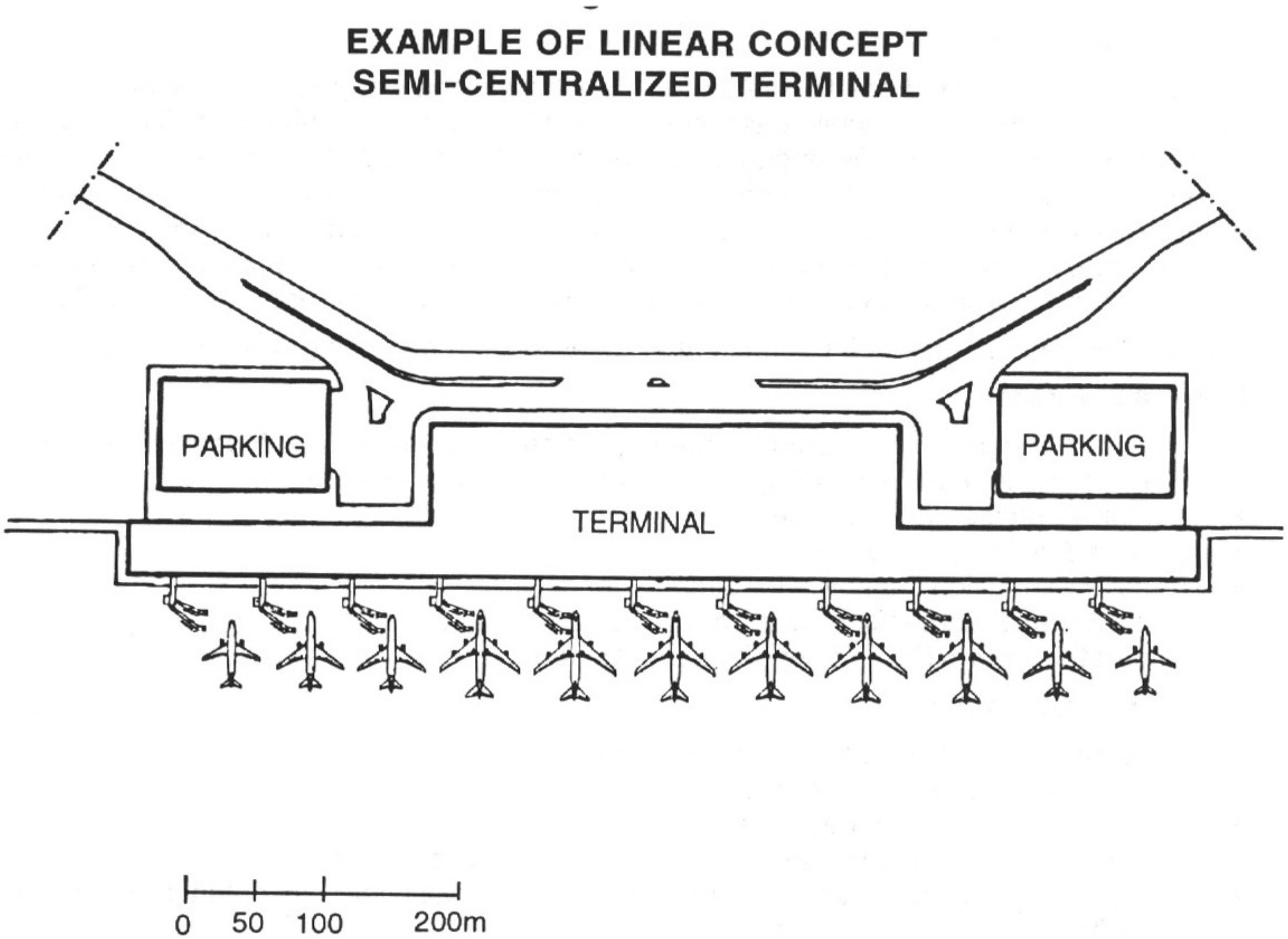


Vertical Distribution

1) One floor terminals
2) One and a half floor terminals
3) Two floor terminals

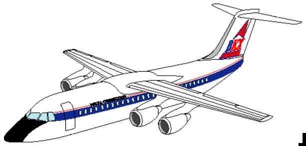
- Used to separate arrival and departing flows
- Provide and added level of security in today's environment

Linear Concept (Centralized Terminal)



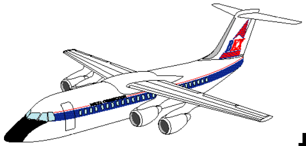
Source: IATA Airport Development Reference Manual

Linear Centralized Terminal (Advantages)



- Short walking distances if check-in facilities are decentralized (and not many transfer passengers)
- Good for passenger orientation
- Provides generous curb length
- Easy and cheap to construct
- Requires simple baggage conveying/sorting systems (reduces the procurement and operation cost of the baggage conveyance system)
- Good for separation of arriving and departing passengers

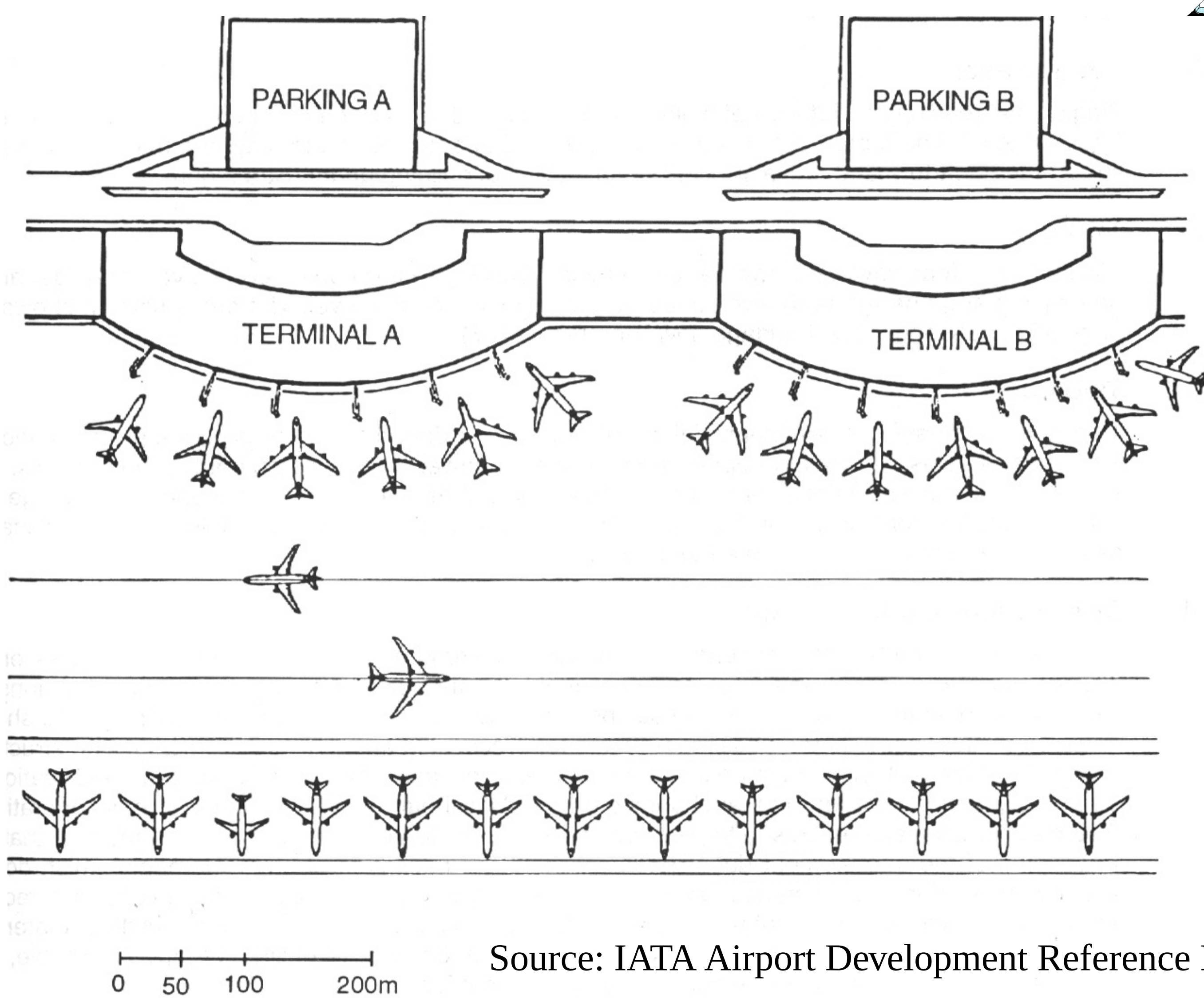
Linear Centralized Terminal (Disadvantages)



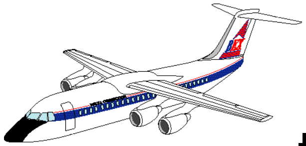
- Decentralization requires duplication of services
- Potentially long walking distances for transfer passengers or with centralized services
- More expensive logistics for handling transfer baggage
- Reduced compatibility of building/apron geometry and future very large capacity aircraft development (i.e., 85-90 m wingspan)
- If a decentralized terminal concept is adopted extensive flight information system is display is required
- Examples: Mexico City, Kansai, London Heathrow Terminal 4, Munich, etc.

Compact Module with Semi-Centralized

Terminal



Source: IATA Airport Development Reference Manual

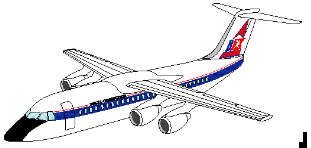


Compact Module (Advantages)

A special variation of the linear concept

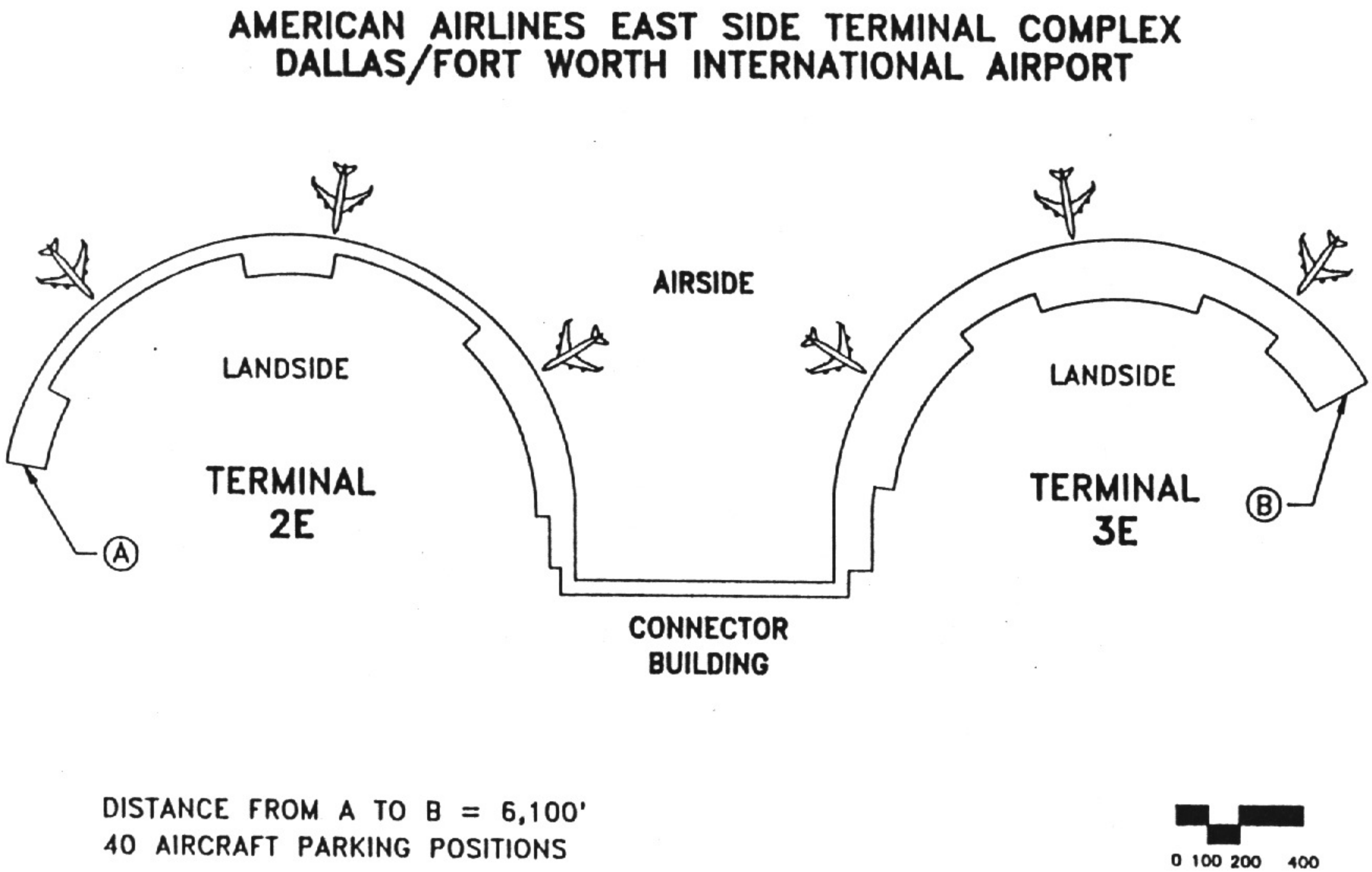
- Saves some space compared to straight linear terminal
- Provides short walking distances is properly designed (see sketches of Kansas City Airport) for terminating passengers
- Increased curb length
- It has been implemented in some of the largest airports
    - Charles de Gaulle Airport Terminal 2 (Paris)
    - Dallas-Fort Worth Airport (Dallas, Texas)
    - Kansas City Airport (extreme case of compactness)

Compact Module (Disadvantages)



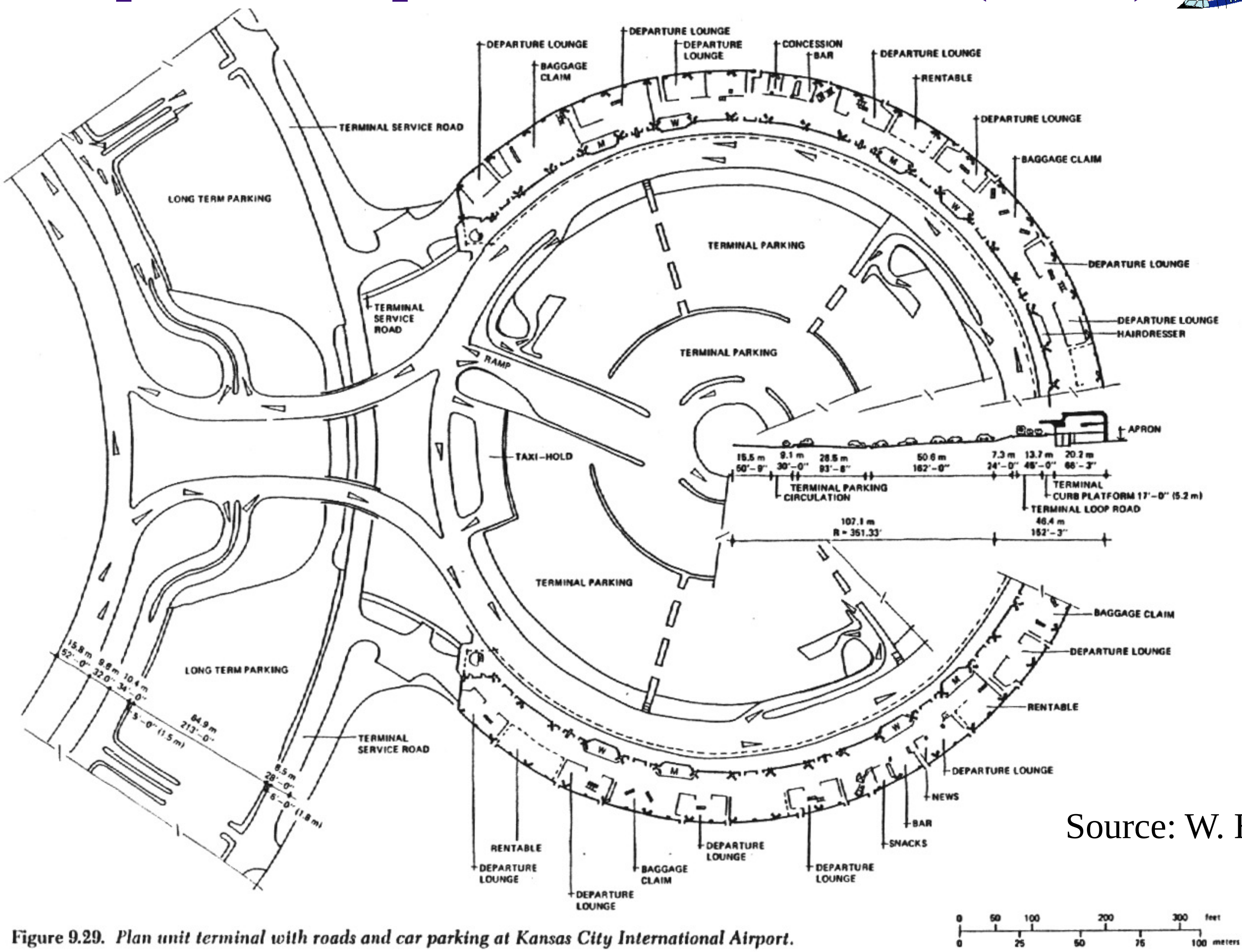
- Can be confusing to the passenger (due to rounded shape - disorienting)
- Requires a very extensive flight information service
- Requires some sort of people mover to transport passengers between terminals (see the solution adopted at DFW)
- Man power requirements might be higher due to duplication of services at each compact terminal
- Usually long walking distances result for transfer passengers
- Transfer of baggage between terminals is also a problem

Example of Compact Module Terminal (DFW)



Source: L.W. Elliot and Associates

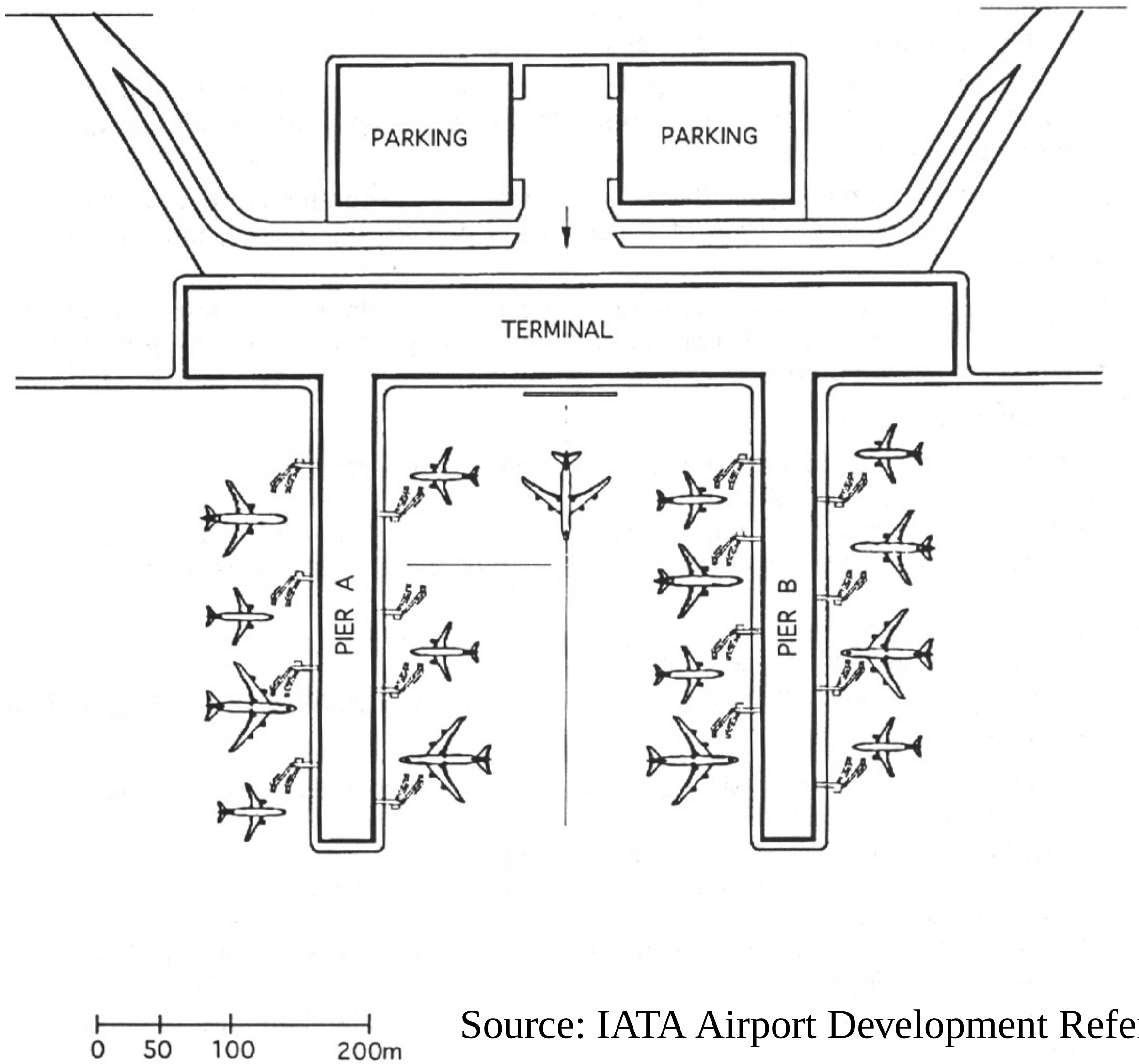
Example of Compact Module Terminal (MCO)



Source: W. Hart

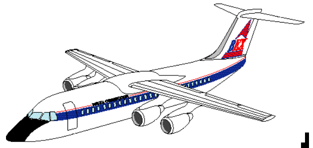
Figure 9.29. *Plan unit terminal with roads and car parking at Kansas City International Airport.*

Pier-Finger Concept with Centralized Terminal



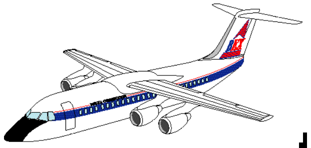
Source: IATA Airport Development Reference Manual

Pier/Finger Concept (Advantages)



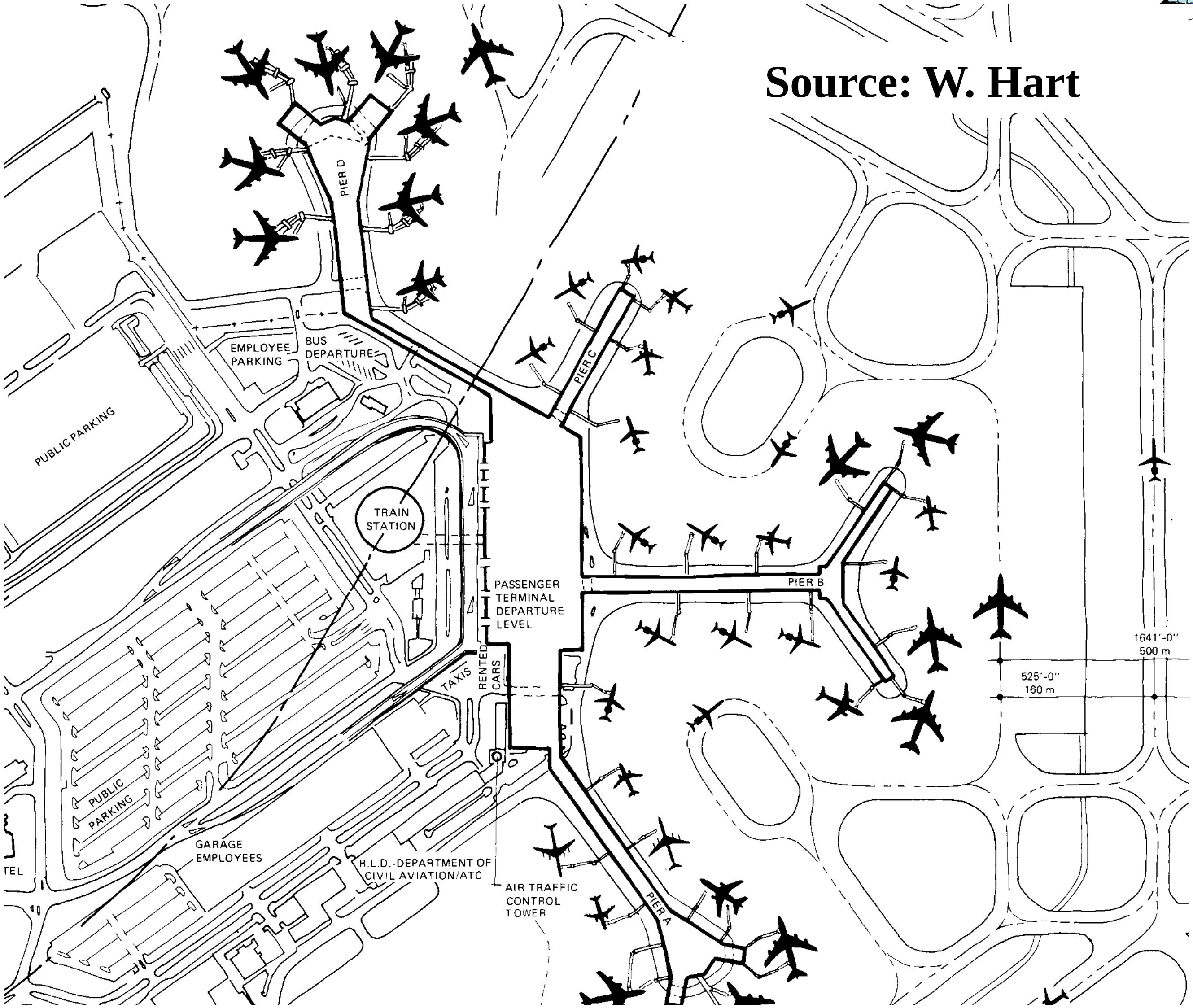
- Centralization of services (less costly)
- Reduces the number of airline and government staff employees to manage the facility (due to the high level of centralization)
- Use of simple flight information services (due to the centralization)
- The best concept for passenger control (security viewpoint)
- Examples: Amsterdam Schiphol, London Heathrow Terminal 3, San Francisco Intl. Terminal, Chicago O’Hare terminals A, B, E, F

Pier/Finger Concept (Disadvantages)

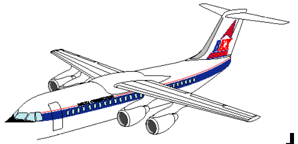


- Potentially long walking distances (specially for long piers)
- The curb length is generally insufficient (congestion is possible)
- Limited expansion capability of the main terminal
- Reduced aircraft maneuverability (instances where the piers are not parallel)
- Separation of arriving and departing passengers should be executed at different levels (3 level finger)
- High capital cost for passenger moving and baggage conveyance systems

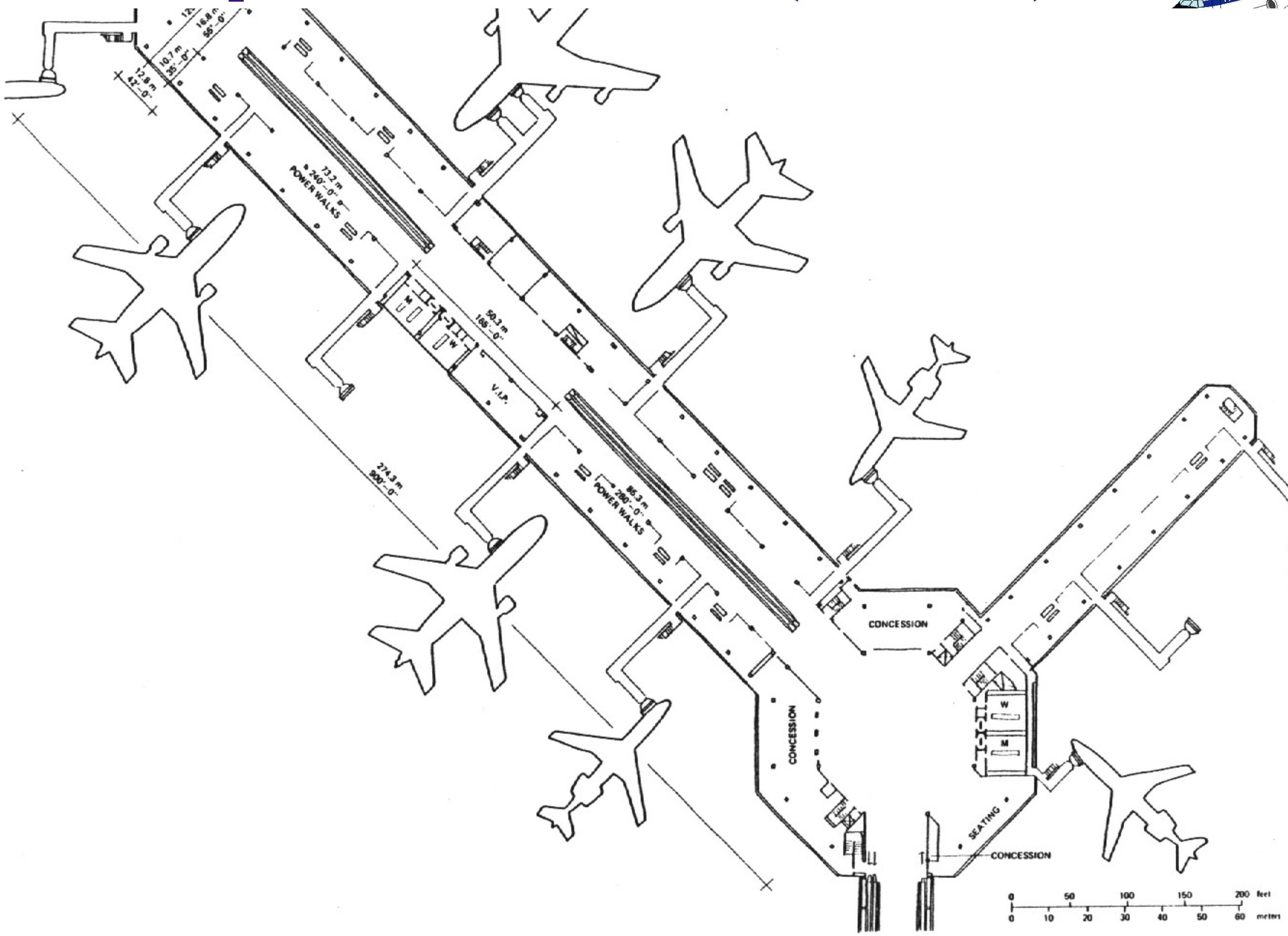
Example of a Pier Concept (Schiphol)



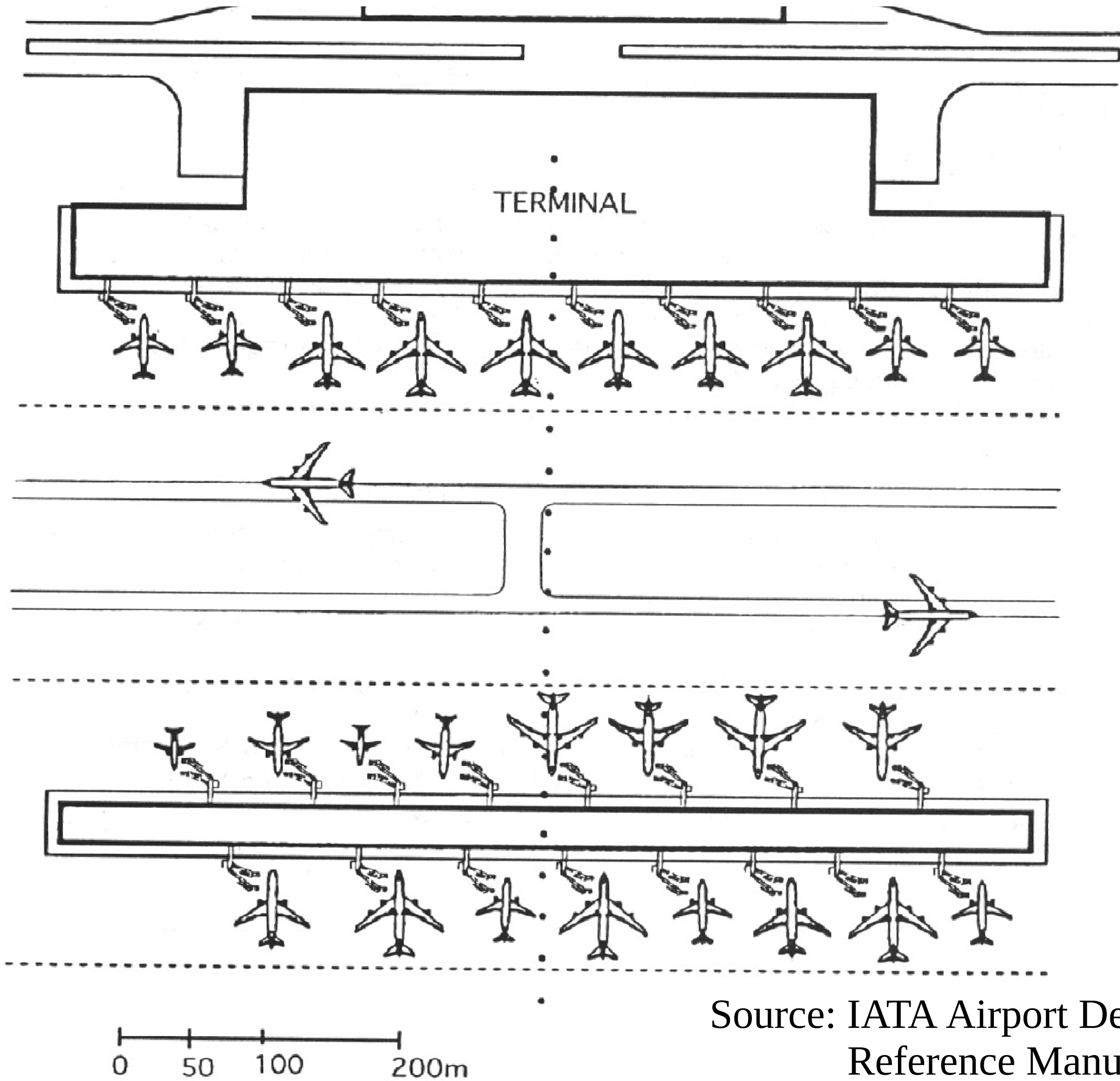
Source: W. Hart



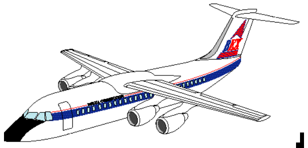
Example of a Pier Terminal (SFO Intl.)



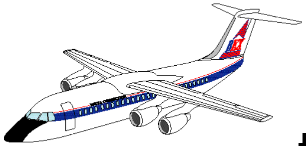
Satellite Concept with Centralized Terminal



Source: IATA Airport Development Reference Manual

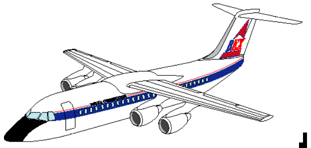


Satellite Concept (Advantages)



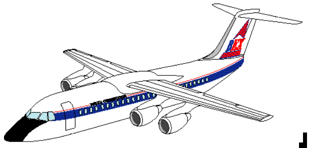
- Allows centralization of airline and government staff
- Capability of good concession areas near the gates (preferred by passengers)
- Simple flight information system
- Good expansion capability (provided land is available)
- Good to control passenger movement (excellent for security)
- Examples: Atlanta, Denver, Charles de Gaulle Terminal 1 (Paris), Tokyo Narita Terminal 2

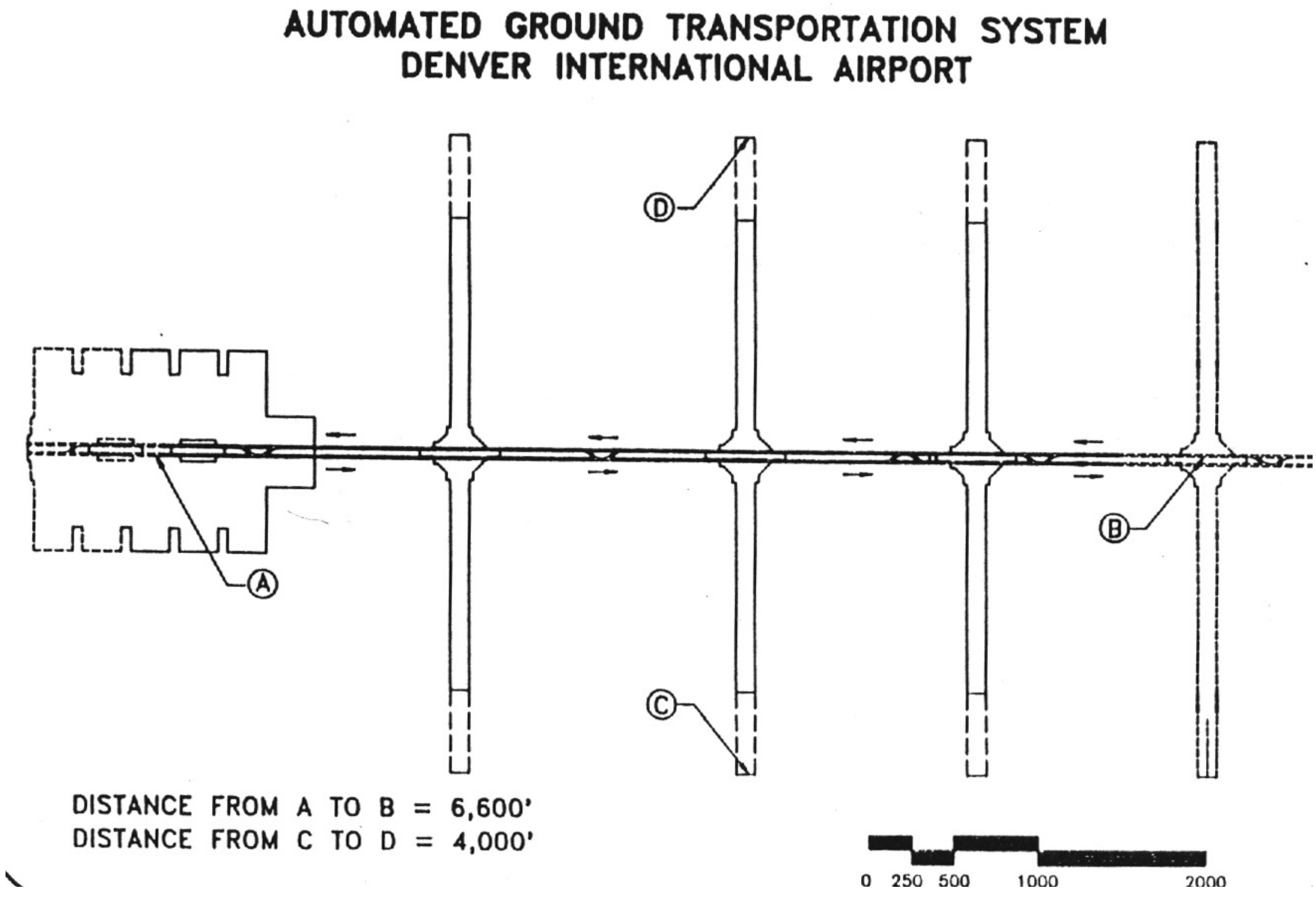
Satellite Concept (Disadvantages)



- High capital and maintenance cost of the passenger moving system
- High capital and maintenance cost of the baggage conveyance system (could be very complex)
- Curbside is usually small and provides an opportunity for congestion
- Transfer passengers require larger connecting times
- Limited expansion capability of the main terminal

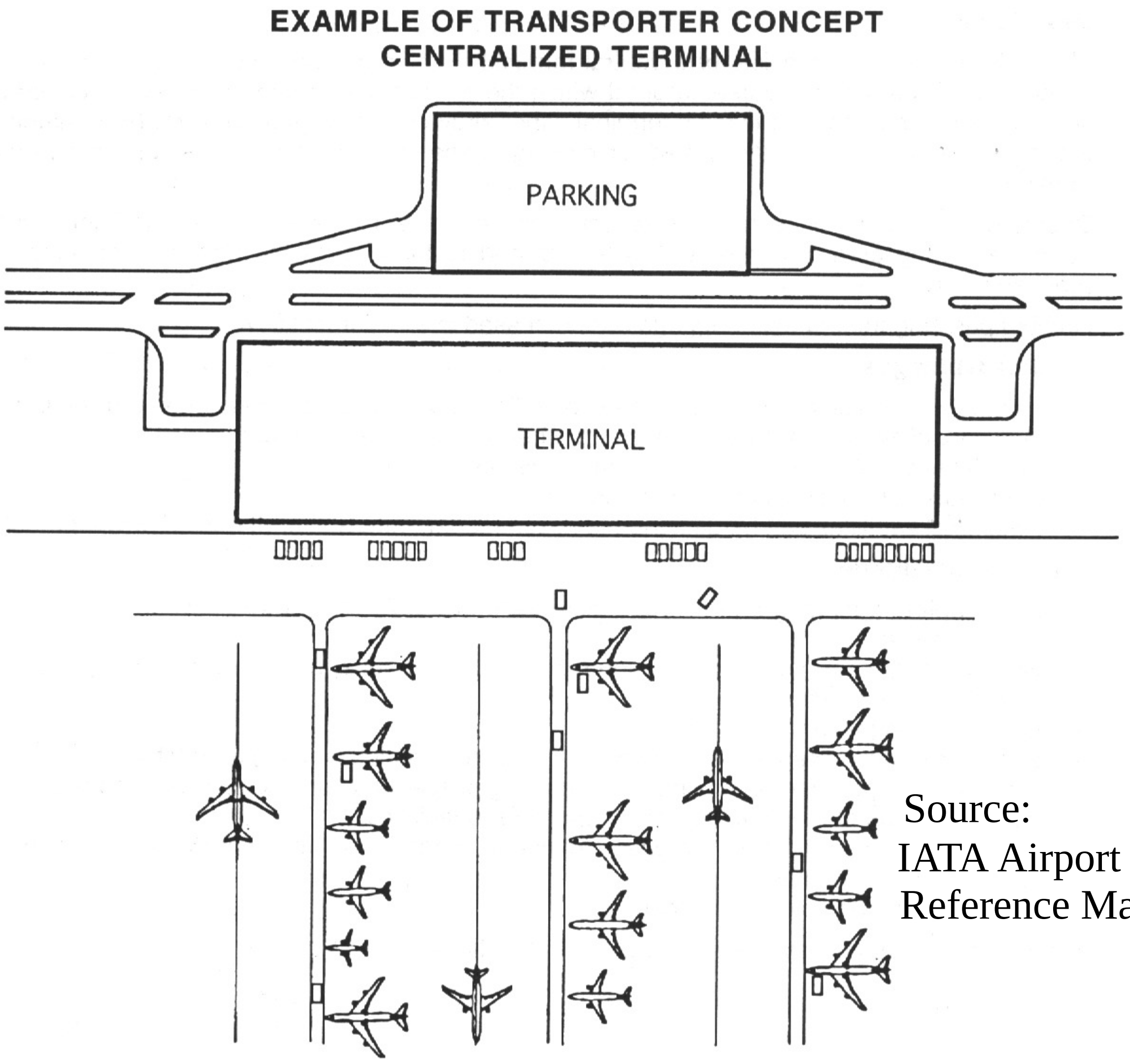
Example of Satellite Concept (Denver)





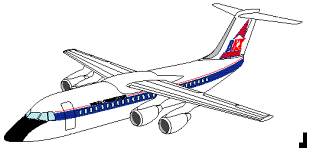
Transporter Concept with Centralized

Terminal



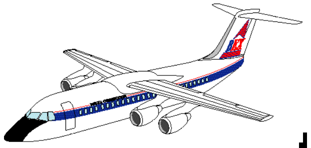
Source:
IATA Airport Development
Reference Manual

Transporter Concept (Advantages)



- Good concept for small to medium size airports (<10 million enplanements)
- Good for aircraft maneuvering
- Simple and smaller main terminal
- Separation of arriving and departing passengers is possible
- Reduced walking distances
- Easy to expand provided land is available
- Examples: Dulles (Washington, DC) and Mirabel (Canada)

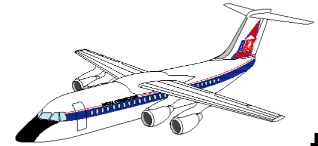
Transporter Concept (Disadvantages)

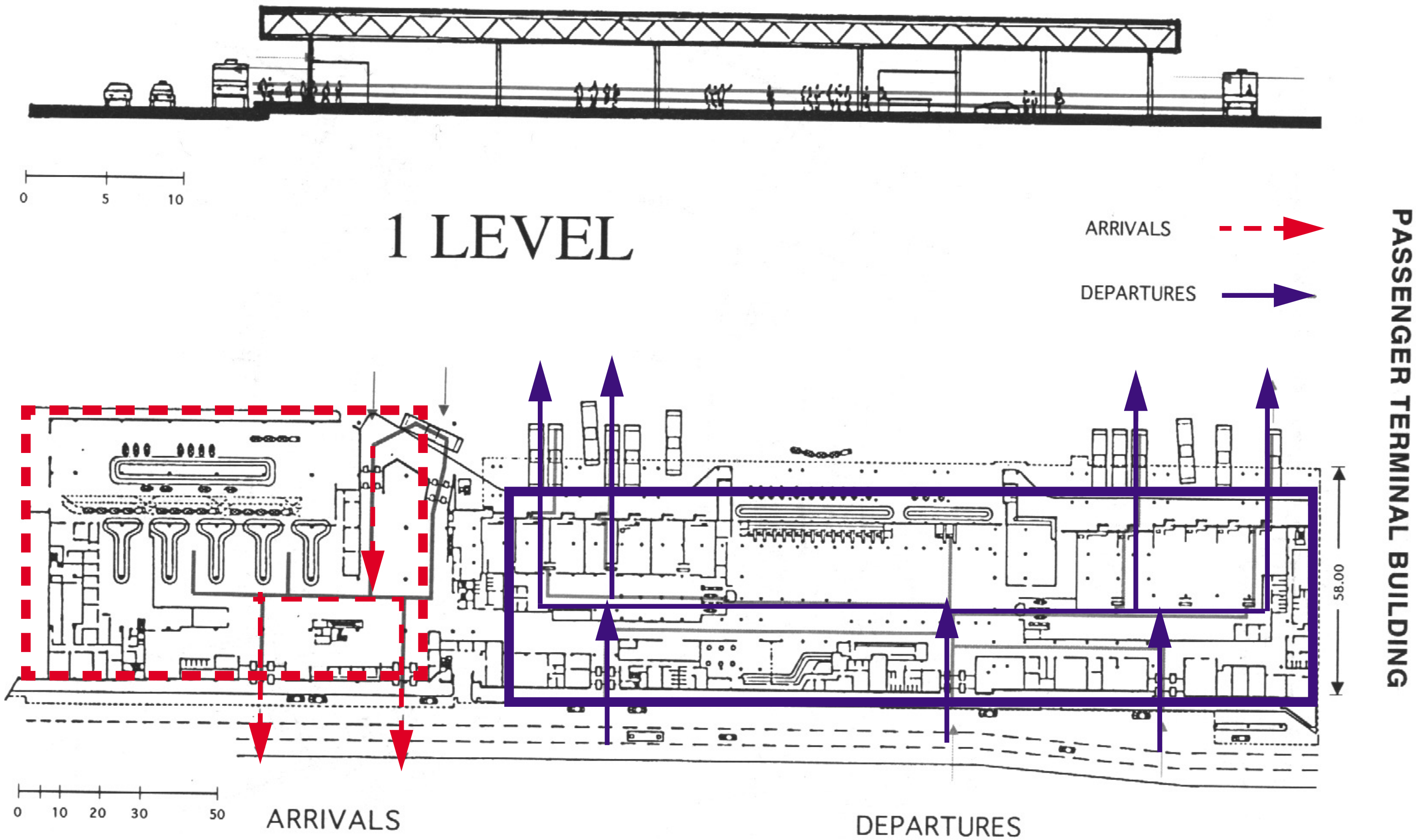


- The concept is impractical when the volume of traffic surpasses 10 million due to transporter delays and frequencies needed
- Larger connection times
- High capital cost and maintenance of transporters
- Curbside might prove insufficient (possible congestion)
- Complexity in the airside to manage transporters and aircraft
- Additional cost of for larger number of ground vehicles
- Creates demand surges due to limited frequency of transporters

Vertical Distribution Concepts

One Floor Airport Terminal

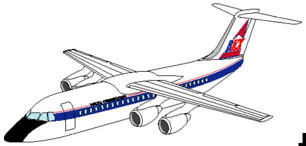




Scale in ft.

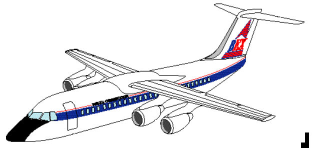
Source: IATA Airport Development Reference Manual

One Floor Airport Terminal Characteristics



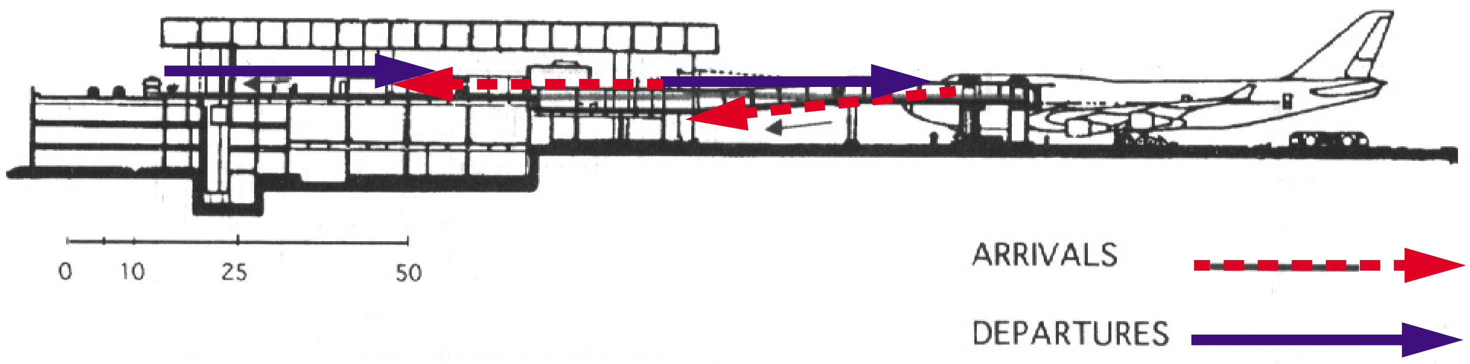
- Simple and easy to implement (low cost)
- Good for passenger orientation
- Provides good amount of curb space
- Limited (or no) capability to use boarding gates
- Generally only apply to small airports
- Passenger flows can be easily controlled (separation inside the terminal)

One and a Half Level Airport Terminal



- Provides a single level curbside (arriving and departing passengers processed at grade)
- Two level terminal building
- Departure lounges on the second level (boarding gates)

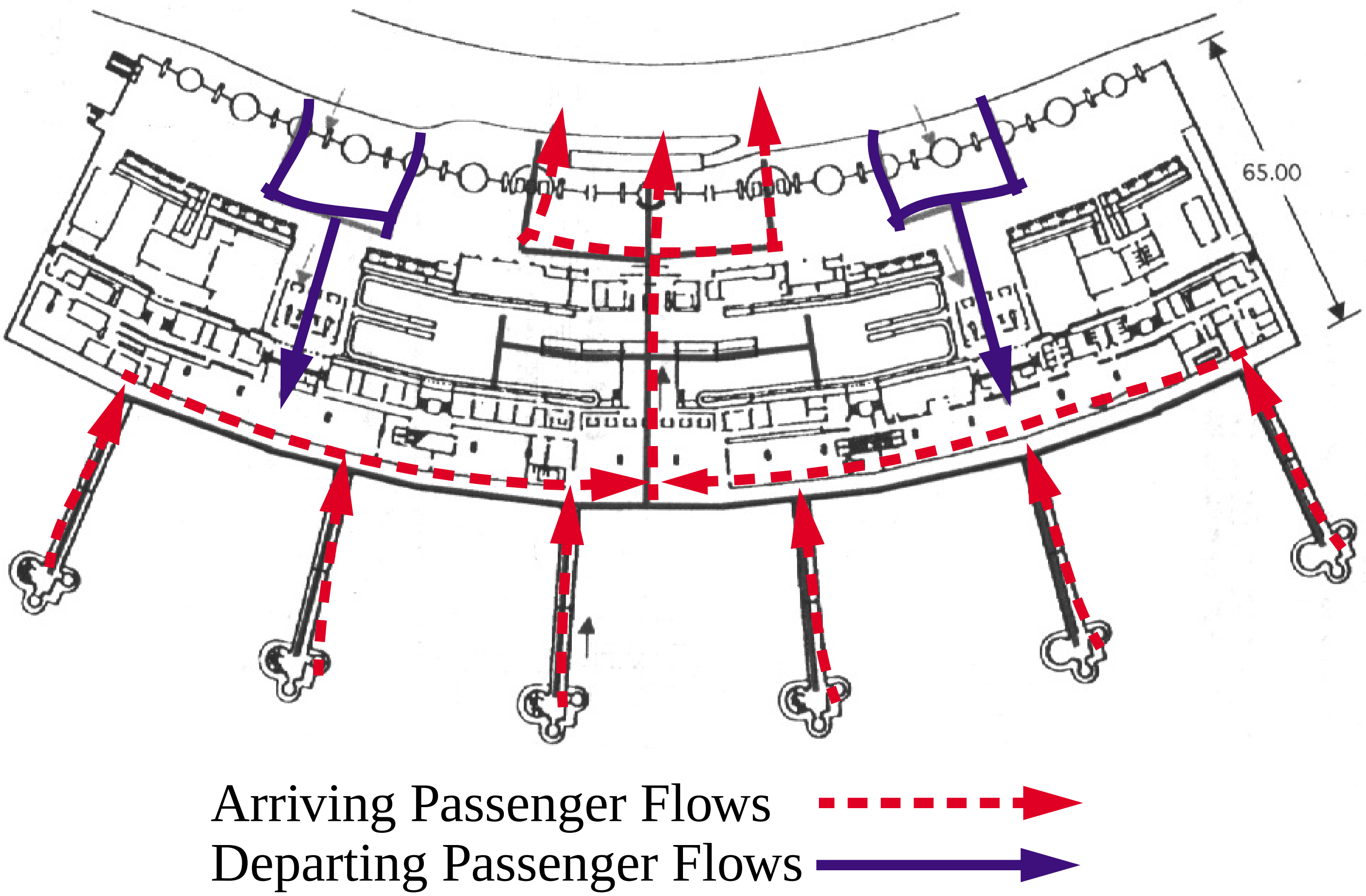
ILLUSTRATION OF A 1½ LEVEL PASSENGER TERMINAL BUILDING



IATA Airport Development Reference Manual

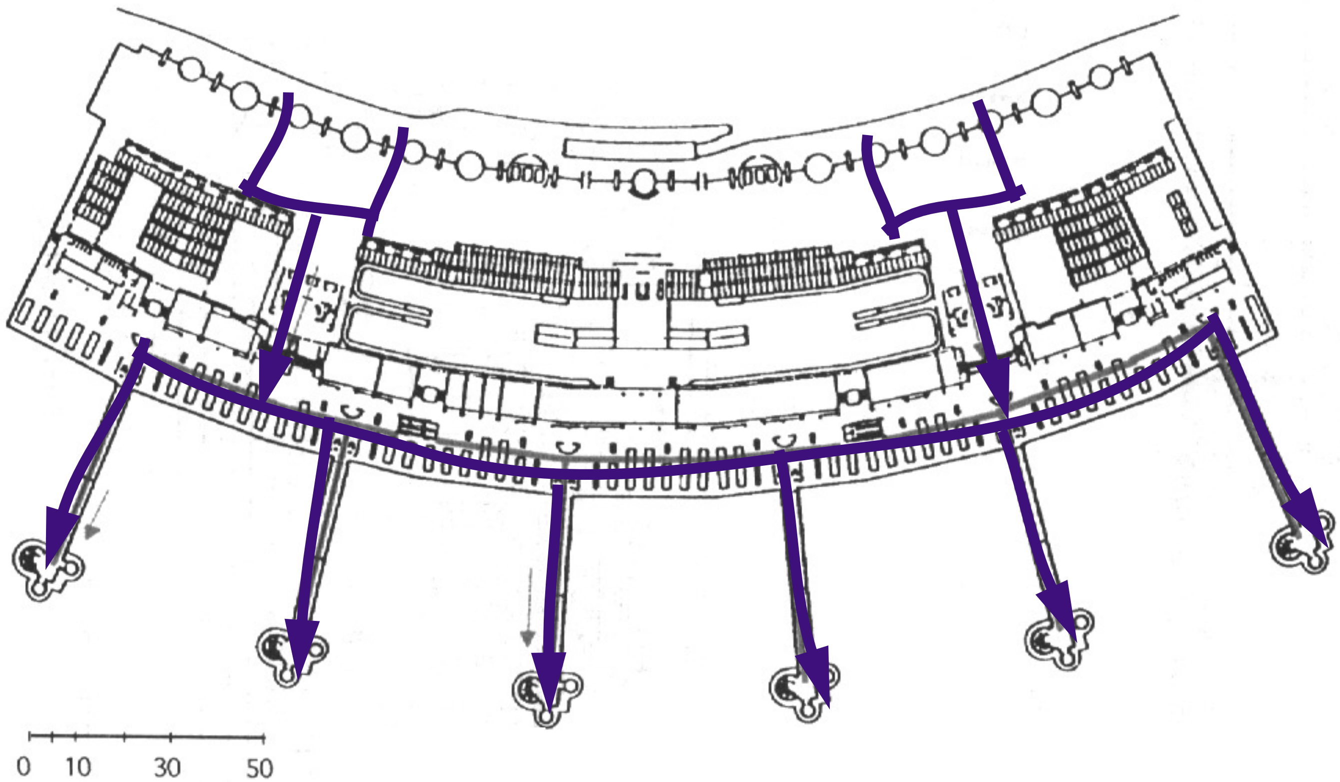
One and a Half Level Airport Terminal

(Arrivals)



Source: IATA Airport Development Reference Manual

One and a Half Level Terminal (Departures)



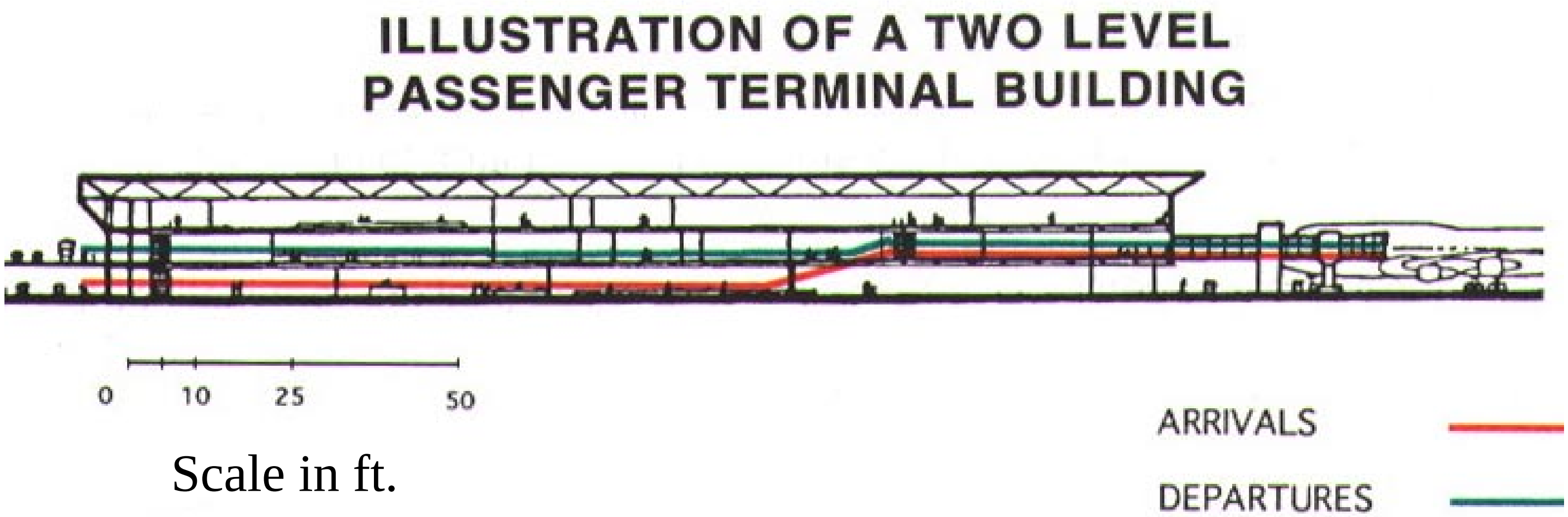
Scale in ft.

Departing Passenger Flows

Source: IATA Airport Development Reference Manual

Two-Level Airport Terminal

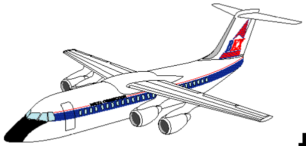
- Good for separating arriving and departing flows inside the airport terminal
- Provides increased curb space

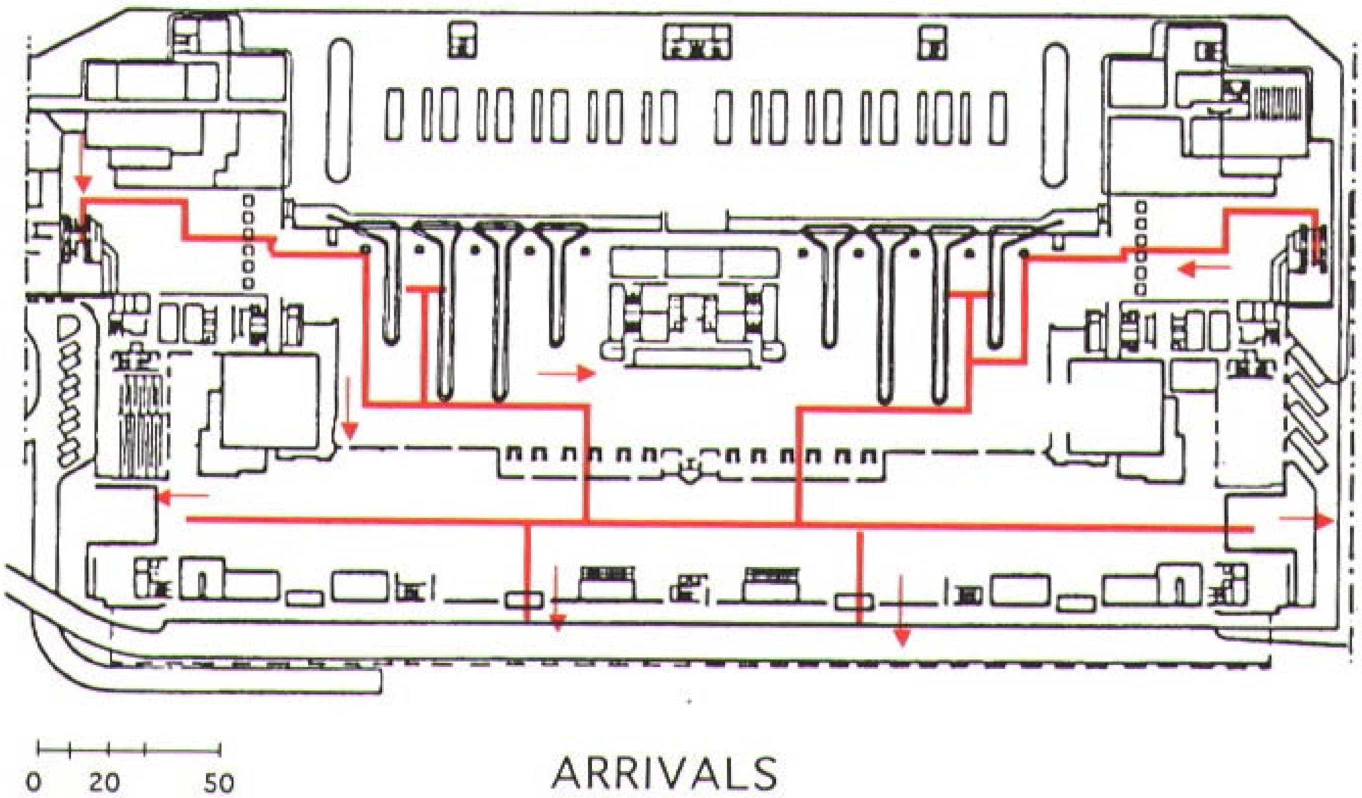


Scale in ft.

Source: IATA Airport Development Reference Manual

Two Level Airport Terminal (Arrivals)

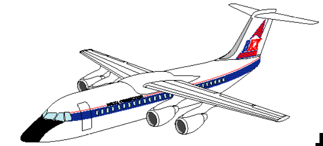


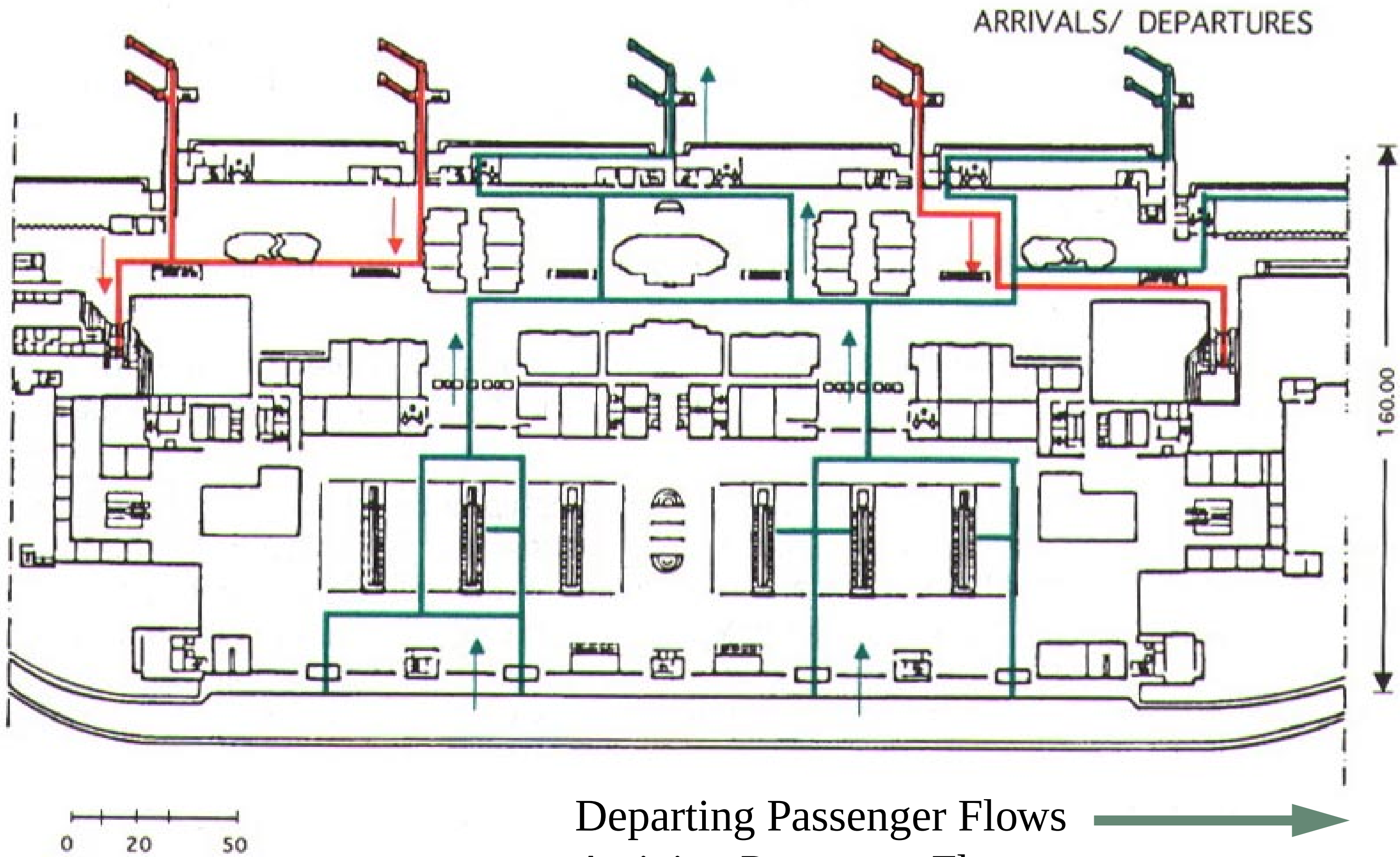


Arriving Passenger Flows

Source: IATA Airport Development Reference Manual

Two Level Airport Terminal (Departures)

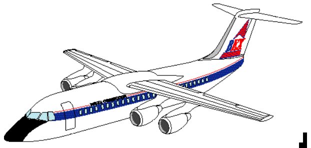




Departing Passenger Flows

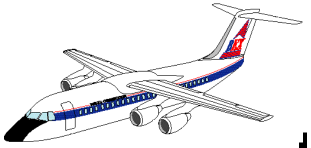
Arriving Passenger Flows

Source: IATA Airport Development Reference Manual



Airport Terminal Level of Service Standards

Level of Service Standards



Proposed by IATA to provide airport terminal design standards. These are static LOS values.

Table 1. IATA Level of Service Standards[a].

	Level of Service (m^2 per occupant)					
	A	**B**	**C**	**D**	**E**	**F**
Check-in Queue Area	1.8	1.6	1.4	1.2	1.0	N/A
Wait / Circulation	2.7	2.3	1.9	1.5	1.0	N/A
Hold Room	1.4	1.2	1.0	0.8	0.6	N/A
Baggage Claim Area (excludes claim service)	2.0	1.8	1.6	1.4	1.2	N/A

a. Source: IATA Airport Development Reference Manual.

Interpretation of LOS Standards (IATA, 1995)

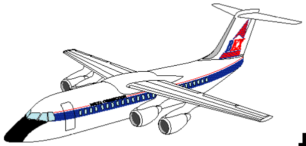


Table 2. Interpretation of Level of Service (IATA).

Legend	**Remarks**
A	Excellent service; free flow conditions; excellent level of comfort
B	High level of service; condition of stable flow; very few delays
C	Good level of service; stable flow; few delays
D	Adequate level of service; condition of unstable flow; acceptable delays
E	Inadequate level of service; condition of unstable flow; unacceptable delays
F	Unacceptable level of service; condition of cross flows; system breakdown

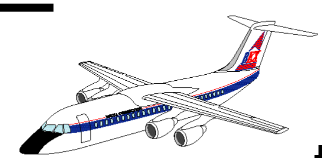
LOS Design Criteria

- Level of service C is perhaps a good design tradeoff for most airport terminals
- LOS B is an excellent design practice if the budget allows it
- Level of service A is too expensive and prohibitive to implement

Examples of Airport Terminal Elements

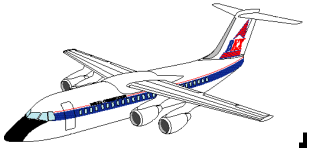
DFW Airport

Personal Space Preferences



- Human factors studies suggest the human body can be approximated using a personal ellipse (personal sphere) of dimensions: 330 mm by 580 mm (depth by shoulder breadth). This however works only well in crowded mass transit vehicles where standees tolerate crowding.
- Some port authorities in the US employ body ellipses of 18 by 24 in for mass transit studies (crowding inside trains)
- Given that passengers at airports carry baggage it is desirable to increase these dimensional standards to at least 5-10 ft^2. This will imply a circle of approximately 760 mm (30 in) which is consistent with the single lane walking criteria used by most airport authorities.

Space for Movement

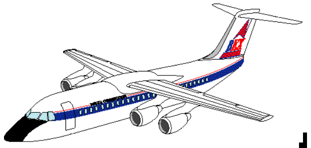


- Provide a minimum of 760 mm (30 in) of lateral spacing between each lane of pedestrians
- Longitudinal spacing for normal walking to avoid conflicts should be on the order of 2.5 to 3.0 m (8-10 ft)
- The resulting net area per pedestrian is then 2-3 m^2 (20-30 ft^2) for free flow
- When queueing is allowed (not pedestrian flow) personal spaces of 0.5-1.0 m^2 (5-10 ft^2) are tolerated
- Stairway spaces are smaller because the presence of treads. Typically, personal spaces of 1-2 m^2 (10-20 ft^2) are needed for unimpeded stair flow

Predestrian Walking Speeds

- Pedestrian speed varies according to pedestrian density and other factors such as age, gender, personal disabilities, environmental factors and trip purpose
- Typical speeds are 85 m/min (270 ft/min)
- College students are known to walk faster than average populations

Principles of Pedestrian Flow



- Uses a hydrodynamic analogy to model pedestrian flow
- The basic pedestrian traffic flow equation is,

$$f = \frac{s}{a} \quad (1)$$

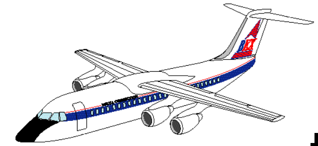
where:

f is the pedestrian volume measured in pedestrians per foot or meter width of traffic way per minute (pr/m-min)

s is the average pedestrian flow speed (m/min)

a is the average are per pedestrian (m^2/pr)

Principles of Pedestrian Flow

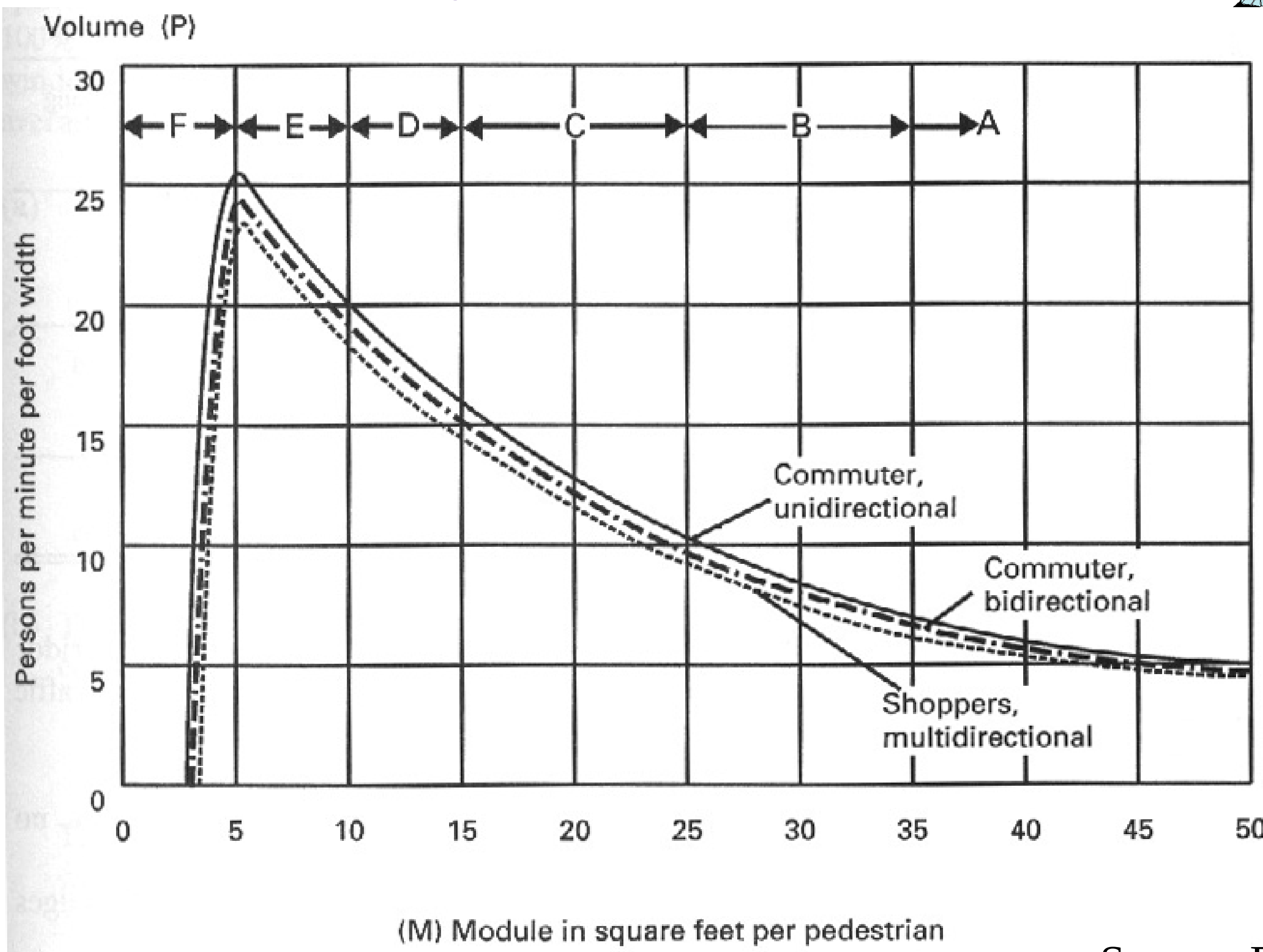


Note that this equation is analogous to that used to model traffic flows on highways. The term a is just the inverse of the flow density (k) typically employed in highway traffic modeling.

Application constraints of Equation (1):

- The pedestrian flow has to be steady (no interruptions)
- Uniform and continuous pedestrian movement

Walkway Levels of Service



Source: Fruin

Interpretation of Walkway LOS

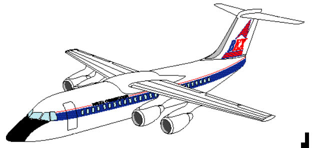
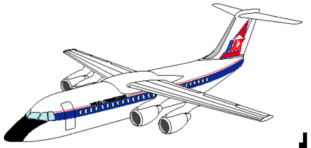


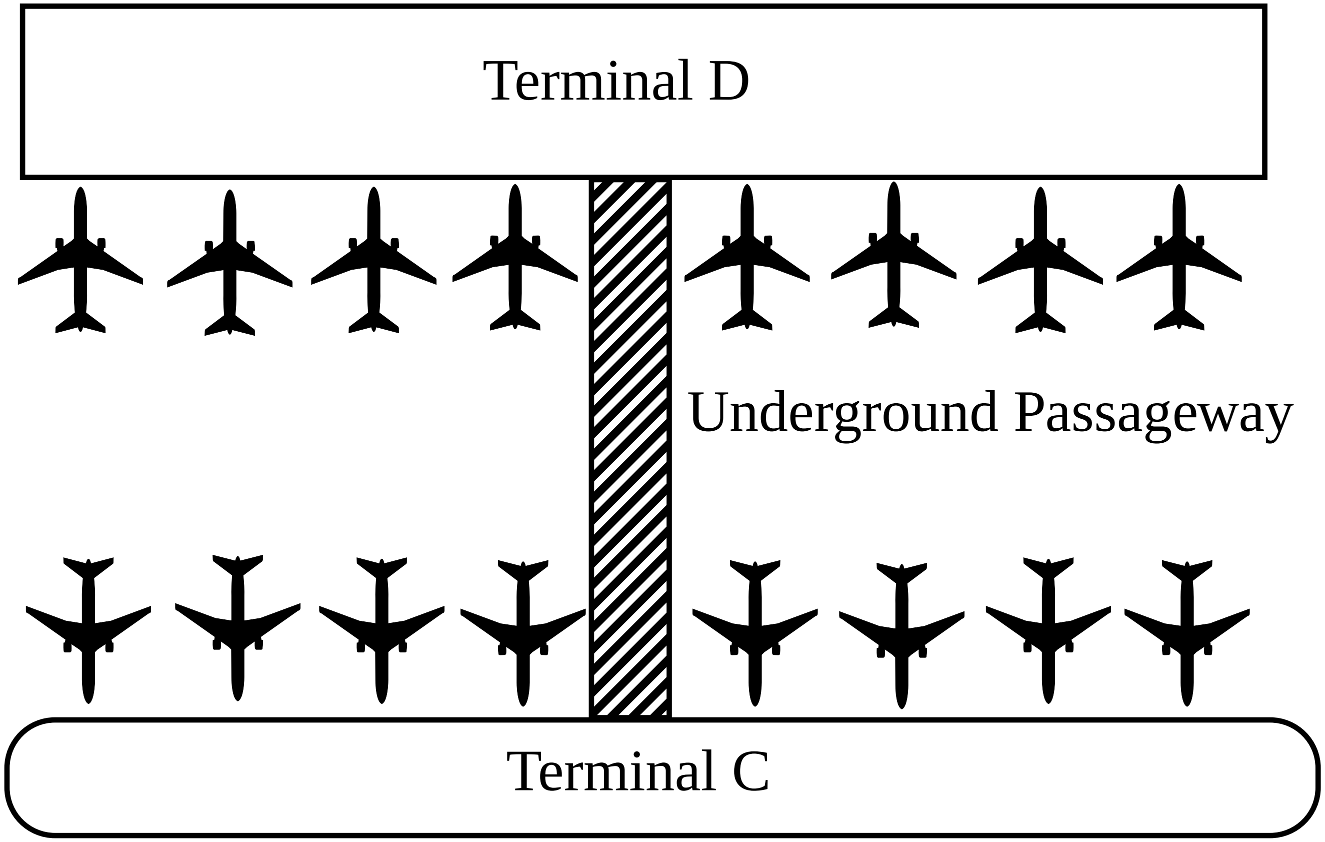
Table 2. Walkway LOS Standards (Source: Fruin)

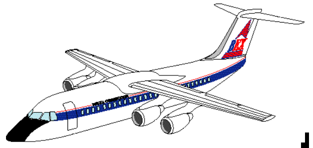
LOS	*f* Pedestrian Flow pr/m-min (pr/ft-min)	*a* Average Area m^2/pr (ft^2/pr)	Description of Flow Conditions
A	<23 (<7)	>3.3 (>35)	Free flow
B	23-33 (7-10)	2.3-3.3 (25-35	Minor conflicts
C	33-49 (10-15)	1.4-2.3 (15-25)	Crowded but fluid, passing is restrictive
D	49-66 (15-20)	0.9-1.4 (10-15)	Significant conflicts, passing and speed restrictions
E	66-82 (20-25)	0.5-0.9 (5-10)	Shuffling walk, passing and crossflows very difficult
F	Variable Flow	<0.5 (<5)	Frequent stops, contacts

Example 1:Pedestrian Flow Equations



Chicago O'Hare has two terminals as show in the figure below.

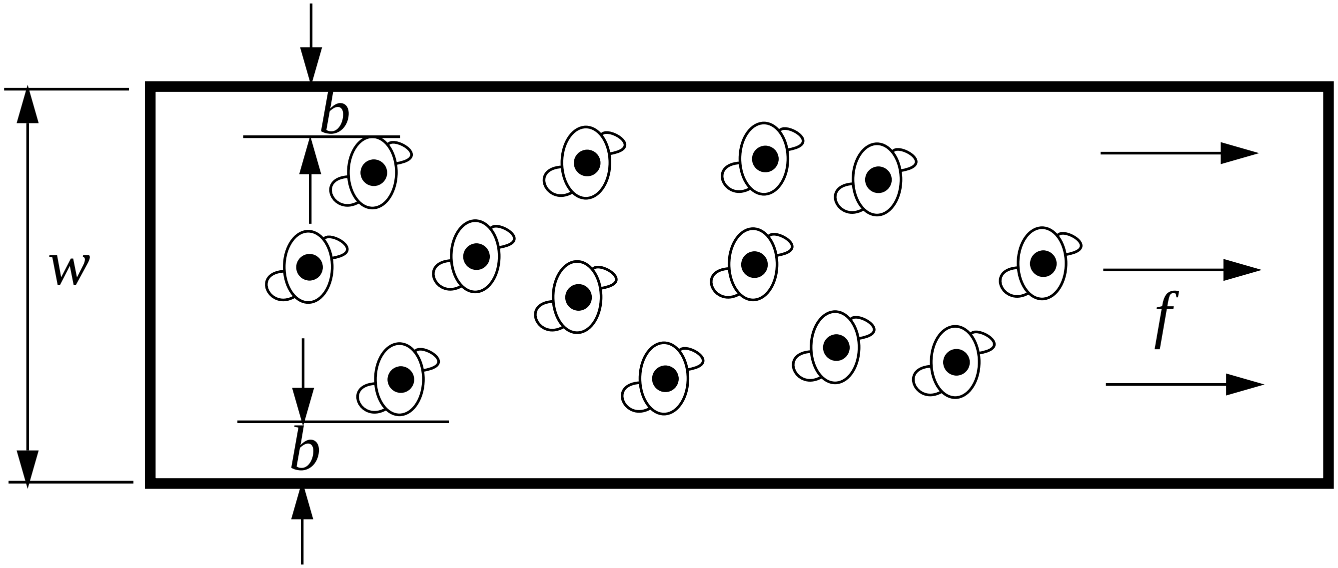




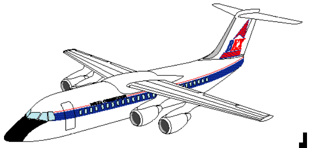
Example Application of Pedestrian Flow Equations

The original design predicted a maximum 15-minute flow of 2,500 passengers.

1) Determine the width of the corridor (w) to serve this expected volume if a high LOS C is used.



Application of Pedestrian Flow Equations



2) Compare with LOS B and A

3) Find the average flow speed under the given conditions

Application of Pedestrian Flow Equations

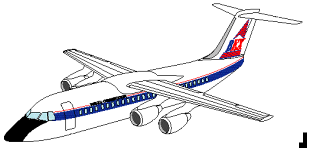
1) 2,500 pedestrians in 15 minutes is equivalent to 166.7 pedestrians per minute (pr/min)

- Looking at the basic walkway LOS curve (on page 50 of this handout) we observe that for LOS C this corresponds to an expected flow of,

$$f = 10 \text{ pr/ft-min}$$

This implies a corridor or 17 ft (for passenger flow) plus 4 ft to account for 2 boundary layers on each side of the passageway. The total corridor width should be 6.5 m (21 ft) for LOS C.

Application of Pedestrian Flow Equations



2) For LOS B the width would be 8.5 m (28 ft) wide

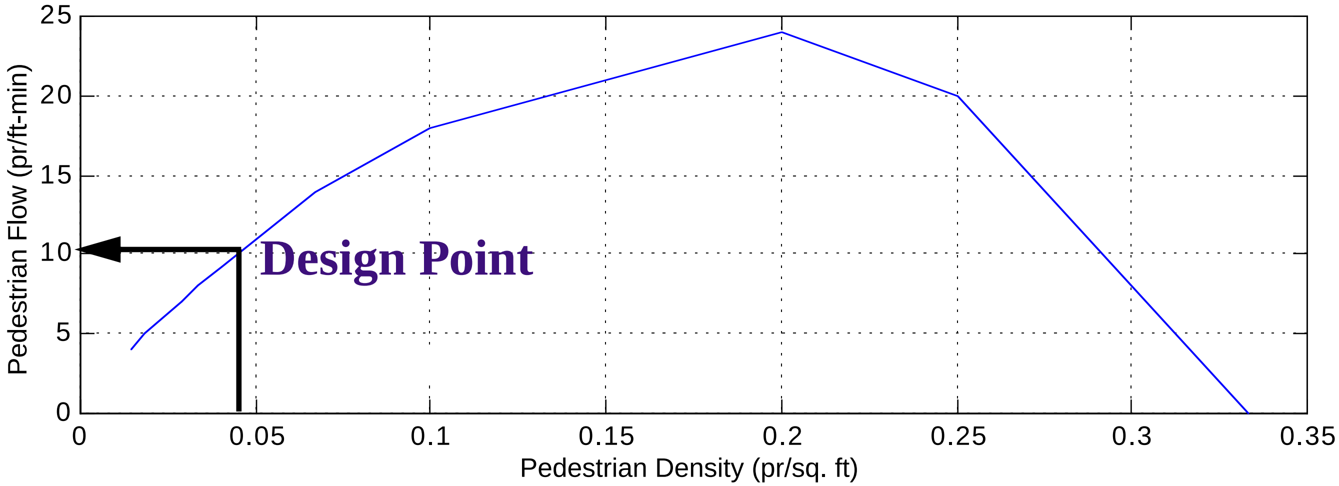
For LOS A (assuming 5 pr/ft-min as the design standard) would yield a corridor 11.7 m (33.8 ft) wide

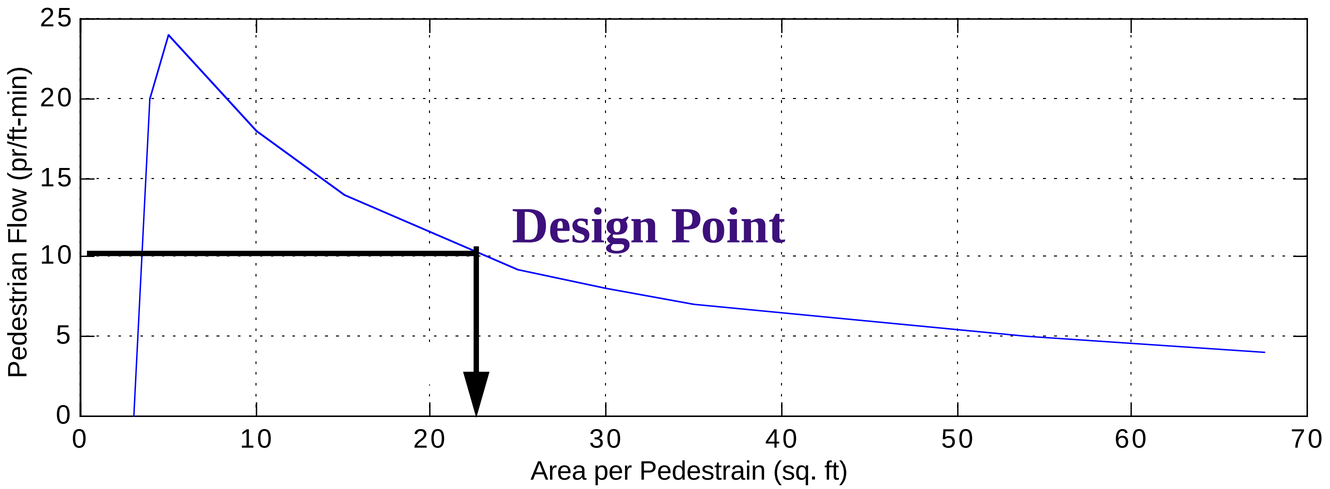
Note that airport terminal construction cost in the US is around $2000-3000 per square meter (regular space not underground).

In our example, a 350 m corridor would have implied a cost difference of 5.5 million dollars at $3,000 per square meter (comparing LOS A vs. LOS C)

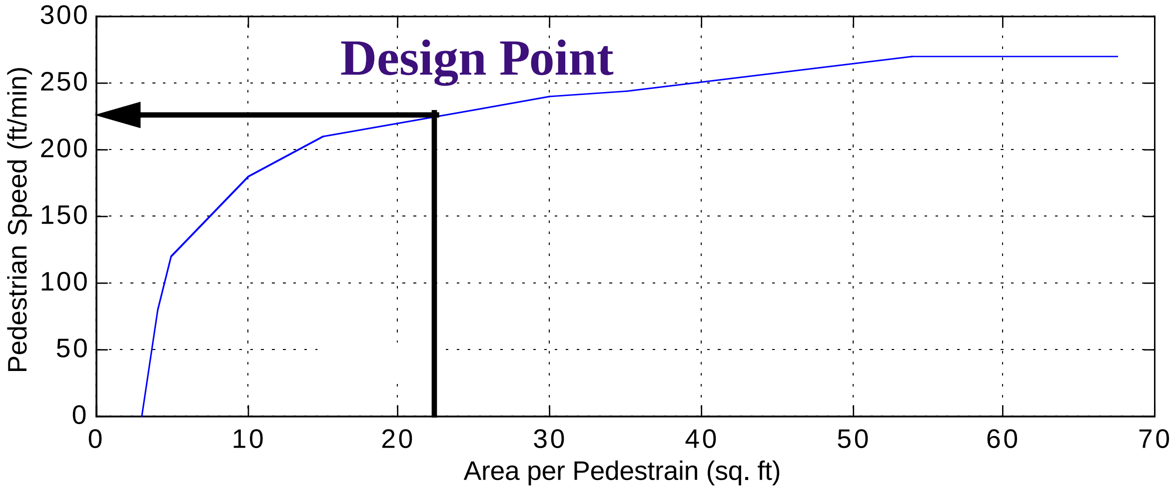
3) The resulting speed in the corridor would be about 67 m/min (220 ft/min)

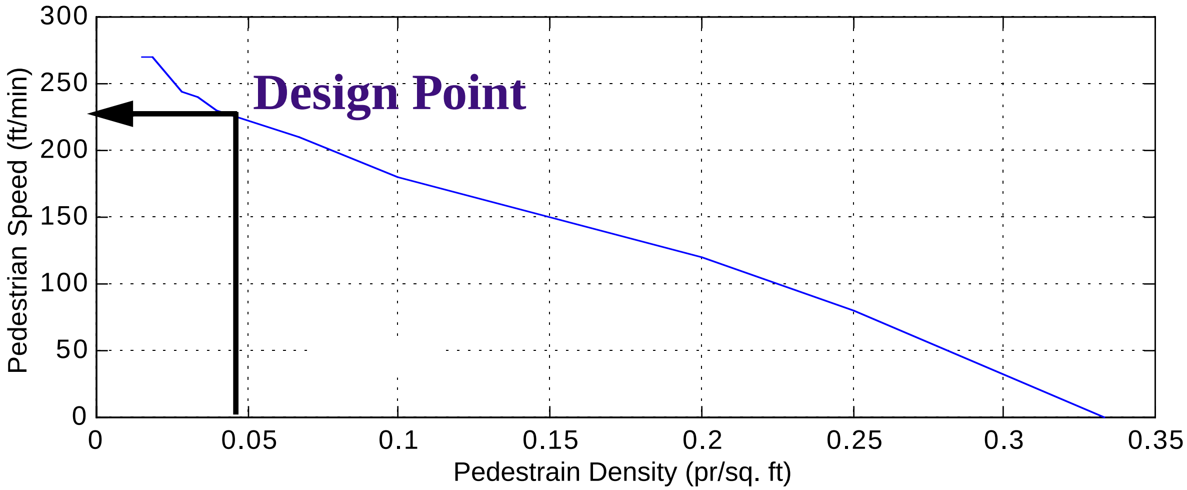
Fundamental Pedestrian Flow Relationships



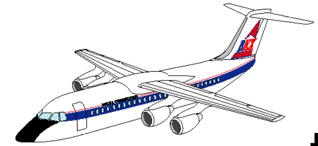


Fundamental Pedestrian Speed-Area and Speed-Density Relationships





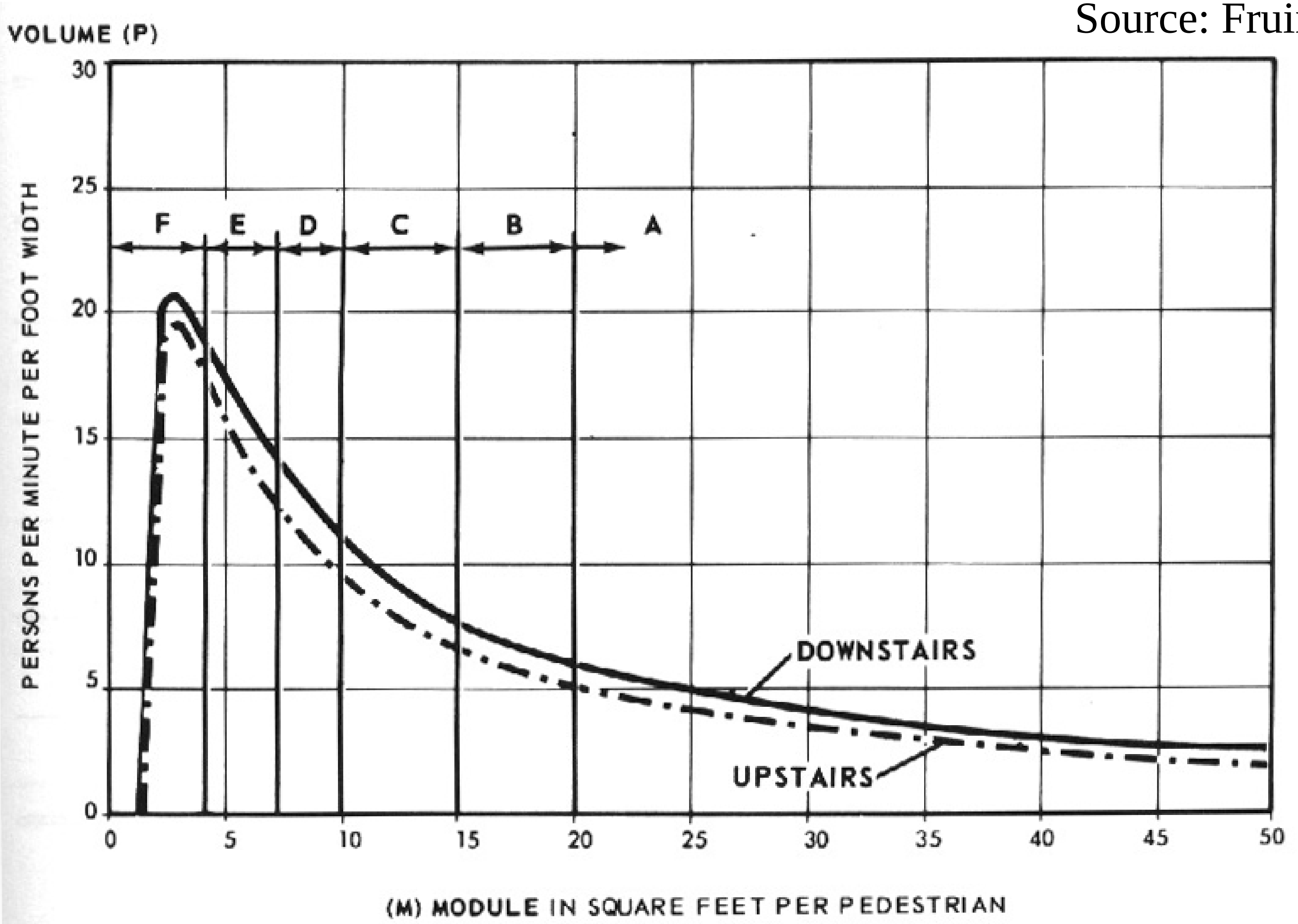
Stairway Pedestrian Flows



- Pedestrian flows decrease in stairways for two obvious reasons:
    - Restricted flow movement (bottleneck effect)
    - Large energy expenditure while negotiating steps (specially true upwards)
- Ascending speeds vary from 15 to 90 m/min (50-300 ft/min) with an average speed of 30.5 m/min (100 ft/min)
- For a single lane motion in stairways use 760 mm width (30 in)
- Use 1520 mm (60 in) minimum for fluid two-way movement
- Design stairway spaces at multiples of 760 mm

Stairway Levels of Service

Source: Fruin



Interpretation of Stairway LOS

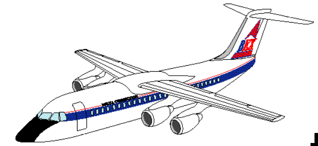
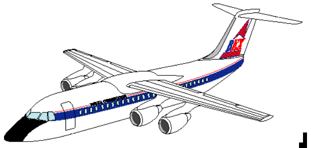


Table 3. Stairway LOS Standards (Source: Fruin)

LOS	***f*** **Pedestrian Flow pr/m-min (pr/ft-min)**	***a*** **Average Area m^2/pr (ft^2/pr)**	**Description of Flow Conditions**
A	<5 (<16)	>1.9 (>20)	Free flow
B	16-23 (5-7)	1.4-1.9 (15-20)	Minor conflicts
C	23-33 (7-10)	0.9-1.4 (10-15)	Crowded but fluid, passing is restrictive
D	33-43 (10-13)	0.7-0.9 (7-10)	Significant conflicts, passing and speed restrictions
E	43-56 (13-17)	0.4-0.7 (4-7)	Shuffling walk, passing and crossflows very difficult
F	Variable Flow	<0.4 (<4)	Frequent stops, contacts

Queueing LOS



- These standards are similar to IATA criteria for queueing
- However, these have been primarily derived from studies of mass transit systems and thus do not include baggage
- These standards are static but can be computed in simulation models by computing the instantaneous state of the system and then taking an average of area available to serve pedestrians.

Interpretation of Queueing LOS

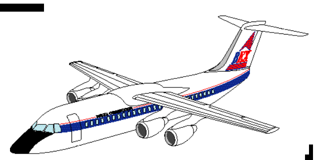


Table 4. Queueing LOS Standards (Source: Fruin)

LOS	*a* Average Area m^2/pr (ft^2/pr)	Interpersonal Spacing m (ft)	Description of Flow Conditions
A	>1.2 (>13)	>1.2 (>4)	Standing, circulation within queueing
B	0.9-1.2 (10-13)	1.1-1.2 (3.5-4)	Standing, partially restricted circulation
C	0.7-0.9 (7-10)	0.9-1.1 (3-3.5)	Standing, restricted circulation
D	0.3-0.7 (3-7)	0.6-0.9 (2-3)	Standing without contact; long term waiting discomfort

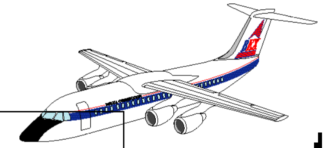
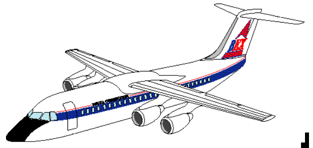


Table 4. Queueing LOS Standards (Source: Fruin)

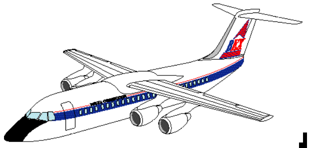
LOS	*a* Average Area m^2/pr (ft^2/pr)	Interpersonal Spacing m (ft)	Description of Flow Conditions
E	0.2-0.3 (2-3)	0.3-0.6 (1-2)	Standing without contact, crowd pressure
F	<0.2 (<2)	<0.3 (<1)	Close contact, Uncomfortable

Walking Distances at Airport Terminals

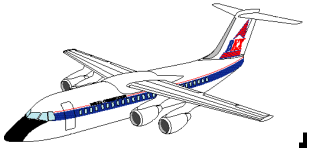


- Numerous surveys in urban studies suggest 400 m. is the maximum walking distance accepted in the U.S. (used in mass transit studies)
- Unfortunately few studies have been conducted to understand how much distance is acceptable at airports terminals
- It is not uncommon today to walk 300-450 m inside large airport terminals and thus passenger seem to accept this fact

Time-Space Analysis of Holding Areas at Airports



- Pedestrian flow equations are limited to instances where the flow of passengers is uniform and continuos
- There are numerous instances where this analysis is of little us when pedestrians traverse areas inside a terminal where they are forced to stop briefly (i.e., security check-in stations)
- In these circumstances the Time-Space approach provides an alternative to estimate sizes of elements inside a terminal for a given level of service



Time-Space Approach

This approach assumes that the area provided per pedestrian in an element of the airport terminal is the quotient of the Total Supply (TS) and the Total Demand (TD)

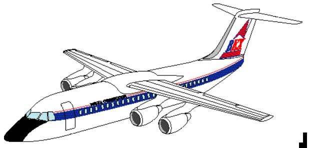
$$a = \frac{TS}{TD} \tag{5}$$

The interpretations of TS and TD are as follows:

$$TS = T \times S \tag{6}$$

$$TD = n \times t \tag{7}$$

Time-Space Approach



where:

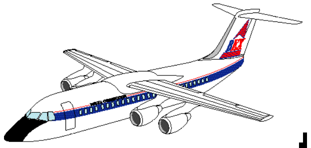
T is the total period of analysis

S is the total area available at the airport terminal site considered

t is the predicted occupancy (or dwell) time per passenger inside the airport terminal element considered

n is the total number of passengers occupying the airport terminal element considered

Example 2: Time-Space Approach



The airport shown in the next figures has two security checkpoints for all passengers boarding aircraft. Each security check point has two x-ray machines. A survey reveals that on the average a passenger takes 45 seconds to go through the system (negative exponential distribution service time).

The **arrival rate** is known to be random (this equates to a Poisson distribution) with a mean arrival rate of one passenger every 25 seconds.

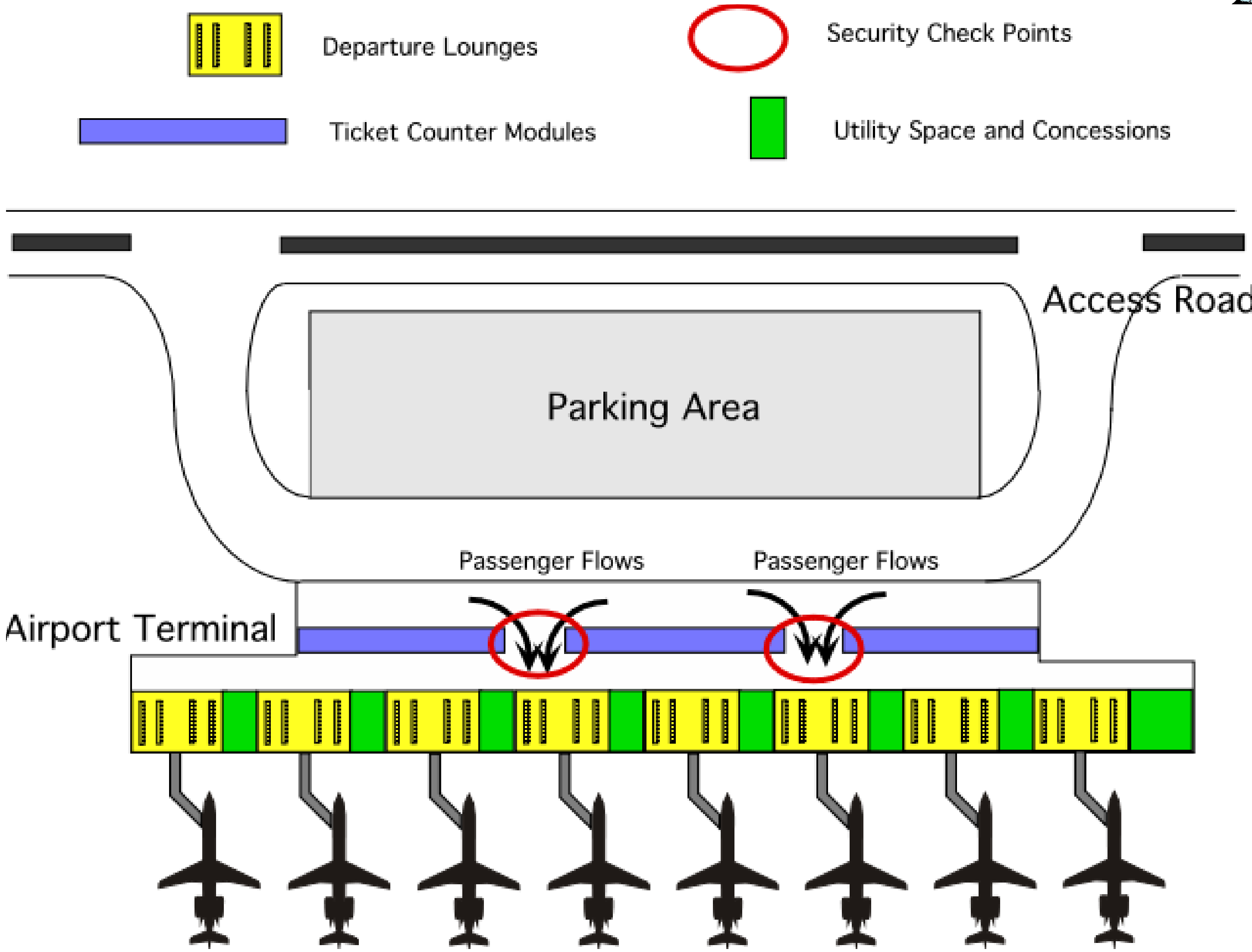
In the design year (2010) the demand for services is expected to grow by 60% compared to that today.

Relevant Operational Questions

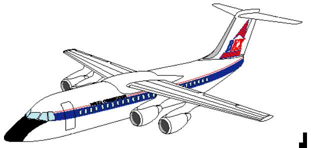
a) What is the level of service provided with two x-ray machines?

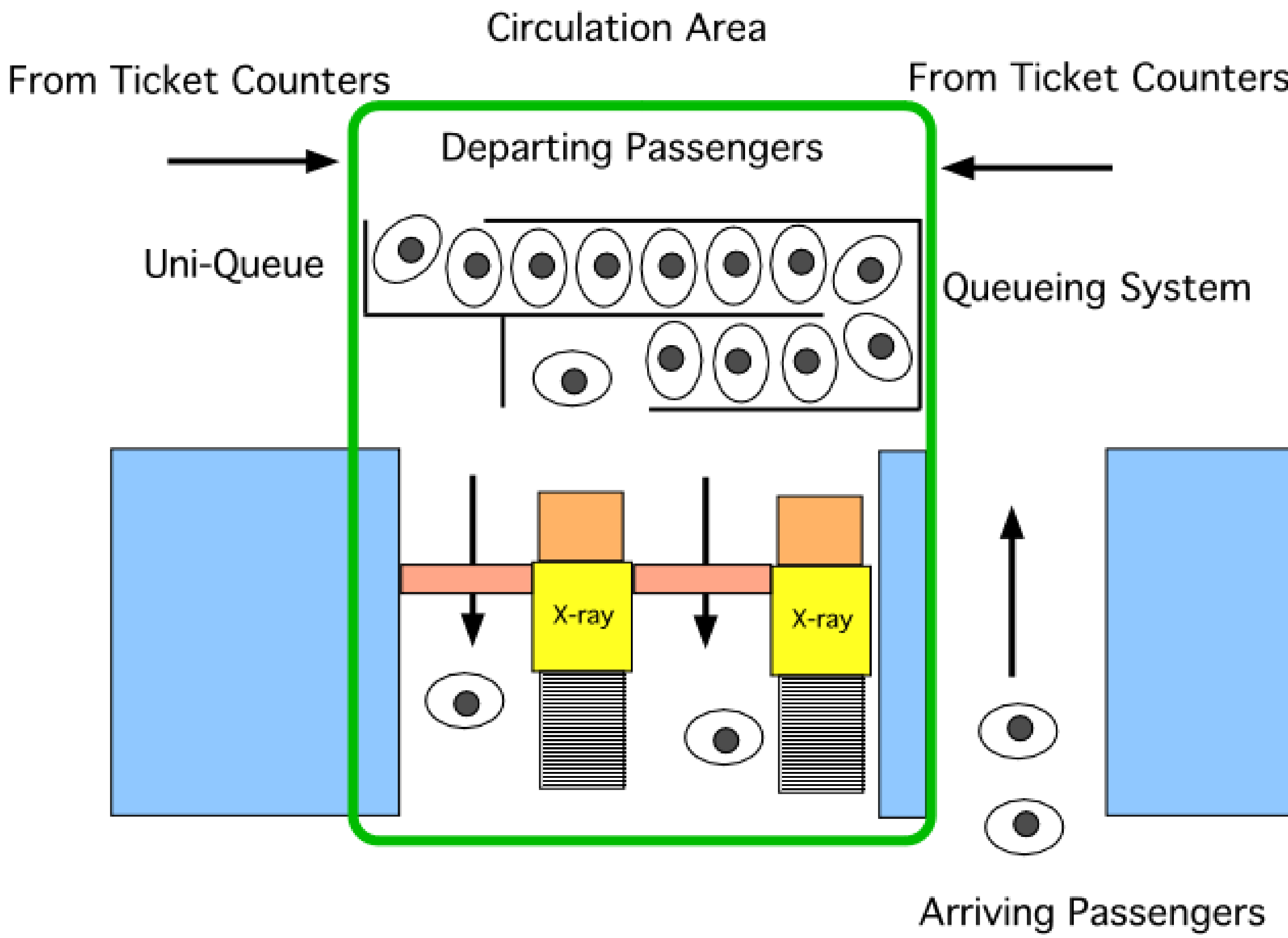
b) If four x-ray machines are installed in the horizon year find the new level of service.

Airport Terminal Layout



Security Check Point Layout





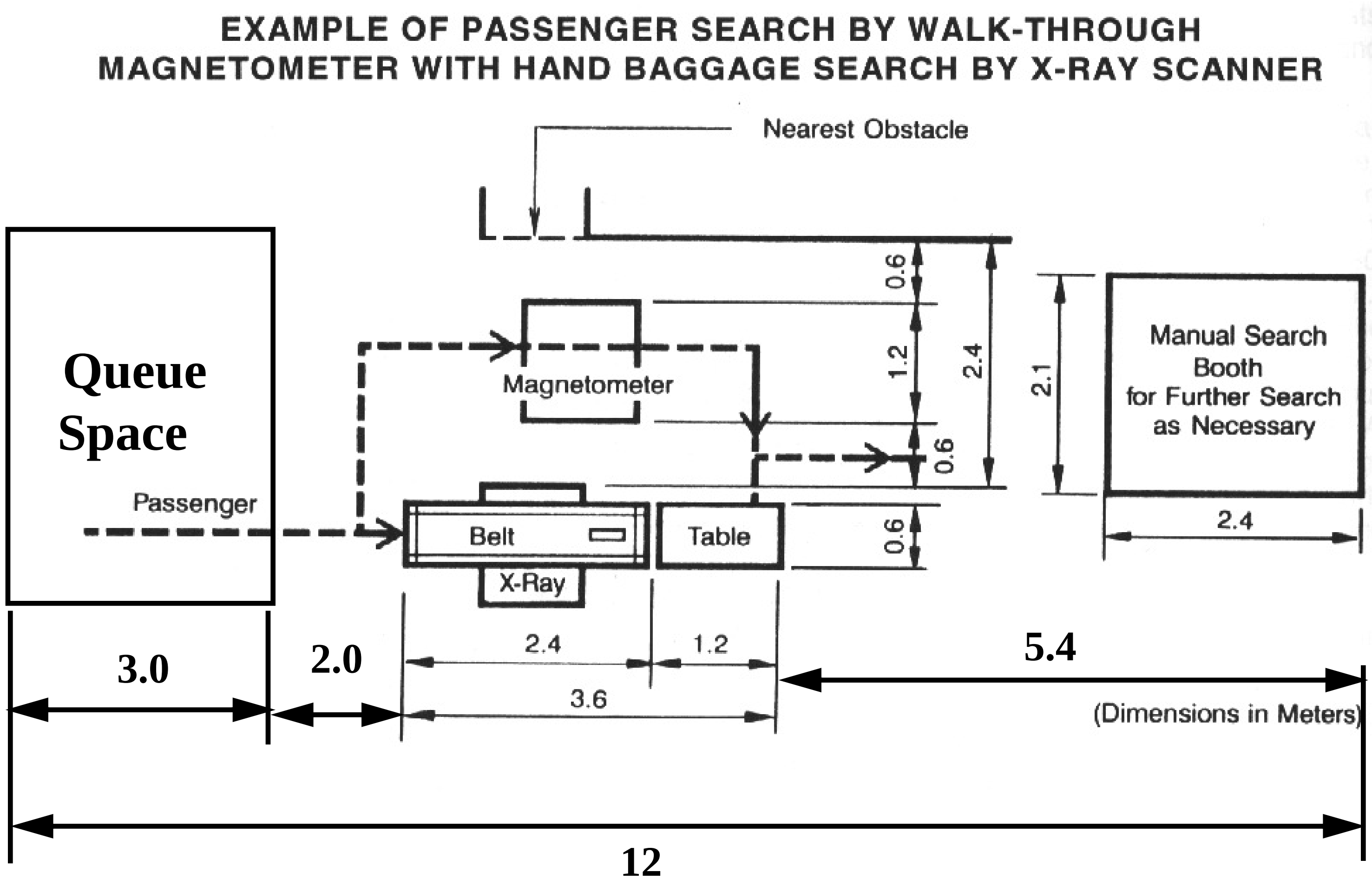
Solution

Since the Time-Space approach requires details about the size of the space provided at the security check point we need to either find this information or assume some reasonable values based on typical security counter spaces.

One good source for typical spaces at airports is IATA's Airport Development Reference Manual (IATA, 1995)

A typical x-ray security layout is shown in the next page

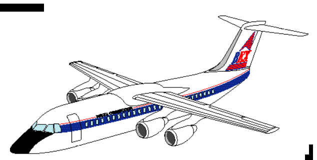
Detail of Security Check Point (IATA)



TS Approach Example

- From the previous diagram an area of 3 by 12 meters is needed for each one of the x-ray stations (so S = 36 sq. meters per station)
- The queue area is actually treated as a 'black box' where the passenger time in the system is the sum of both the service time and the queueing time
- Note that since the queue length is not known according to this *naive* model, some estimate of the passage time, t, is necessary. Running the steady-state stochastic model for two servers we obtain an average time in the system of 4 minutes (3.95 min) and thus 4.5 minutes is a reasonable estimate that includes walking time through the black box.

TS Approach Example



$$a = \frac{TS}{TD} = \frac{T \times S}{n \times t} = \frac{1\,hr \times 72\ m^2}{144\ pr\ \times 0.075\ hr} = 6.7\,\frac{m^2}{pr}$$

Looking at the table of walkway levels of service this space would have an equivalent LOS of A

Note that this model requires an estimate of the transit times across the terminal section being analyzed (something that is not always possible)

Other Applications of the TS Approach

The same method has been used to estimate the width of corridors where there is flow interruption activities. For example, window shopping.

Let $S = wl$ be the space available for an activity inside an airport terminal. Here w is the width of the are in question and l is the length of the area in question. Then,

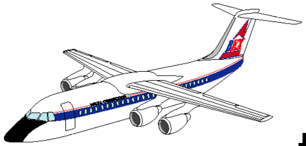
$$w = \frac{ant}{Tl} \tag{8}$$

Application of TS to Corridor Design

Using example 1 (Chicago O'Hare underground passageway) and compare the answers using the TS method.

- The corridor length is 1,100 ft (*l*)
- At 220 ft/min it takes 5 minutes to traverse this corridor at LOS C speed (previously computed)
- Assume LOS C (use the same 25 ft^2/pr as before)
- Read the value of a from the chart (20 ft^2/pr)
- 2,500 passengers in 15 minutes (n)

TS Approach to Corridor Design



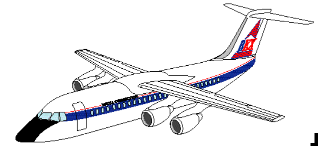
Applying equation (8),

$$w = \frac{ant}{Tl} = \frac{25 \times 2500 \times 5}{15 \times 1100} = 18.8ft$$

Note that just like before we need to add 2 ft on each side to account for boundary layers at the corridor edges.

The resulting corridor according to this method is then 22.8 ft (or 6.95 m).

Pedestrain Flow Uses in Terminal Airport Models

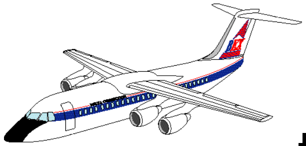


All simulation languages can extract the instantaneous values of state variables of the system:

- Queue lengths
- Delays (or waiting times)

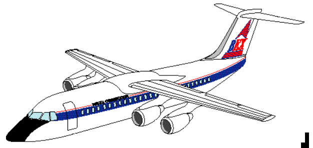
- These state variables (or statistical metrics in some models) should have en effect in the future (at time $t + \Delta t$ in the simulation) behavior of temporary entities of the model
- If passengers are modeled individually define an attribute (to each passenger) that changes the delay times of future activities (such as moving through a congested corridor)

LOS Modeling in Airport Terminal Models

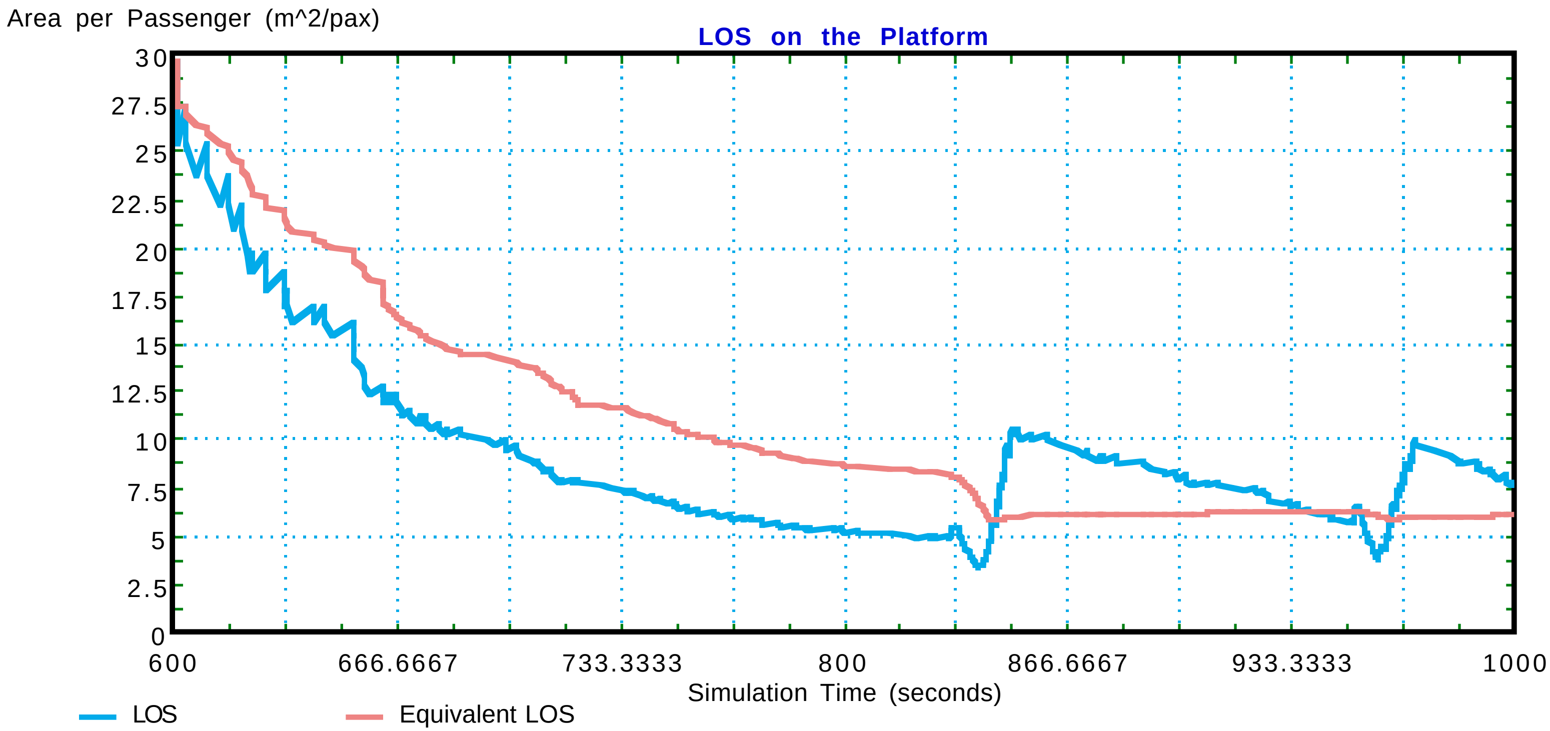


- Simulation models are much more refined that current methods to estimate levels of service and as such, they describe dynamically a situation that static models such as the TS approach cannot
- Sometimes, however, is necessary to compare the outputs of airport terminal simulation models with LOS standards such as those stated in the literature (Fruin, IATA, etc.)
- One approach to obtain concurrent LOS statistics in your models is to define resources that have physical size attributes associated with them. Once this is done you can compute LOS statistics such as passengers per unit area during the entire simulation.

LOS Modeling in Airport Terminal Models

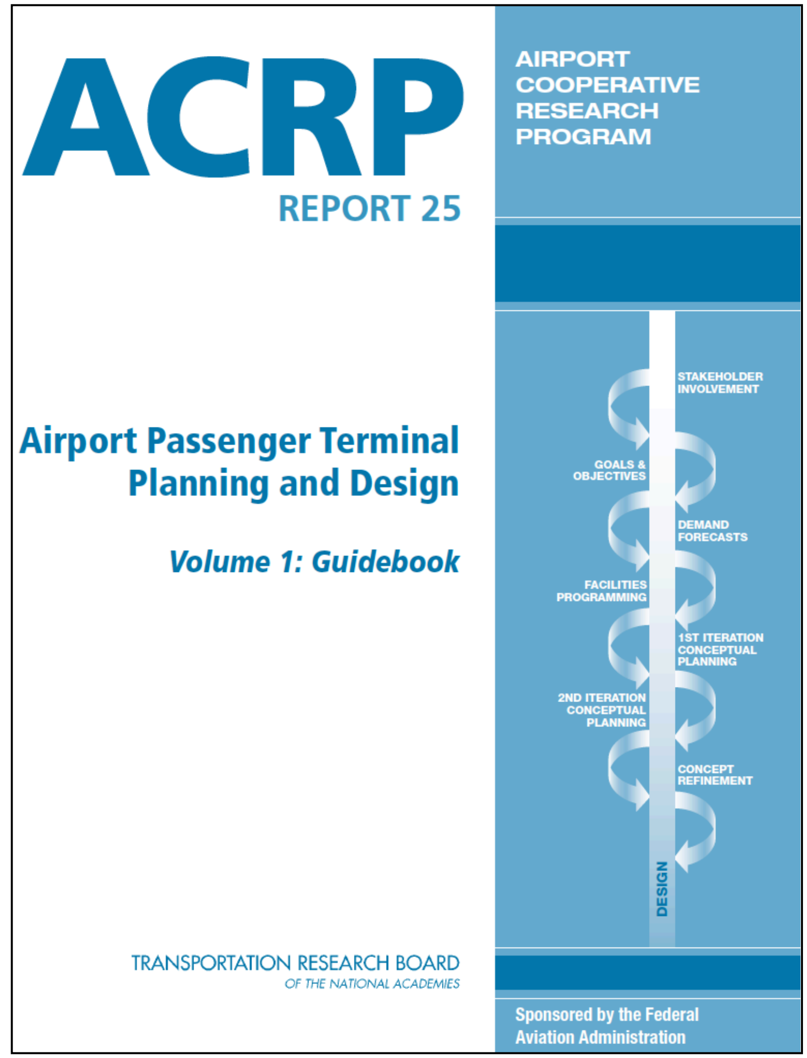


For example, the plot below shows dynamically how LOS varies for a hybrid simulation of an APM system over time. Notice that at the end we could collect averages.



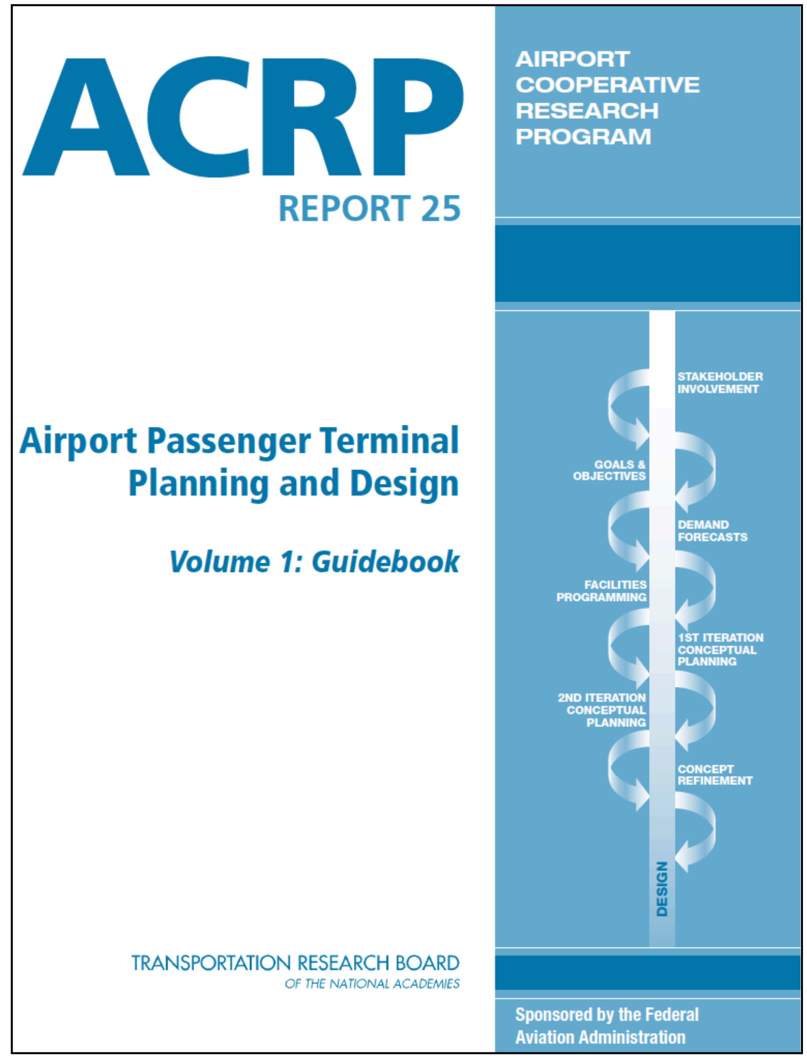
Airport Cooperative Research Program

- Administered by the Transportation Research Board (TRB)
- FAA funded project to improve the state of knowledge in airport design practice
- ACRP report 25 : Airport Passenger Terminal Planning and Design
  - Volume 1: Guidebook
  - Volume 2: Excel application



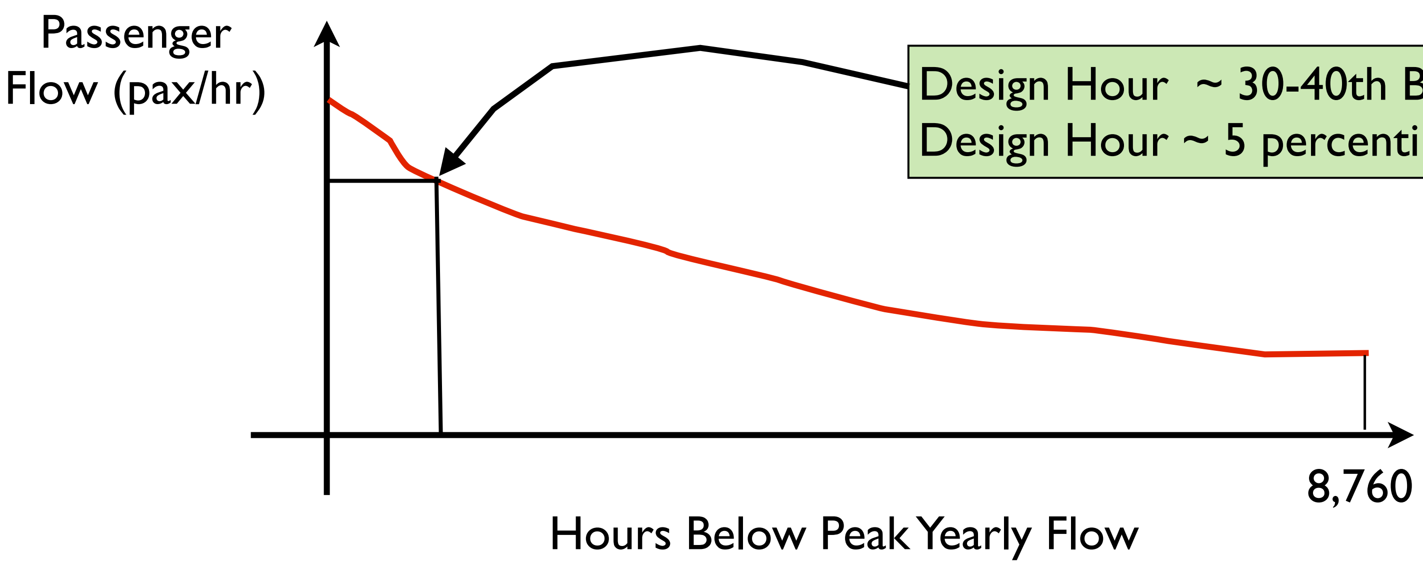
ACRP Report # 25

- Spreadsheet Models
  - CD-ROM contains 11 spreadsheet model
  - Practical learning exercises and several airport-specific sample data sets
  - A user's guide to assist the user in the correct use of each model
  - Terminal planning as design hour determination, gate demand, check-in and passenger and baggage screening



Design Hourly Flows

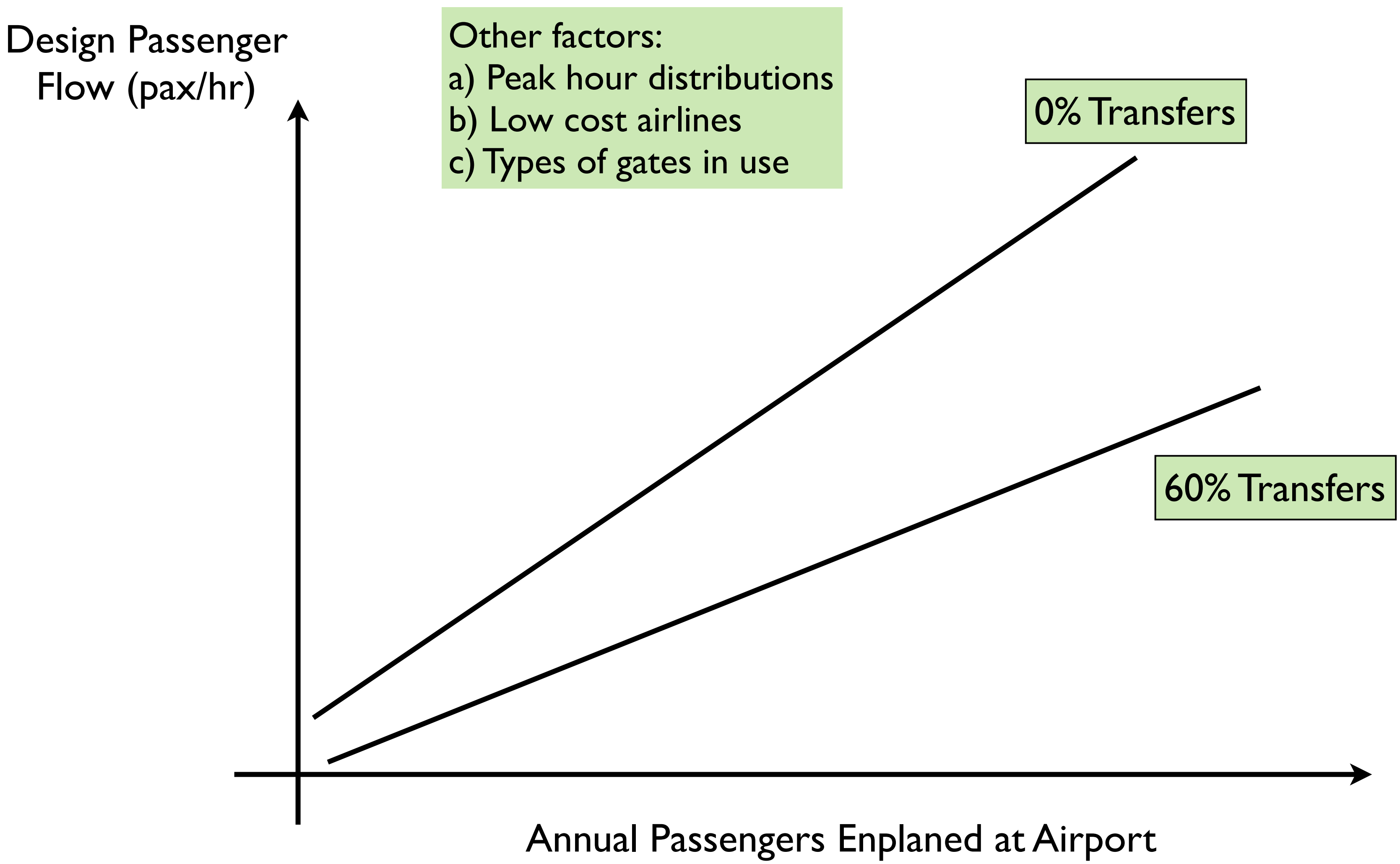
- Goal:
  - To estimate passenger flows in the design hour
  - To estimate hourly flights to be used to size future gate and airport terminal requirements
- Use baseline data to understand the variations of passenger flows and flights over a long period of time



Relationship Between Annual and Hourly Flows

- Many studies have been conducted to establish a relationship between annual passengers and design hourly flows
- The characteristics of the passenger using the airport influence the hourly design values (i.e., transfer vs destination airports)
- Examples:
  - Atlanta Hartsfield - 60% of passengers transfer
  - Punta Cana - ~0% passengers transfer
- Discuss in class how various airport services are affected

Relationship Between Annual and Hourly Flows (2)



Sample Airport Design Hour Spreadsheet

REQUIRED DATA: Historical Enplanement data from the last 5 complete calendar years

Total Commercial Passenger Enplanements

(1) RESET ALL INPUTS

Year	January	February	March	April	May	June	July	August	September	October	November	December
2004	339,212	335,431	380,372	383,986	384,009	412,229	433,519	438,881	359,801	392,988	389,683	390,748
2005	351,751	343,331	410,799	410,089	417,314	431,319	448,310	453,798	381,840	396,737	390,193	386,018
2006	346,250	345,682	406,676	412,639	410,434	430,066	437,895	446,311	373,111	401,655	395,973	407,416
2007	371,721	365,513	432,975	433,370	438,341	452,244	456,592	478,329	388,735	414,229	390,115	366,854
2008	350,450	350,533	408,656	392,136	385,109	398,749	411,909	419,764	342,455	362,867	325,972	344,026

(2) (3)

Year	Total	Monthly Average	Maximum Value	Peak Month	PM % of Year	
2004	4,640,859	386,738	438,881	August	9.5%	
2005	4,821,499	401,792	453,798	August	9.4%	
2006	4,814,108	401,176	446,311	August	9.3%	
2007	4,989,018	415,752	478,329	August	9.6%	
2008	4,492,626	374,386	419,764	August	9.3%	Average Peak Month
			Average Peak Month	AUGUST	9.4%	Percentage of Annual

(4)

You have determined AUGUST to be the Peak Month

Proceed to Next Step

Data Input Cells	
Calculated Values	
Linked/Shared Values	

(1) Click the 'RESET ALL INPUTS' button to begin.

(2) Input the most recent full calendar year into Cell A11 (i.e. 2008)

(3) Input monthly enplanements data from one of the following sources: Airport records, U.S. DOT (T-100), FAA (Air Traffic data), or OAG(using Scheduled Seats).

(4) Review the Peak Month results in Cells E14:E18 and Select the most common month, giving more weight to more recent years, in Cell E19.

-->The Peak Months should be consistent; if not, specific knowledge of the conditions affecting the variation should be investigated. If the variation is due to the similarity between certain months, data from earlier years may be gathered to help confirm the most common peak month.

Peak Month Average Day

USE THIS WORKSHEET TO DETERMINE THE PEAK MONTH AVERAGE DAY

RESET ALL INPUTS (1)

REQUIRED DATA: Peak Month Operations & Seats data

Proceed to Next Step

Peak Month: AUGUST (2)

(3)

	Day of Week	Daily Operations: Arrivals	Daily Operations: Departures	Daily Scheduled Seats: Arriving	Daily Scheduled Seats: Departing	%Diff. (Ops)	%Diff. (Seats)	%Diff. (Total)
10	Sunday	142	142	11,826	11,699	0.08	0.09	0.17
11	Monday	155	155	12,744	12,705	0.09	0.07	0.16
12	Tuesday	153	153	12,657	12,618	0.07	0.05	0.12
13	Wednesday	153	153	12,657	12,618	0.07	0.05	0.12
14	Thursday	156	156	12,922	12,883	0.11	0.10	0.21
15	Friday	156	156	12,922	12,883	0.11	0.10	0.21
16	Saturday	122	120	10,597	10,471	0.36	0.29	0.65
	Average	148	148	12,332	12,268			

(4)

Data Input Cells	
Calculated Values	
Linked/Shared Values	

(1) Click the 'RESET ALL INPUTS' button to begin.

(2) Access the most recent OAG or Airport data for one entire week within the Peak Month and Input the Arrival and Departure operations and seats data into Cells D9 : G15 in the worksheet. This week should not contain any holidays.

(3) Input the date of the first day of the selected week and Select the first day of the month from the dropdown list in Cells B9 and C9 and the remaining cells will auto fill.

(4) Select a day of the sample week as the average day of the month that closely matches the average weekday. Use the % difference values in H9:J15 to help choose the average day. Avoid any holidays or other anomalies.

(5) Access the most recent OAG or Airport data for the Peak Month Average Day. This data will include 1) Origin or Destination, 2) Time of Departure or Arrival, 3) Seat Configuration, and 4) Published Carrier.

Raw Schedule to Arrival Data

USE THIS WORKSHEET TO CONVERT A RAW SCHEDULE INTO ARRIVAL DATA FOR A ROLLING 10 MINUTE MODEL

1 RESET ALL INPUTS

3 UPDATE PIVOT TABLE

Proceed to Next Step

2

Regional Level Factor(seats): 60

4

ORIGIN	PUBLISHED CARRIER	SEATS CONFIGURATION	ARRIVAL TIME	Air Carrier/ Regional	Domestic/ International	10 Minute Bucket	Flight Counter	Group Forming
ATL	DL	183	11:02	Air Carrier	D	67	1	DAir Carrier67
ATL	DL	183	13:12	Air Carrier	D	80	1	DAir Carrier80
ATL	DL	183	18:06	Air Carrier	D	109	1	DAir Carrier109
ATL	DL	124	20:38	Air Carrier	D	124	1	DAir Carrier124
ATL	DL	183	22:11	Air Carrier	D	134	1	DAir Carrier134
AUS	AA	140	9:15	Air Carrier	D	56	1	DAir Carrier56
CVG	DL	183	10:33	Air Carrier	D	64	1	DAir Carrier64
DEN	UA							DAir Carrier58
DEN	UA							DAir Carrier76
DEN	UA							DAir Carrier101
DEN	UA							DAir Carrier119
DEN	UA							DAir Carrier136
DEN	F9							DAir Carrier60
DEN	F9							DAir Carrier81
DEN	F9							DAir Carrier117
DEN	F9							DAir Carrier136
DFW	AA							DAir Carrier52
DFW	AA							DAir Carrier60
DFW	AA							DAir Carrier67
DFW	AA							DAir Carrier74
DFW	AA							DAir Carrier78
DFW	AA							DAir Carrier89
DFW	AA							DAir Carrier98
DFW	AA							DAir Carrier108
DFW	AA							DAir Carrier120
DFW	AA							DAir Carrier134
EWR	CO							DAir Carrier72
EWR	CO							DAir Carrier90
EWR	CO							DAir Carrier121
IAH	CO							DAir Carrier65
IAH	CO							DAir Carrier85
IAH	CO							DAir Carrier100
IAH	CO							DAir Carrier115
IAH	CO							DAir Carrier125

Designation Table for Dom/Int

5

ORIGIN	Total	D or I
ATL	5	D
AUS	1	D
CVG	1	D
DEN	9	D
DFW	10	D
EWR	3	D
IAH	6	D
LAS	11	D
MSP	3	D
OAK	9	D
ORD	8	D
PDX	4	D
PHX	16	D
SEA	9	D
SFO	11	D
SJC	16	D
SLC	6	D
SMF	7	D
STL	1	D
Grand Total	136	D
		D
		D
		D
		D
		D
		D
		D
		D
		D
		D
		D
		D
		D
		D

(1) Click the 'RESET ALL INPUTS' button to begin.

(2) Access either OAG, Airport or another source of data for the most recent or nearest Peak Month Average Weekday, and Input the departure schedule data.

(3) Click the 'UPDATE PIVOT TABLE' button to populate the summary of destinations table starting in Cell J5.

(4) Adjust the Regional Level Factor to the level most appropriate to the market. (*60 is the FAA default*)

(5) Review the destinations and Change any international destinations to an 'I', if desired, using the drop down list. (*The default is set as "D" for Domestic*)

-->The required departure schedule data consists of Destination, Departure Time, Seats Configuration, and Published Carrier.

--> Time should be in the 24 hour format. (e.g. 8:30, 12:01, 18:35)

The data prepared in this worksheet drives the Peak Hour worksheet which will show the Peak Hour based on Rolling 10 Minute buckets.

Design Hour Activity Levels

USE THIS WORKSHEET TO FORECAST DESIGN HOUR ACTIVITY LEVELS

REQUIRED: RECENT FORECAST DATA

(1) RESET INPUTS

ANNUAL

Calendar Year		Total Enplanements	
Base			
2008		4,492,626	
Forecast			(2)
2010		4,168,100	
2015		4,732,800	
2020		5,381,300	
2025		6,104,700	
2030		6,925,300	

PEAK MONTH

Base		9.4%	Peak Month Factor
2008	(3)	419,764	~from Peak Month Tab
Forecast	Peak Month Factor		
2010	9.4%	391,800	
2015	9.4%	444,900	
2020	9.4%	505,800	
2025	9.4%	573,800	
2030	9.4%	651,000	

PEAK MONTH AVERAGE DAY

Base		31	# of Days in Peak Month
2008	(4)	13,540	
Forecast			
2010		12,640	
2015		14,350	
2020		16,320	
2025		18,510	
2030		21,000	

DESIGN HOUR

	% of Average Day	Enplaned	% of Average Day	Deplaned
Base				
2008	15.4%	2,080	12.6%	1,700
Forecast				
2010	15.4%	1,950	12.6%	1,590
2015	15.0%	2,150	12.2%	1,750
2020	14.7%	2,400	12.0%	1,960
2025	14.0%	2,590	11.7%	2,170
2030	13.5%	2,840	11.5%	2,420

(1) Click the 'RESET INPUTS' button to clear the input cells.

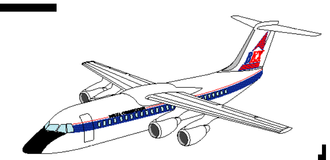
(2) Access the most recent forecast available to the airport and Input the Annual Enplanement Values in Cells C13:C17. If no recent or updated forecast exists at the airport, use the lastest TAF forecast from the FAA.

(3) Input the desired or expected Peak Month Factors for the Forecast years into Cells B22:B26.

(4) Input the number of Days in the Peak Month selected in Tab 1.

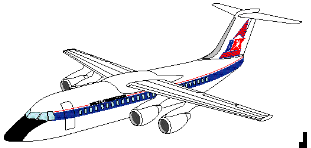
(5) Input the desired or expected Enplaned and Deplaned Design Hour Factors into Cells B41:B45 and D41:D45 respectively.

--> The Design Hour Enplanements and Deplanements forecast values can be used in the Terminal Planning Spreadsheet Models if desired.



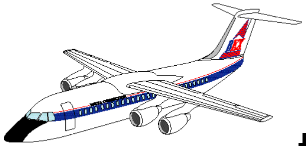
Application of Stochastic and Deterministic Queueing Theory in Airport Terminal Design

Basic Discussion



- Use stochastic queues with care - airport terminals are very dynamic and might never reach steady-state conditions
- Use stochastic queues when the demand is less than the supply function (i.e., demand < capacity)
- Use deterministic queues when the demand exceeds supply (saturation or congested conditions)

Multiserver Stochastic Queueing Equations

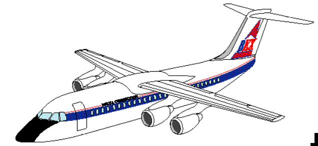


Assume an infinite source queue with constant λ and μ

- Poisson arrivals with parameter λ_n
- Probability function of service completions is negative exponential with parameter μ_n
- Only one arrival or service occurs at a given transition

For more information on queueing models consult any Operations Research textbook (i.e., Hillier and Lieberman, 1996)

Multi-server Queueing Equations (I)



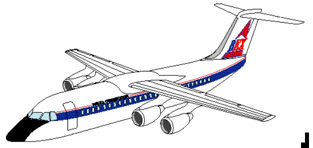
$\rho = \lambda / s\mu$ utilization factor

Probabilities of zero and n entities in the system

$$P_0 = 1 \Big/ \left(\sum_{n=0}^{s-1} \frac{(\lambda/\mu)^n}{n!} + \frac{(\lambda/\mu)^s}{s!} \left(\frac{1}{1 - (\lambda/s\mu)} \right) \right) \tag{1}$$

$$P_n = \begin{cases} \dfrac{(\lambda/\mu)^n}{n!} P_0 & 0 \le n \le s \\ \dfrac{(\lambda/\mu)^n}{s!\, s^{n-s}} P_0 & n \ge s \end{cases} \tag{2}$$

Multi-server Queueing Equations (II)



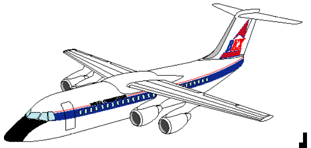
Expected no. of entities in system

$$L = \frac{\rho P_0 \left(\frac{\lambda}{\mu}\right)^s}{s!(1-\rho)^2} + \frac{\lambda}{\mu} \qquad (3)$$

Expected no. of entities in queue

$$L_q = \frac{\rho P_0 \left(\frac{\lambda}{\mu}\right)^s}{s!(1-\rho)^2} \qquad (4)$$

Multi-server Queueing Equations (III)



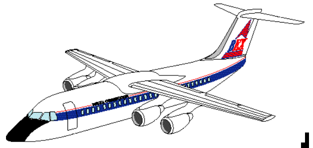
Average waiting time in queue

$$W_q = \frac{L_q}{\lambda} \qquad (5)$$

Average waiting time in system

$$W = \frac{L}{\lambda} = W_q + \frac{1}{\mu} \qquad (6)$$

Example 3: Level of Service at Airport Terminal Security Checkpoints

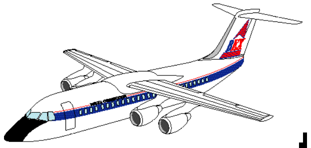


The airport shown in the next figures has two security checkpoints for all passengers boarding aircraft. Each security check point has two x-ray machines. A survey reveals that on the average a passenger takes 45 seconds to go through the system (negative exponential distribution service time).

The **arrival rate** is known to be random (this equates to a Poisson distribution) with a mean arrival rate of one passenger every 25 seconds.

In the design year (2010) the demand for services is expected to grow by 60% compared to that today.

Relevent Operational Questions



a) What is the current utilization of the queueing system (i.e., two x-ray machines)?

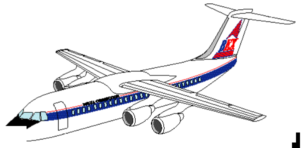
b) What should be the number of x-ray machines for the design year of this terminal (year 2010) if the maximum tolerable **waiting time in the queue** is 2 minutes?

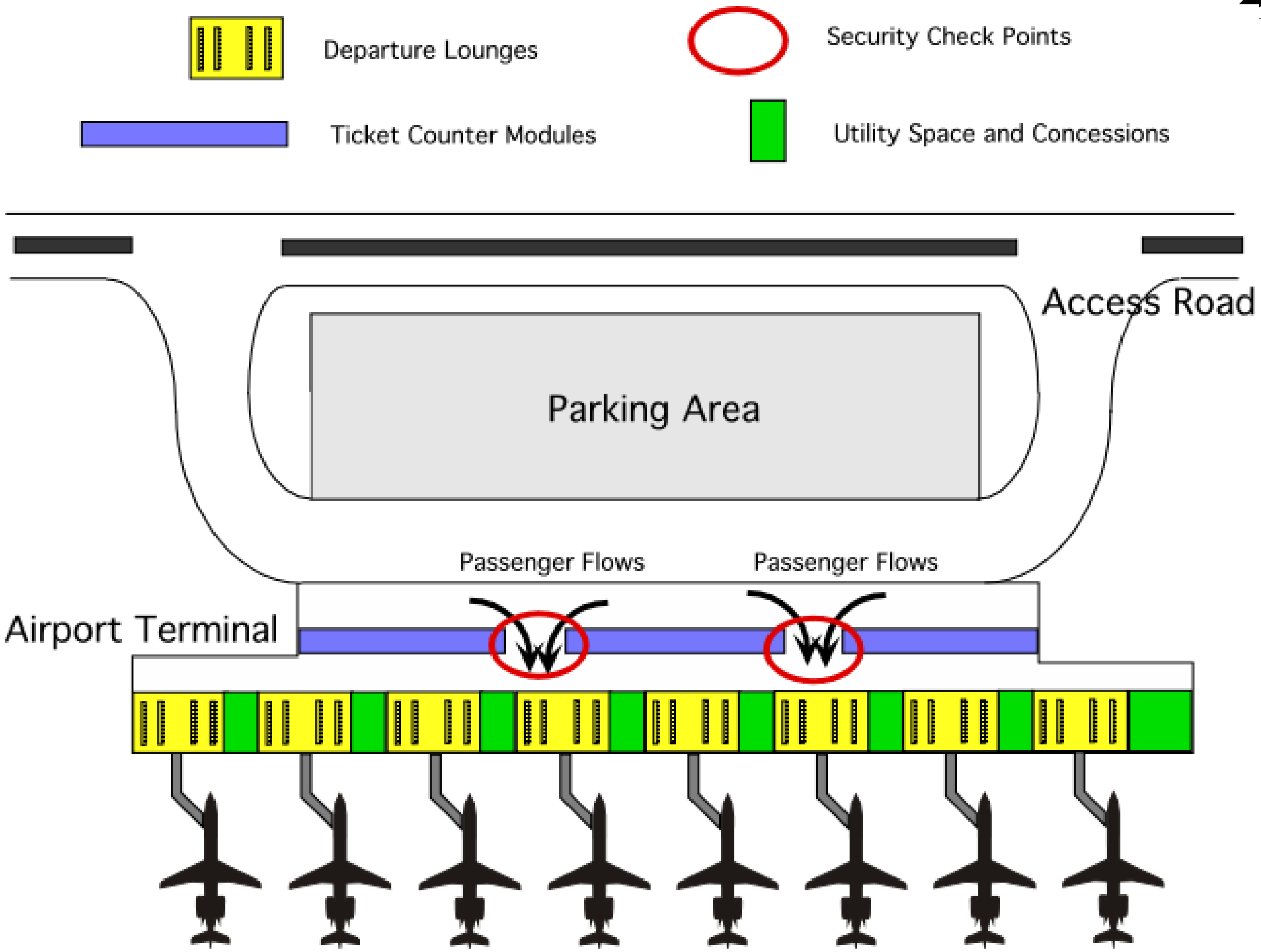
c) What is the expected number of passengers at the checkpoint area on a typical day in the design year (year 2010)?

d) What is the new utilization of the future facility?

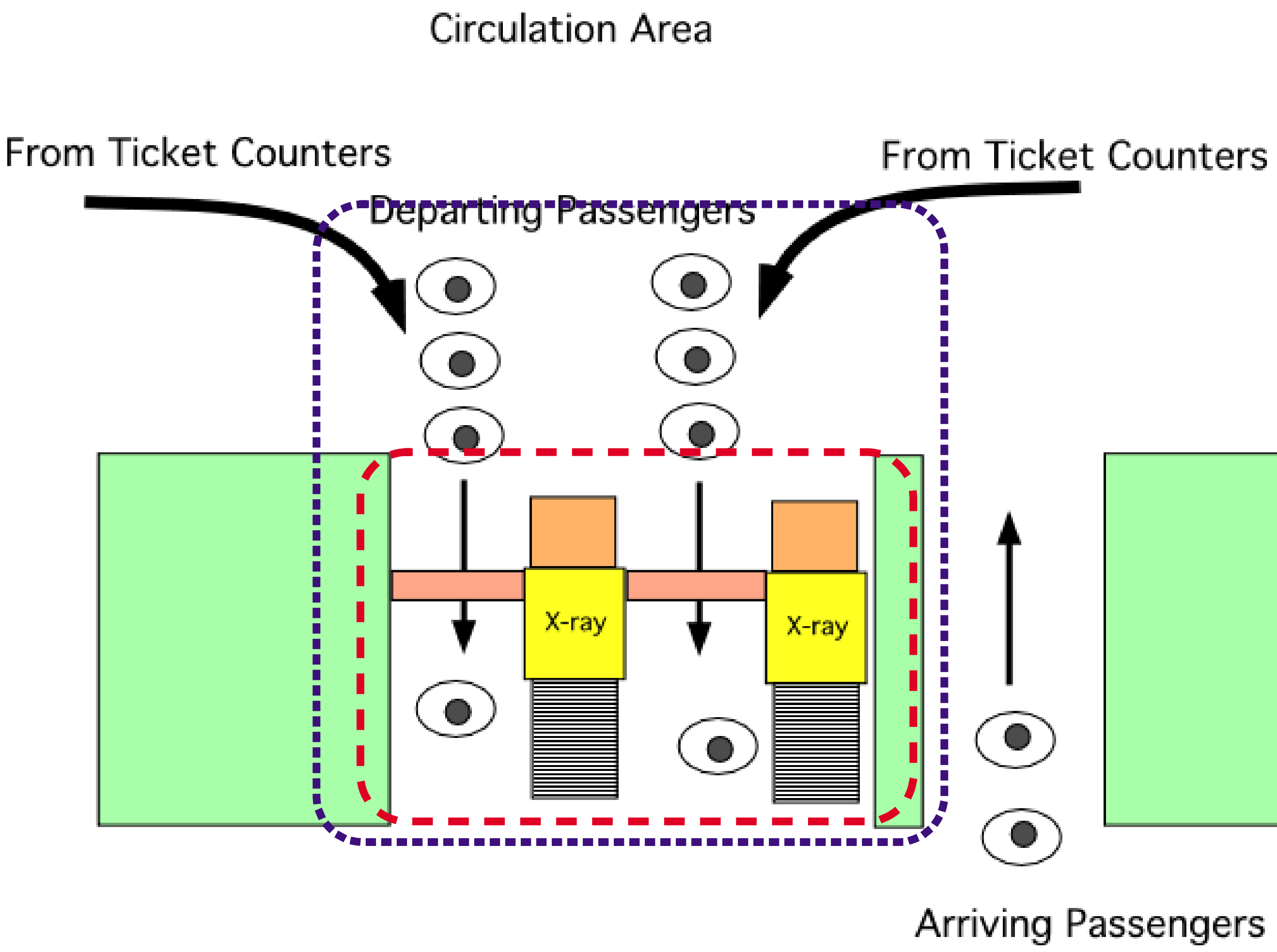
e) What is the probability that more than 4 passengers wait for service in the design year?

Airport Terminal Layout

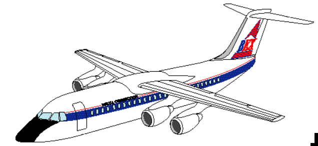




Security Check Point Layout



Security Check Point Solutions

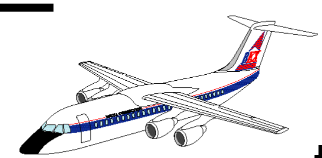


a) Utilization of the facility, ρ. Note that this is a multiple server case with infinite source.

$\rho = \lambda / (s\mu) = 140/(2*80) = 0.90$

Other queueing parameters are found using the steady-state equations for a multi-server queueing system with infinite population are:

Idle probability = 0.052632
Expected No. of customers in queue (Lq) = 7.6737
Expected No. of customers in system (L) = 9.4737
Average Waiting Time in Queue = 192 s
Average Waiting Time in System = 237 s



b) The solution to this part is done by trail and error (unless you have access to design charts used in queueing models. As a first trial lets assume that the number of x-ray machines is 3 (s=3).

Finding Po, $$P_0 = \sum_{n=0}^{s-1} \frac{(\lambda/\mu)^2}{n!} + \frac{(\lambda/\mu)^s}{s!}\left(\frac{1}{1-(\lambda/s\mu)}\right)$$

Po = .0097 or less than 1% of the time the facility is idle

Find the waiting time in the queue,

***Wq* = 332** s

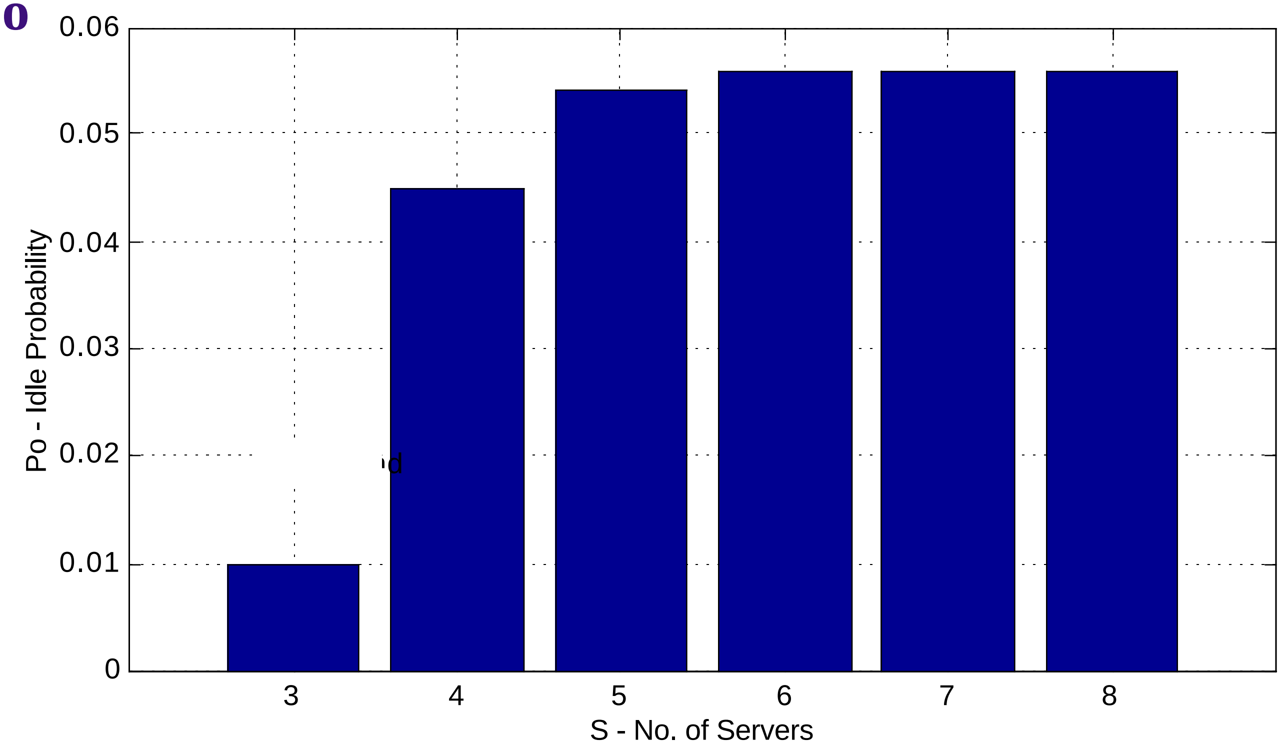
Since this waiting time violates the desired two minute maximum it is suggested that we try a higher number of x-ray machines to expedite service (at the expense of cost). The following figure illustrates the sensitivity of P_o and L_q as the number of servers is increased.

Note that four x-ray machines are needed to provide the desired average waiting time, *Wq*.

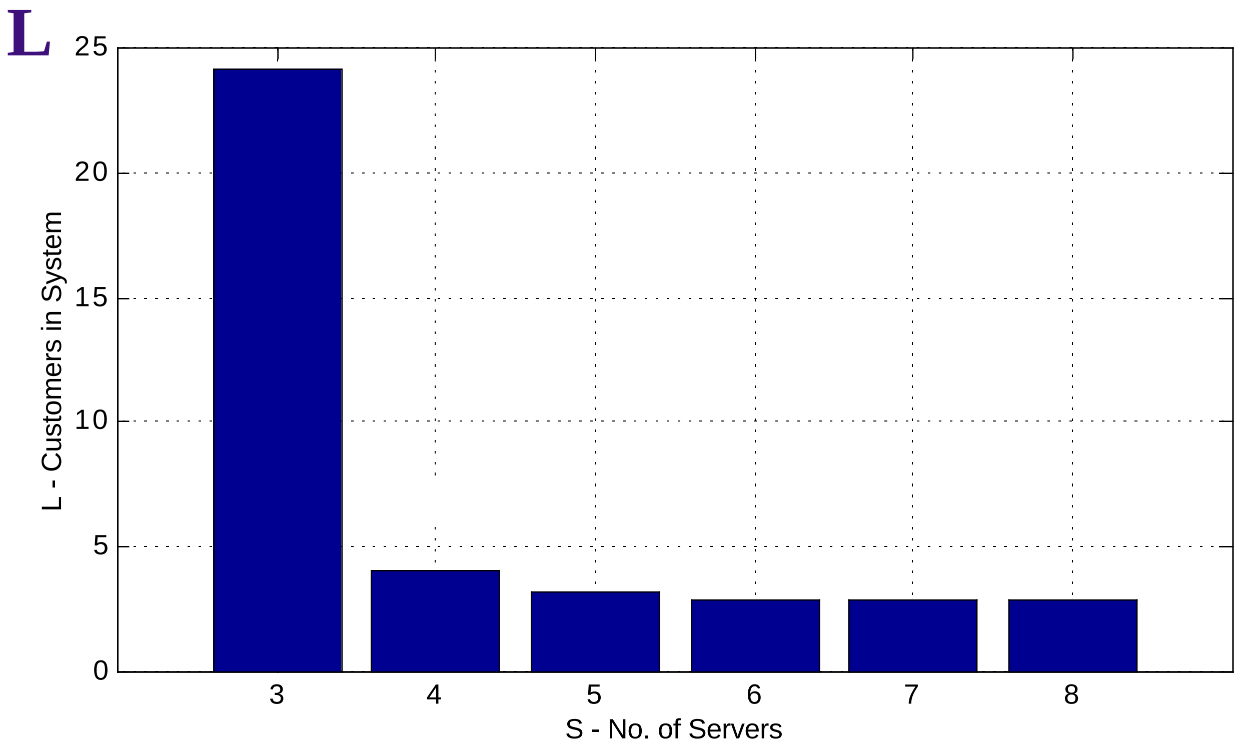
Sensitivity of *Po* with *S*

Note the variations in Po as S increases.

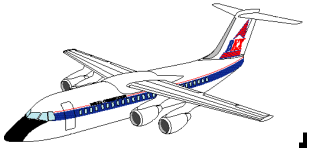
P_o



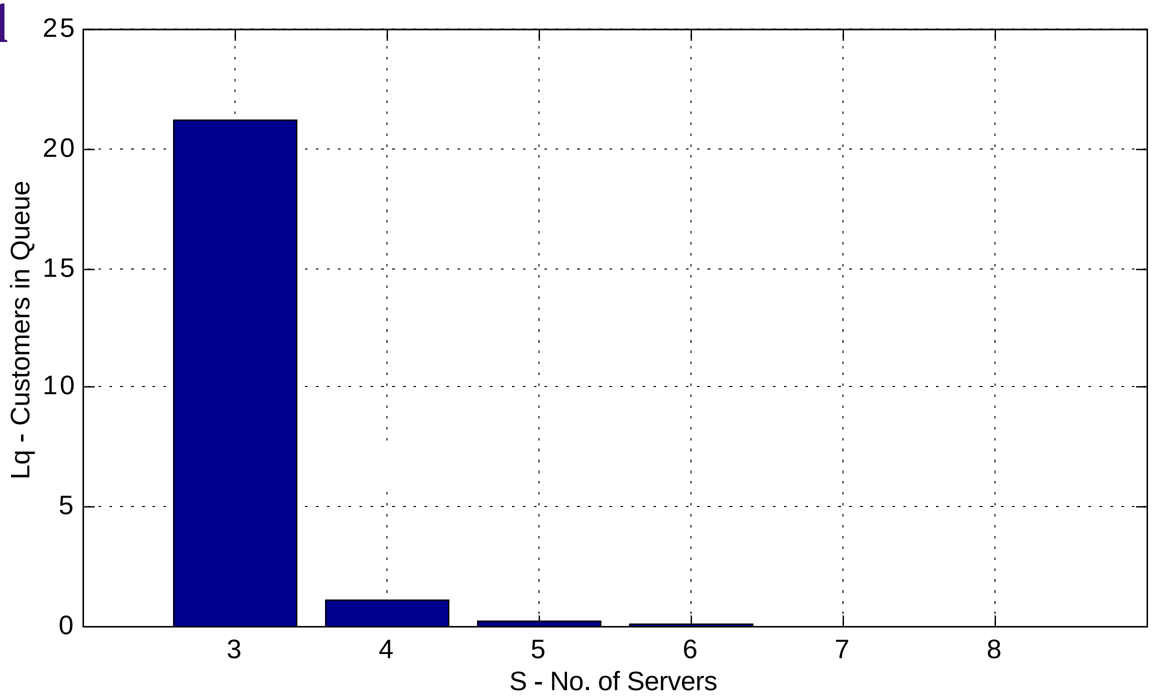
Sensitivity of *L* with *S*



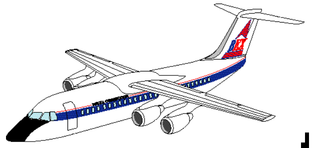
Sensitivity of *Lq* with *S*

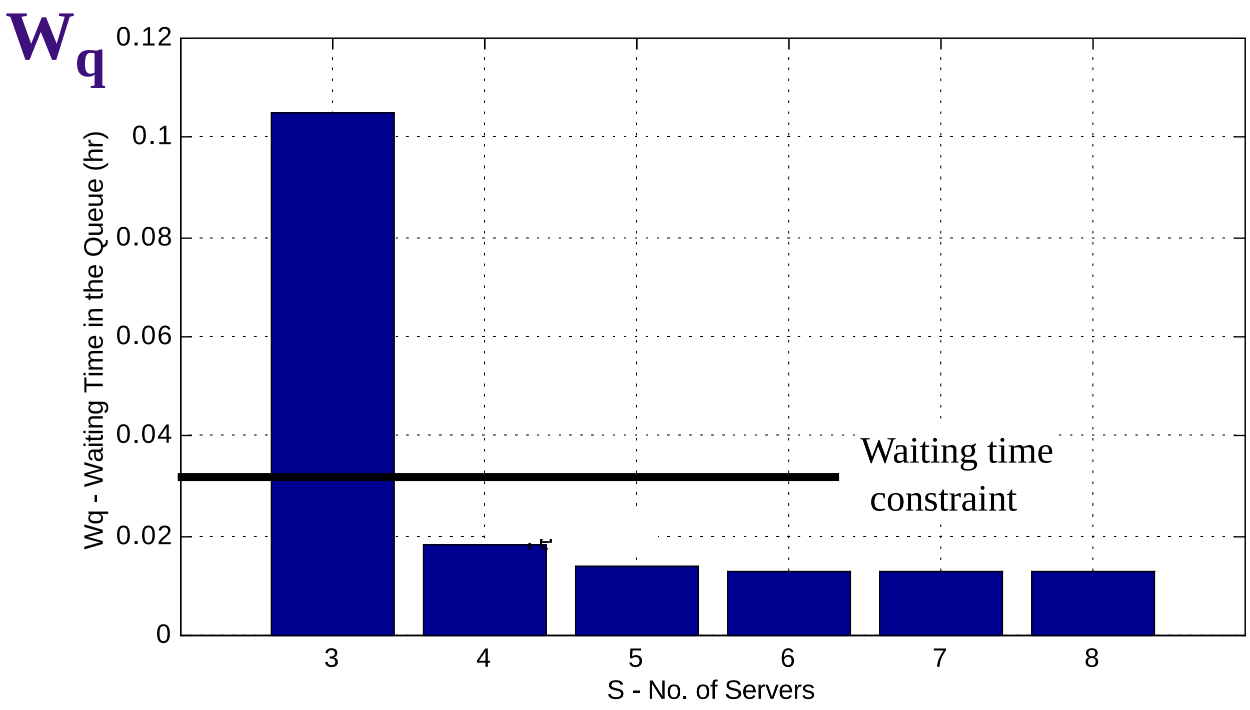


L_q



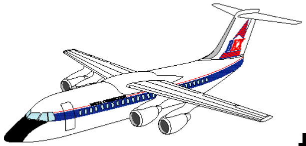
Sensitivity of *Wq* with *S*





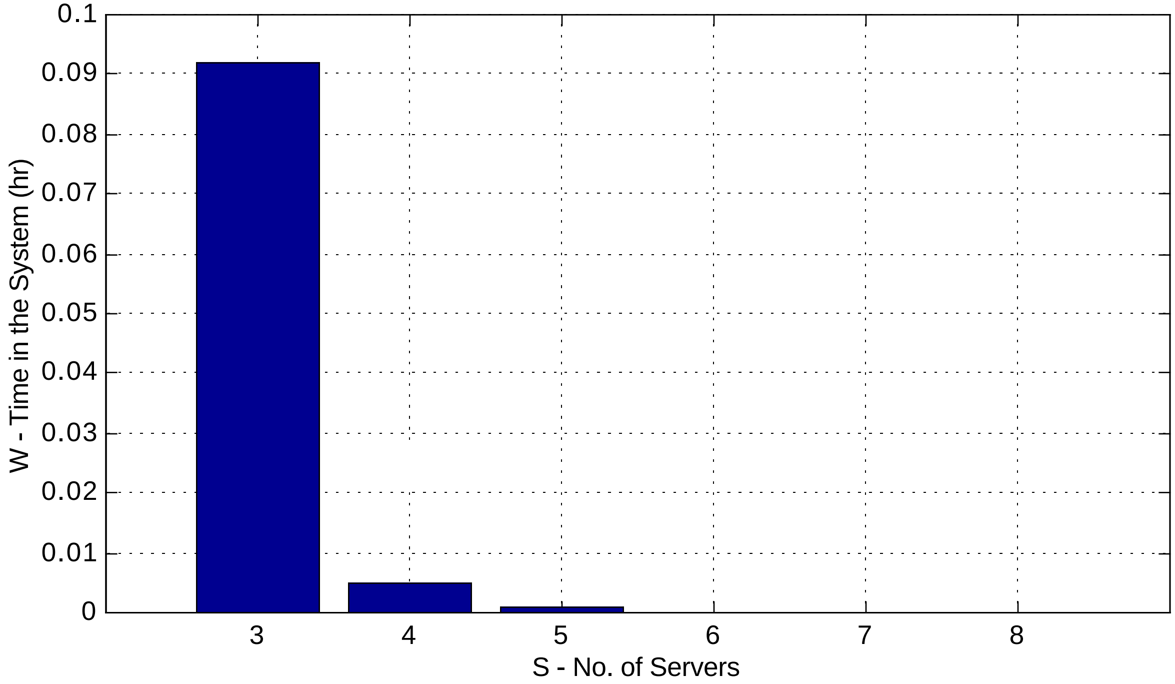
This analysis demonstrates that 4 x-ray machines are needed to satisfy the 2-minute design constraint.

Sensitivity of *W* with *S*

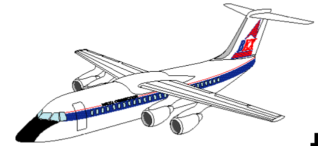


Note how fast the waiting time function decreases with *S*

W



Security Check Point Results



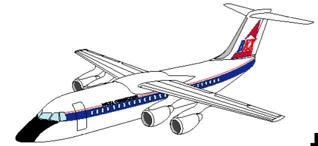
c) The expected number of passengers in the system is (with S = 4),

$$L = \frac{\rho P_0 \left(\frac{\lambda}{\mu}\right)^s}{s!(1-\rho)^2} + \frac{\lambda}{\mu}$$

***L* =** 4.04 passengers in the system on the average design year day.

d) The utilization of the improved facility (i.e., four x-ray machines) is

$\rho = \lambda / (s\mu)$ = 230/ (4*80) = **0.72**



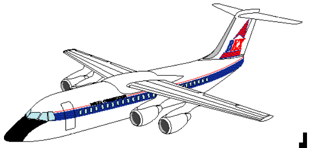
e) The probability that more than four passengers wait for service is just the probability that more than eight passengers are in the queueing system, since four are being served and more than four wait.

$$P(n > 8) = 1 - \sum_{n=0}^{8} P_n$$

where,

$$P_n = \frac{(\lambda/\mu)^n}{n!} P_0 \quad \text{if } n \le s$$

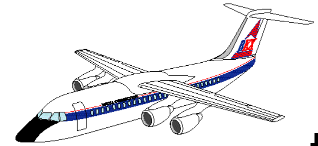
$$P_n = \frac{(\lambda/\mu)^n}{s! s^{n-s}} P_0 \quad \text{if } n > s$$



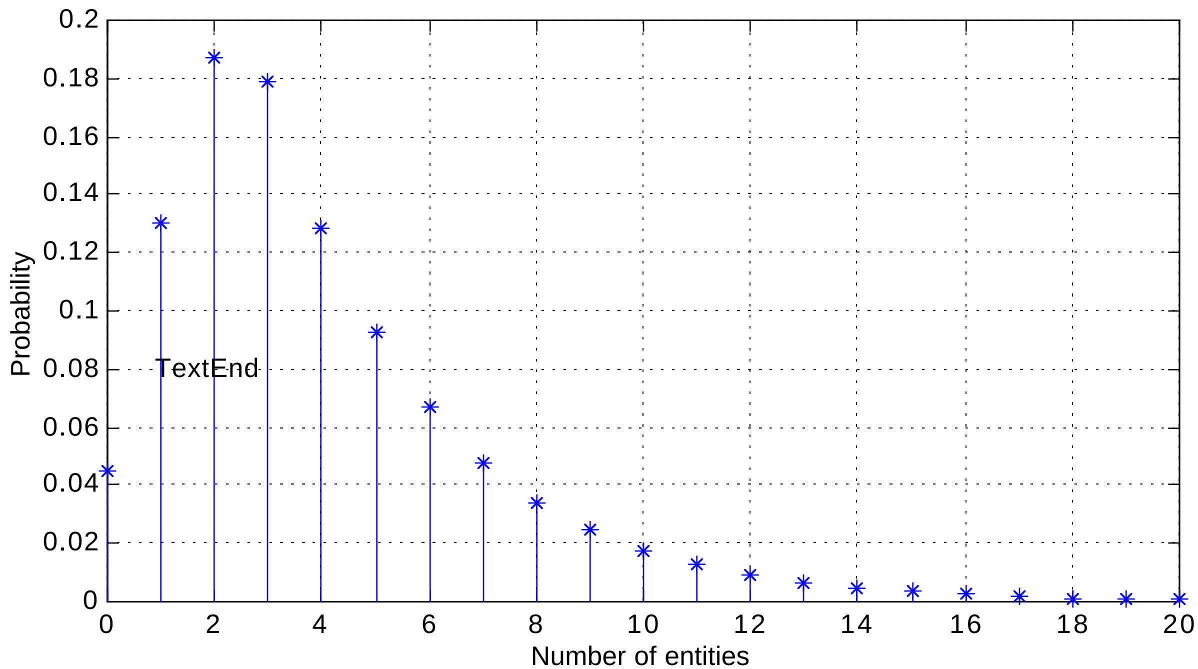
from where, $P_n > 8$ is 0.0879.

Note that this probability is low and therefore the facility seems properly designed to handle the majority of the expected traffic within the two-minute waiting time constraint.

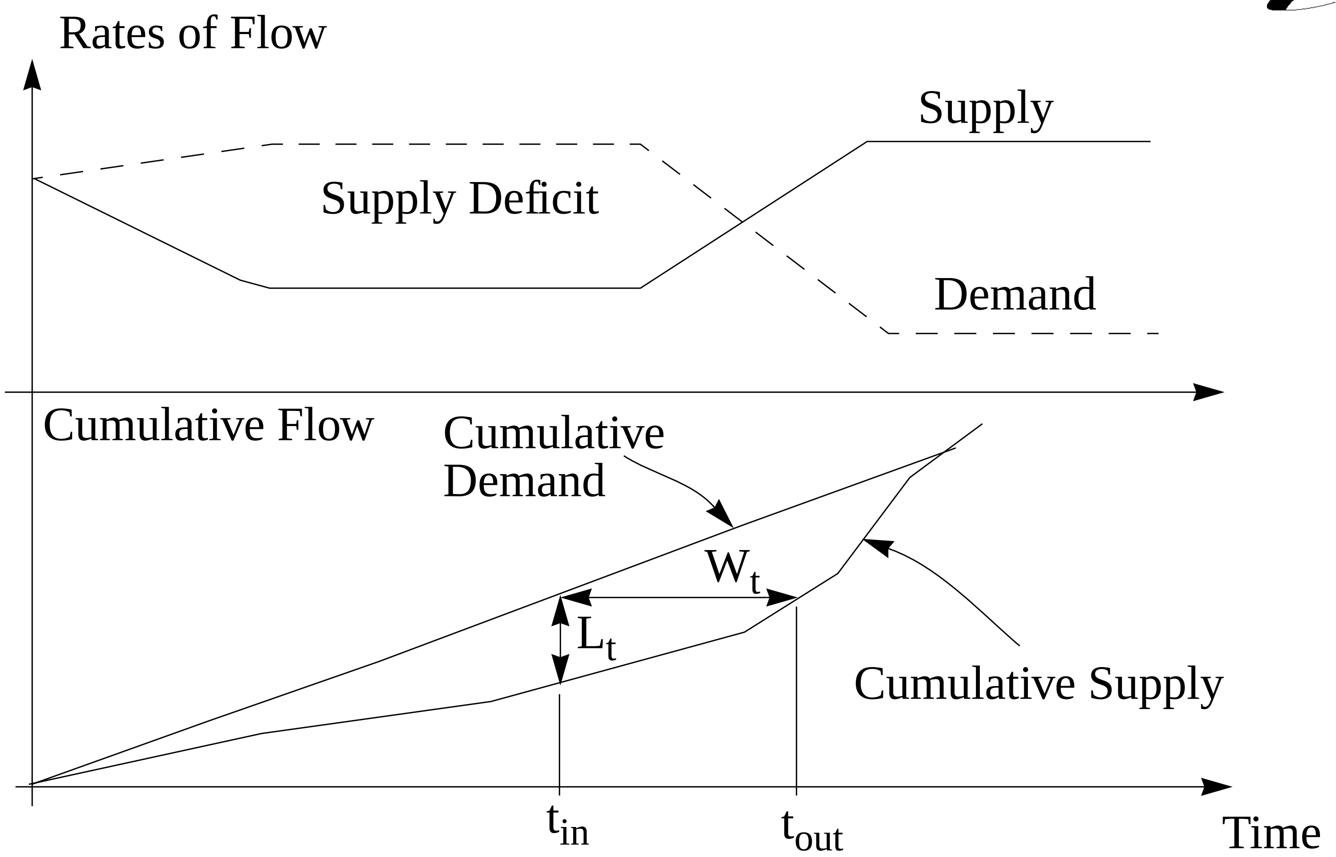
PDF of Customers in System (L)



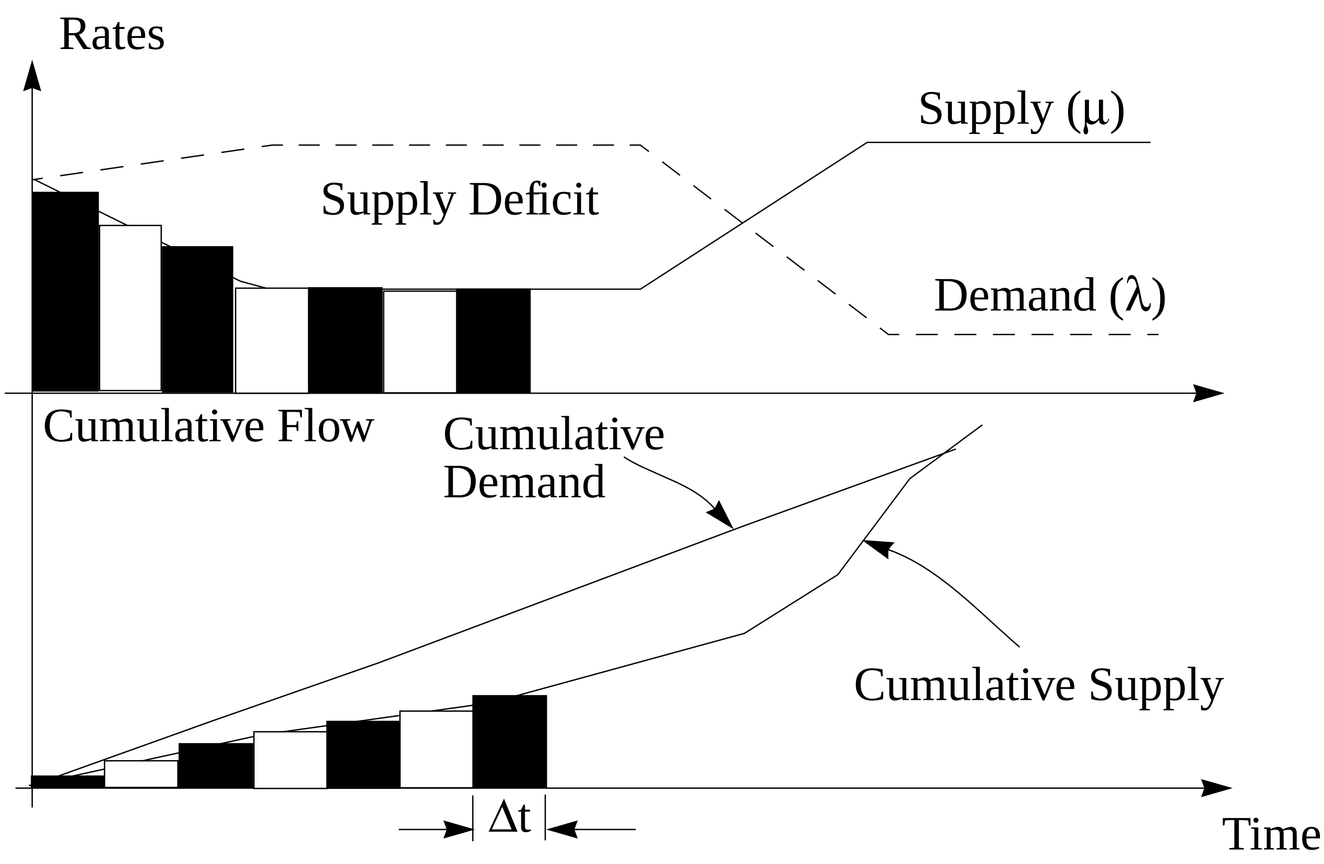
The PDF below illustrates the stochastic process resulting from poisson arrivals and neg. exponential service times



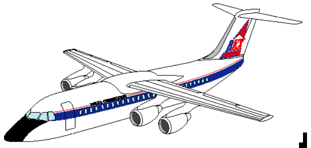
Deterministic Queue



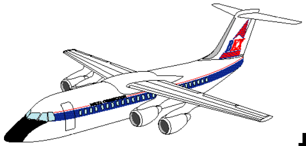
Numerical Estimation of Queueing Parameters



Deterministic Queue Parameters



- The queue length, L_t , (i.e., state of the system) corresponds to the vertical distance between the cumulative demand and supply curves
- The waiting time, W_t, denoted by the horizontal distance between the two cumulative curves in the diagram is the individual waiting time of an entity arriving to the queue at time t_{in}
- The total delay is the area under bounded by the cumulative demand and supply curves
- The average delay time is the quotient of the total delay and the number of entities processed



State of System Definition

Define the state of the system as L_t,

$$L_t = \int_0^t (\lambda_t - \mu_t)\,dt$$

L_t is the instantaneous queue length

λ_t is the arrival rate function (demand)

μ_t is the service rate function (supply)

Differential Equation Representation

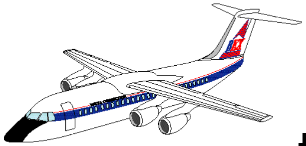
Most continuous simulations can be expressed as a set of first order differential equations. The previous state equation for L_t implies:

$$\frac{dL_t}{dt} = (\lambda_t - \mu_t)$$

This equation can be solved numerically (integrating forward with respect to time) if expressed in finite difference form,

$$L_t = L_{t-1} + (\lambda_t - \mu_t)\Delta t$$

A Word About Integration Algorithms



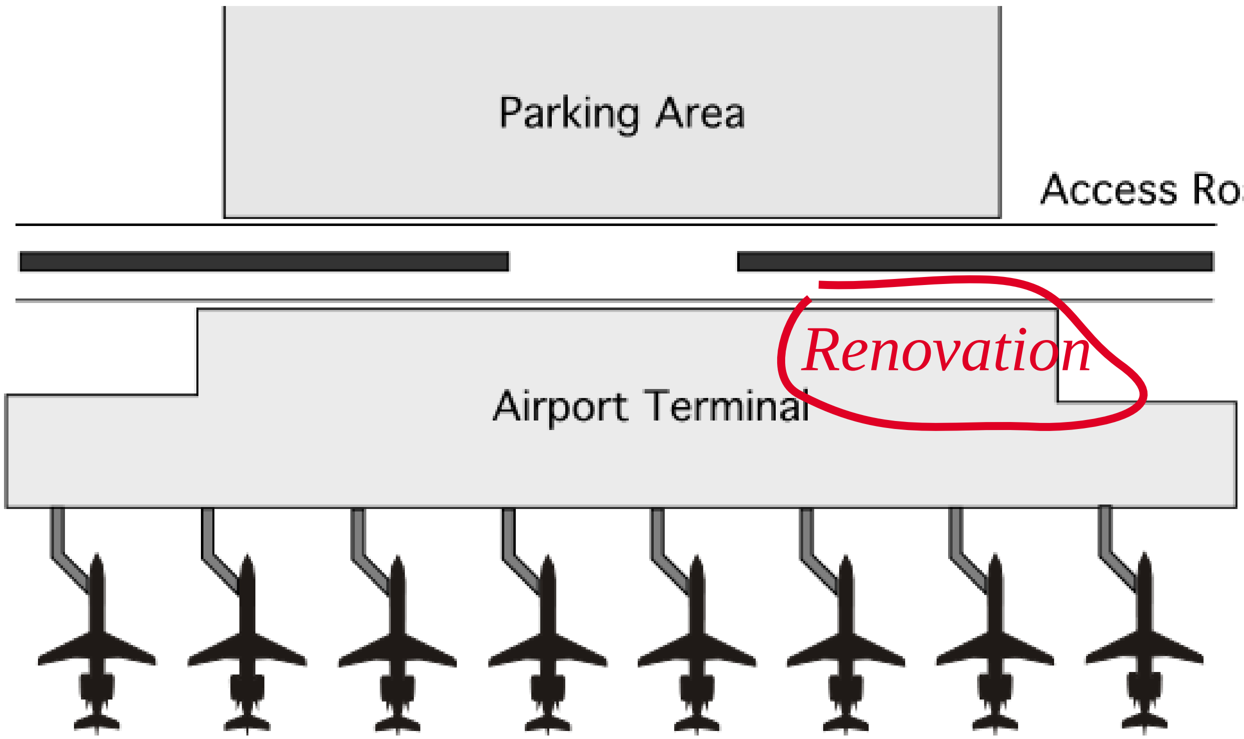
Several techniques can be implemented to solve a set of first order differential equations:

Euler Method - Simplest representation of rate variables (assumes rate variables are constant throughout the integration step size)

Runge- Kutta Methods - Several variations exist of these methods (3rd, 4th, 5th order). Uses a weighted average rate to estimate state variables every integration step. More accurate but more demanding computationally.

Example 5 - Airport Layout

This example assumes all service areas (ticket counters, security checks, etc.) to be equally spaced inside the airport terminal)



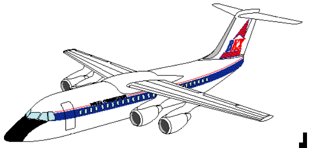
Mathematical Description of the Problem

$\lambda = 1500$ for $0 < t < 1$

$\lambda = 500$ for $t > 1$

where, λ is the arrival function (demand function) and t is the time in hours. Estimate the following parameters:

- The maximum queue length, $L(t)_{max}$
- The total delay to passengers, T_d
- The average length of queue, L
- The average waiting time, W
- The delay to a passenger arriving 30 minutes hour after the terminal closes for repairs



Problem Solution (I)

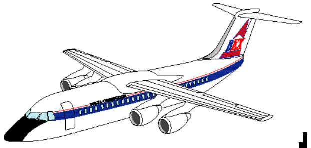
The demand function has been given explicitly in the statement of the problem. The supply function (μ)as stated in the problem is,

$\mu = 1000$ if $t < 2$

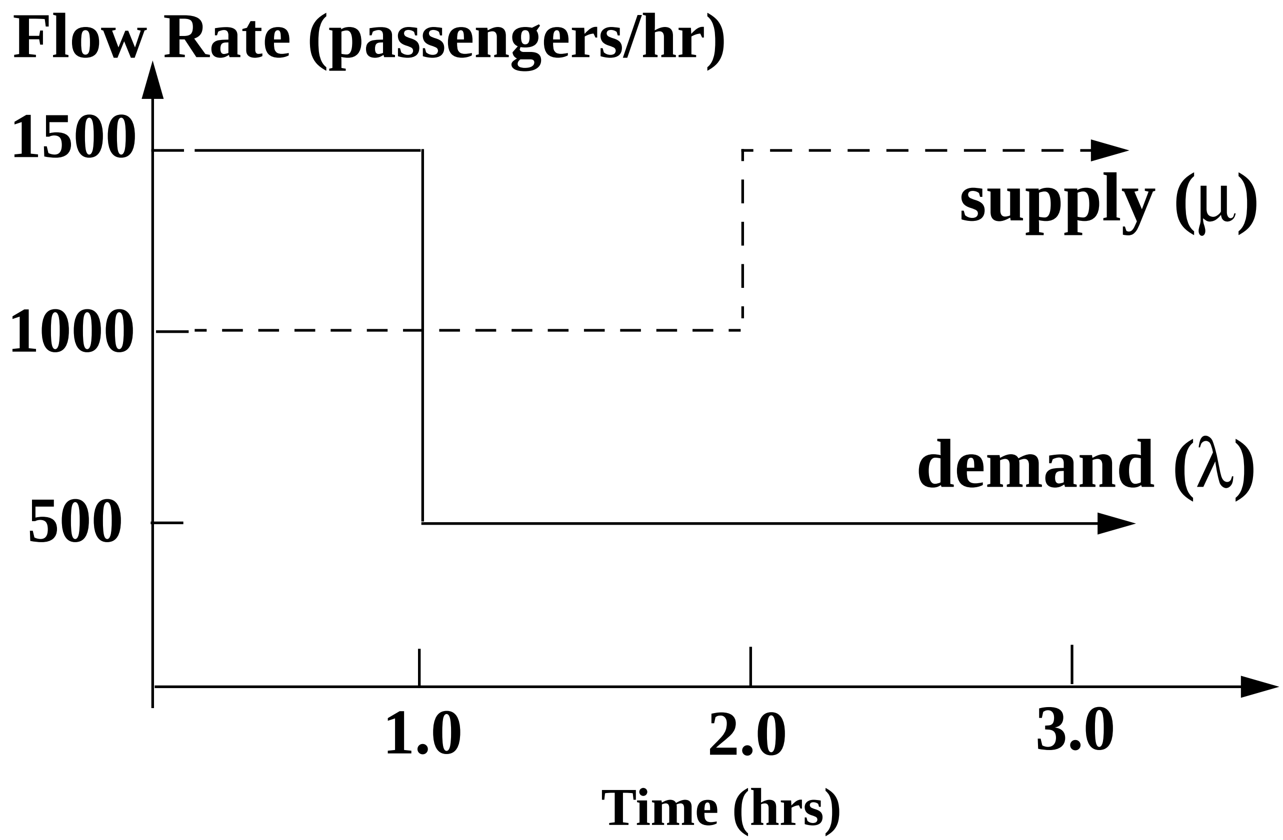
$\mu = 1500$ if $t > 2$

Plotting the demand and supply functions might help understanding the problem

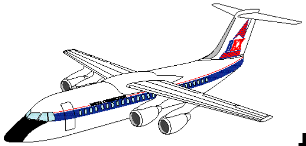
Problem Solution (II)



Demand and supply functions for the sample problem

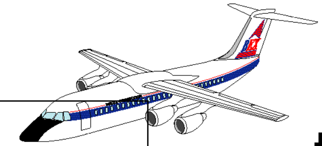


Problem Solution (III)



Sample table simulation using a spreadsheet approach

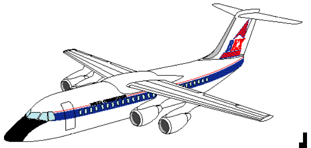
Simulation Time (hr)	State Variable (L_t)	Rate Variable (λ_t)	Rate Variable (μ_t)	Sum of Rates (λ_t-μ_t)	(Sum of Rates) Δt
0	0.0	1500.0	1000.0	500.0	100.0
0.2	100.0	1500.0	1000.0	500.0	100.0
0.4	200.0	1500.0	1000.0	500.0	100.0
0.6	300.0	1500.0	1000.0	500.0	100.0
0.8	400.0	1500.0	1000.0	500.0	100.0
1.0	500.0	500.0	1000.0	-500.0	-100.0



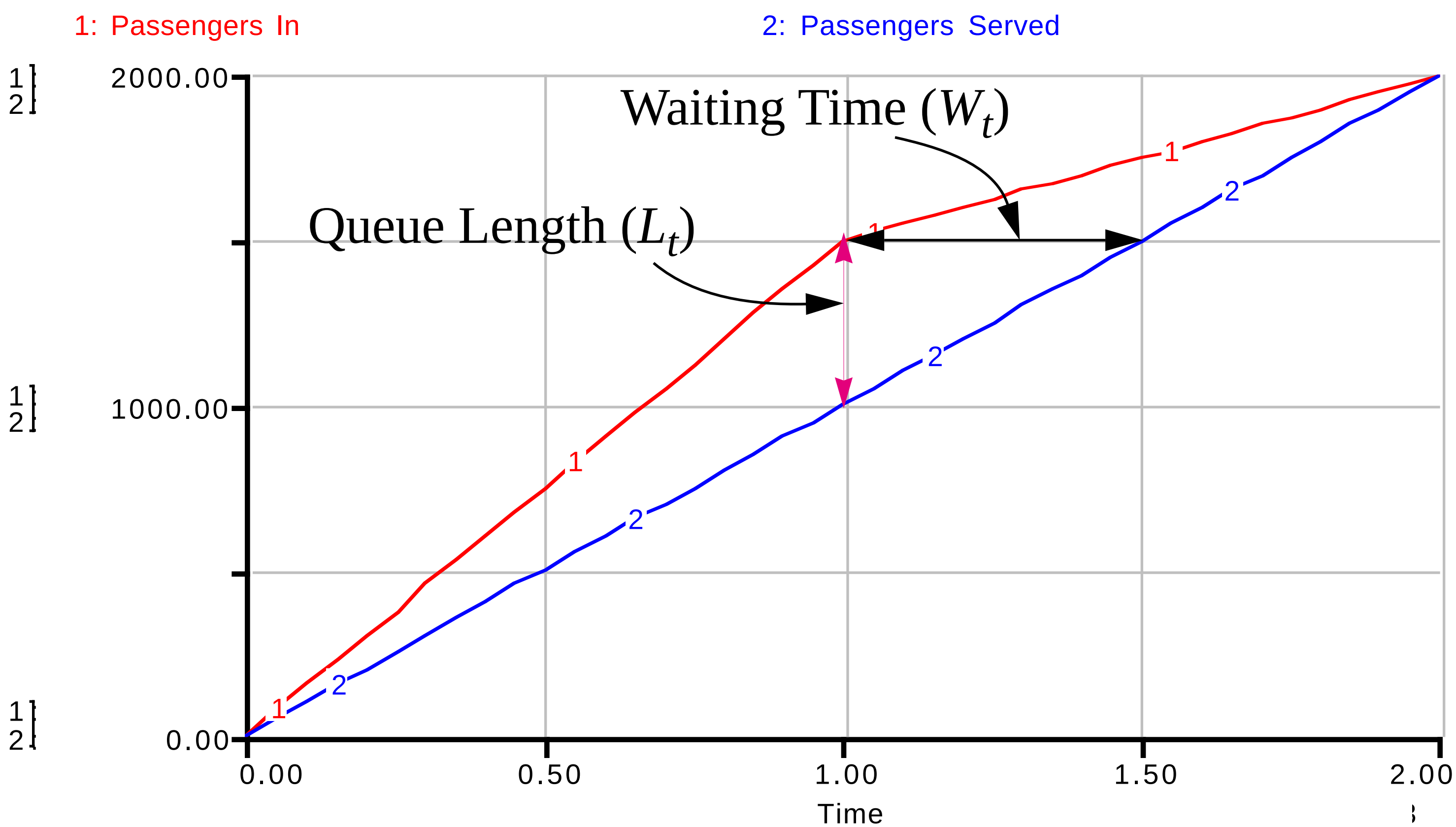
Simulation Time (hr)	State Variable (L_t)	Rate Variable (λ_t)	Rate Variable (μ_t)	Sum of Rates (λ_t-μ_t)	(Sum of Rates) Δt
1.2	400.0	500.0	1000.0	-500.0	-100.0
1.4	300.0	500.0	1000.0	-500.0	-100.0

This procedure uses Euler's Method to estimate state variables (i.e., rates λ_t and μ_t are assumed constant throughout every numerical integration interval).

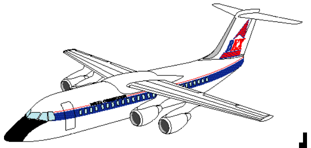
Problem Solution (IV)



Cumulative flow plots can help visualize the problem



Problem Solution (V)



The average queue length (L) during the period of interest, we evaluate the total area under the cumulative curves (to find total delay)

T_d = 2 [(1/2)(1500-1000)] = 500 passengers-hour

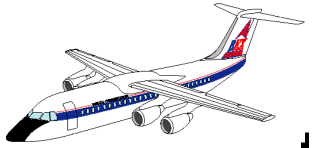
a) The maximum number of passengers in the queue, $L(t)$

max,

$L(t)_{max}$ = 1500 - 1000 = 500 passengers at time t=1.0 hours

Find the average delay to a passenger (W)

Problem Solution (VI)



$$W = \frac{T_d}{N_d} = 15 \text{ minutes}$$

where, T_d is the total delay and N_d is the number of passengers that where delayed during the queueing incident.

$$L = \frac{T_d}{t_q} = 250 \text{ passengers}$$

where, T_d is the total delay and t_d is the time that the queue lasts.

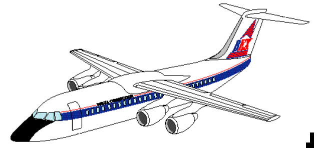
Problem Solution (VII)

Now we can find the delay for a passenger entering the terminal 30 minutes after the partial terminal closure occurs. Note that at t = 0.5 hours 750 passengers have entered the terminal before the passenger in question. Thus we need to find the time when the supply function, $\mu(t)$, achieves a value of 750 so that the passenger "gets serviced". This occurs at,

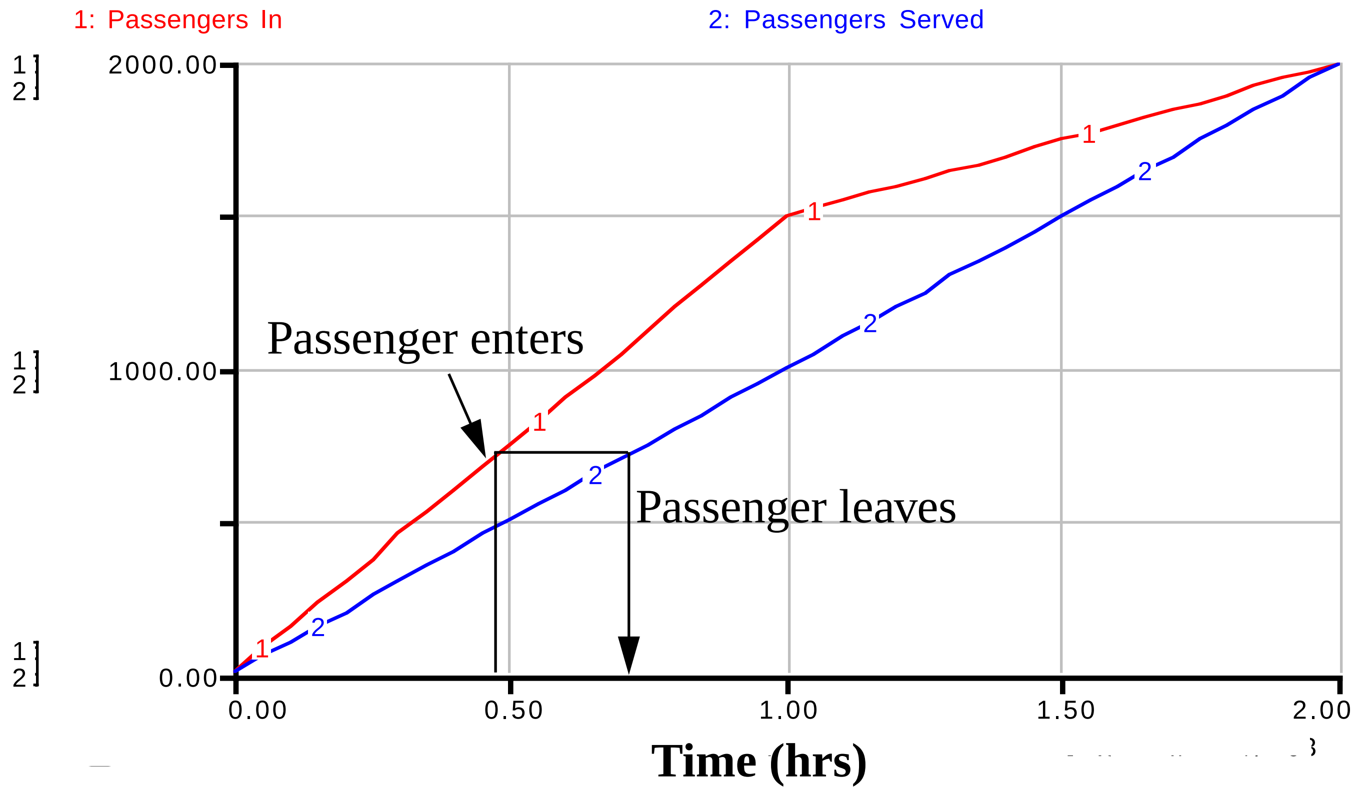
$$\mu(t + \Delta t) = \lambda(t) = 750$$

therefore Δt is just 15 minutes (the passenger actually leaves the terminal at a time $t+\Delta t$ equal to 0.75 hours). This can be shown in the diagram on the next page.

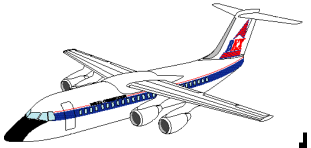
Problem Solution (VIII)



Demand and supply functions for example problem



Handling Complex Time-Varying Behaviors



The methodology described in previous pages can be extended to understand complex airport time-varying behaviors.

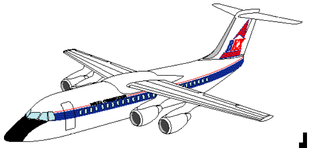
Examination of the basic state equation,

$$L_t = L_{t-1} + (\lambda_t - \mu_t)\Delta t$$

reveals that as long as the arrival and service flow rates (i.e., λ_t and μ_t are known functions of time - regardless their mathematical complexity - the process of finding the state, L_t, is simple using numerical integration.

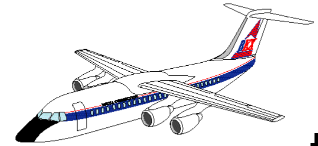
People Conveyance Systems

People Conveyance Systems



- At airports it is necessary to implement people conveyance systems such as **electrical escalators**, **moving sidewalks** (or power walks), and **Automated People Movers** (APM)
- The general goals of these systems are:
  - Reduce connection times
  - Changes in vertical flows (2-level terminals)
  - Reduce the actual walking distances for passengers
  - Improve the level of service (indirectly the image of the airport)
  - Move large volumes of passengers per unit of time

Electrical Escalator Capacities



Electrical escalators come in various widths and tread speeds. Shown below are some standard escalators used in the US.

Table 7. Typical Characteristics of Electrical Escalators (Fruin).

Width at Hip mm (in)	Width at Tread mm (in)	Theoretical Capacity (pr/hr)	Practical Capacity (pr/hr)
813 (32)	610 (24)	5,000	2,040[a]
		6,700	2,700[b]
1219 (48)	1016 (40)	8,000	4,080
		10,700	5,400

a. 90 ft/min linear speed

b. 120 ft/min linear speed

Electrical Escalator Examples

Source: San Diego Airport Authority

Atlanta APM Station (A.A. Trani)

Moving Sidewalks

- Mechanical-electrical systems used to reduce walking distance at many airports
- Share similar performance characteristics with electrical escalators
- Given the horizontal disposition of movinf sidewalks add 10% to the practical capacity of an escalator

Moving Sidewalks Examples

Charlotte Douglas Airport (A.A. Trani)

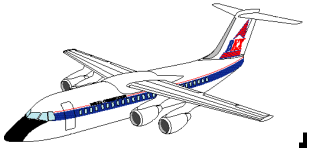
Denver Intl. Airport (A.A. Trani)

More Examples

DFW Airport (A.A. Trani)

DFW Intl. Airport (A.A. Trani)

APM Fundamentals



Automated People Mover (APM) Systems:

1. Fully automated

2. No drivers

3. Operating on a guideway

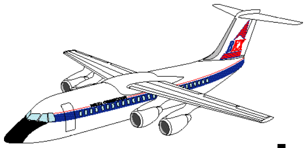
4. Exclusive right-of-way

5. Expensive (40-80 Million per mile)

6. Link between airport terminal activities

7. Link to other transportation modes (i.e., mass transit)

APM Background



Tampa International Airport

- In 1971
- First APM system

City of Miami

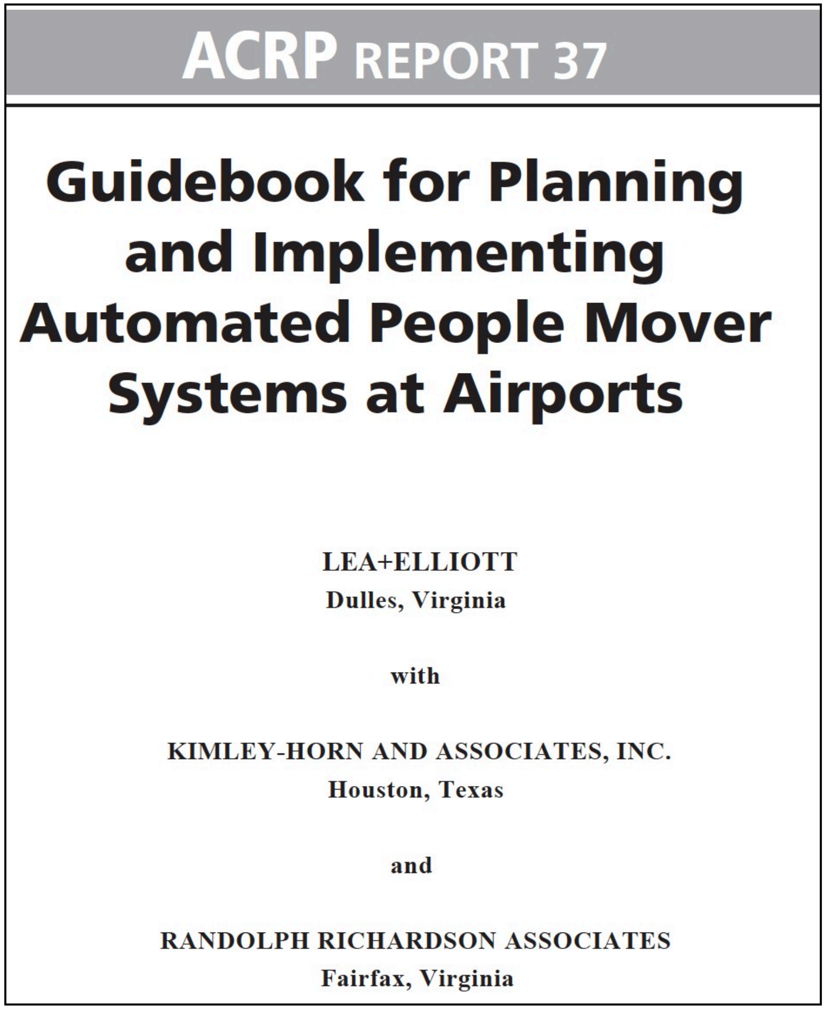
- In 1986
- First DPM in the United States

Today, more than 20 airports (44 worldwide) have APM systems in the United States including:

- SEATAC, Atlanta, Chicago, Dallas-Forth Worth, Denver, Orlando, etc.

Automated People Mover References

- Airport Cooperative Research Program (ACRP)



ACRP REPORT 37

Guidebook for Planning and Implementing Automated People Mover Systems at Airports

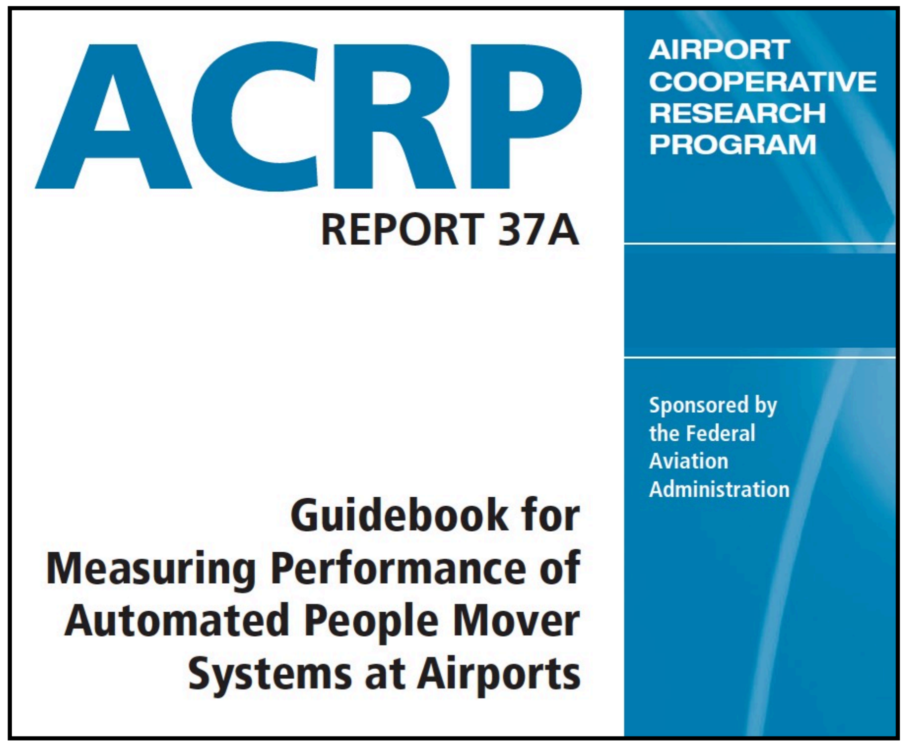
LEA+ELLIOTT
Dulles, Virginia

with

KIMLEY-HORN AND ASSOCIATES, INC.
Houston, Texas

and

RANDOLPH RICHARDSON ASSOCIATES
Fairfax, Virginia



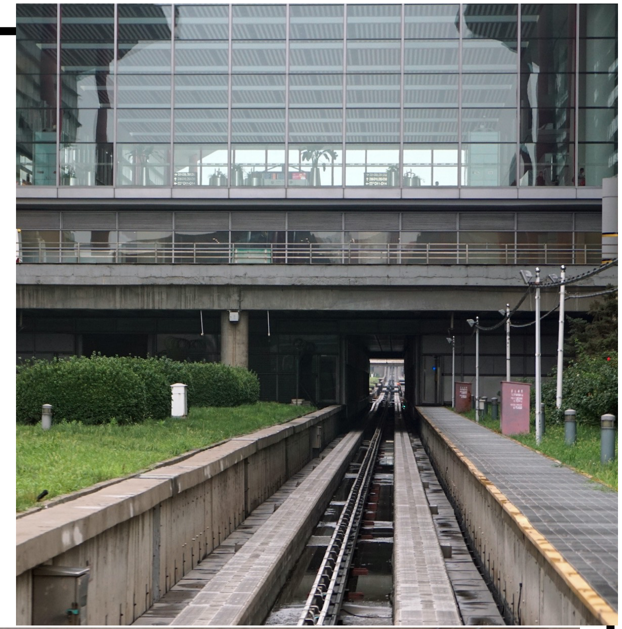
ACRP
REPORT 37A

AIRPORT COOPERATIVE RESEARCH PROGRAM

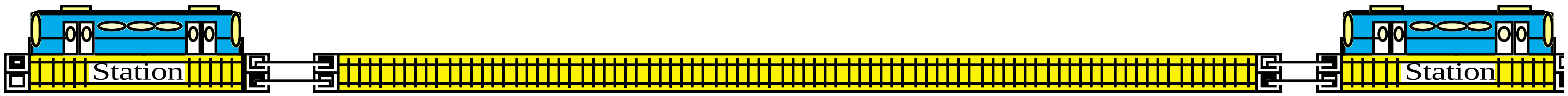
Sponsored by the Federal Aviation Administration

Guidebook for Measuring Performance of Automated People Mover Systems at Airports

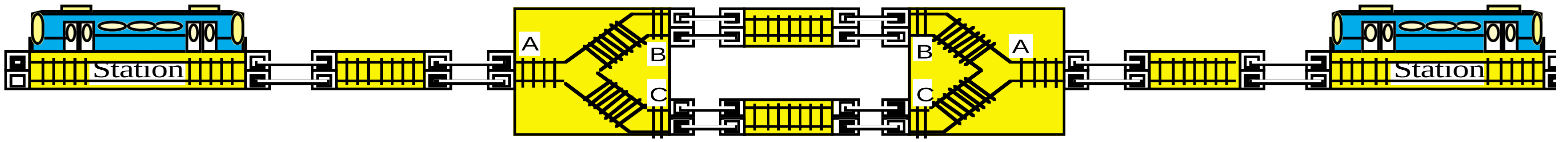
APM Systems



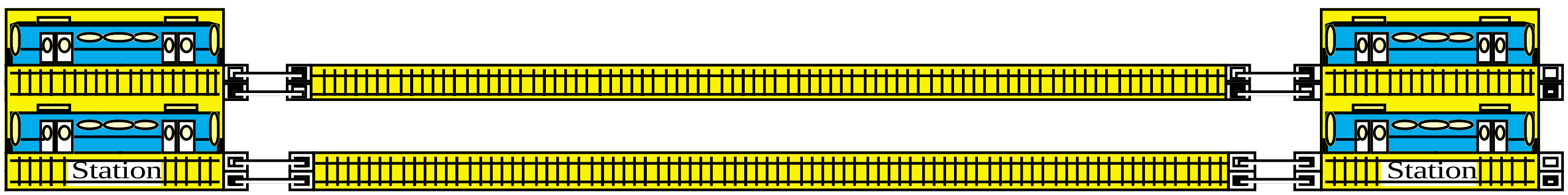
APM Configurations



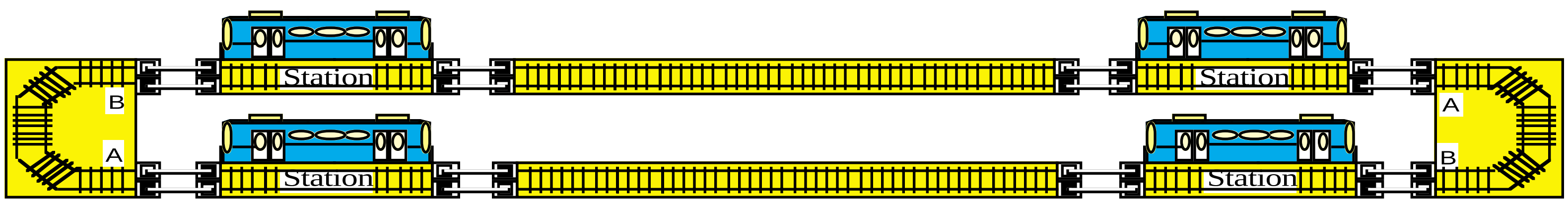
Single-Lane Shuttle



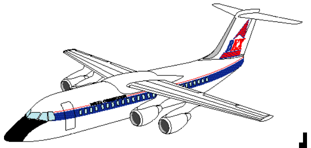
Single-Lane Shuttle with Bypass



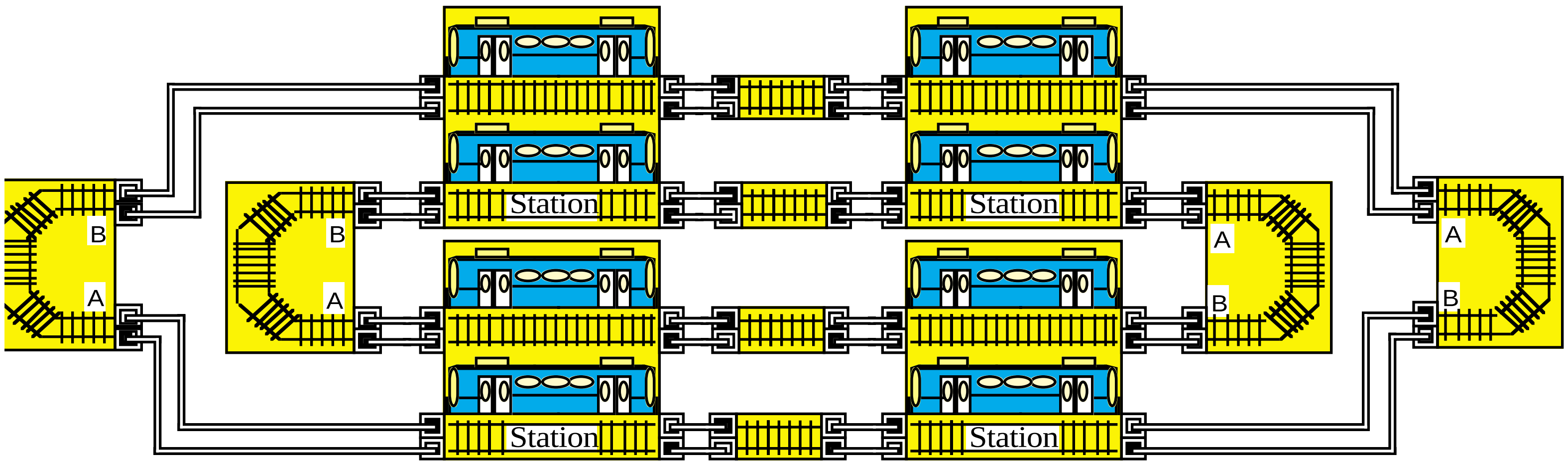
Double-Lane Shuttle



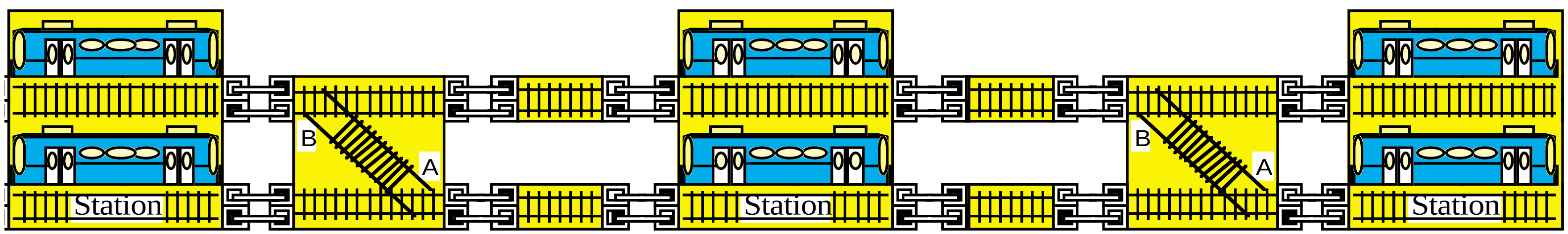
Single-Lane Loop



APM Configurations (cont.)



Double-Lane Loop



Pinched Loop with Turnbacks

Airside Automated People Movers

Airport	Year Opened	Alignment Configuration	APM Function[1]	Length (miles)[2]
Tampa	1971	Shuttles	O/D	0.7[3]
Seattle	1973	Shuttle & Loops	O/D	1.7[3]
Miami	1980	Shuttle	O/D	0.4
Atlanta	1980	Pinched Loop	Transfer	1.0
Orlando	1981	Shuttles	O/D	1.5[3]
Las Vegas	1985, 1998	Shuttles	O/D	0.2, 0.6
Singapore	1990, 2006	Shuttles	Transfer	0.7[3]
London (Stan)	1991	Pinched Loop	O/D	0.4
Tokyo	1992	Shuttles	Transfer	0.2
Pittsburgh	1992	Shuttle	Transfer	0.4
Cincinnati	1994	Shuttle	Transfer	0.2
Frankfurt	1994	Pinched Loop	Transfer	1.0
Osaka Kansai	1994	Shuttle	Transfer	0.7
Denver	1995	Pinched Loop	Transfer	1.2
Kuala Lumpur	1998	Shuttle	O/D	0.8
Hong Kong	1998	Pinched Loop	Transfer	0.8
Houston	1999	Pinched Loop	Transfer	0.7
Rome	1999	Shuttle	O/D	0.4
Detroit	2002	Shuttle	Transfer	0.7
Zurich	2003	Shuttle	O/D	0.7
Taipei	2003	Shuttle	O/D	0.8
Minn/St. Paul	2002	Shuttle	Transfer	0.5
Dallas/Fort Worth	1974, 2005	Loops	Transfer	4.9
Madrid	2006	Pinched Loop	Transfer	1.7
Paris–CDG	2007	Shuttle	O/D	0.4
Mexico City	2007	Shuttle	O/D	1.9
London LHR	2008	Shuttle	O/D	0.4
Beijing	2008	Pinched Loop	O/D	1.2
Seoul	2008	Shuttle	O/D	0.6
Washington Dulles	2010	Pinched Loop	Transfer	1.9

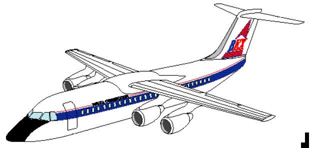
source: ACRP Report 37 (2010)

Landside Automated People Movers

Airport	Year Opened	Alignment Configuration	Service To	Length (miles)[1]
Houston	1981	Loop	Terminals	1.0[2]
London Gatwick	1987	Shuttle	Terminals, Intermodal	0.7
Tampa	1990	Pinched Loop	Parking, Car Rental	0.6
Paris–Orly	1991	Pinched Loop	Terminals, Intermodal	4.5
Chicago	1993	Pinched Loop	Terminals, Parking, Intermodal	2.7
Newark	1996	Pinched Loop	Terminals, Parking, Intermodal, Car Rental	3.2
Minneapolis/St. Paul	2001	Shuttle	Parking, Intermodal, Car Rental	0.2
Dusseldorf	2002	Pinched Loop	Parking, Intermodal	1.6
New York–JFK	2003	Pinched Loop	Terminals, Parking, Intermodal, Car Rental	8.1
Birmingham (UK)	2003	Shuttle	Intermodal	0.4
San Francisco	2003	Loops	Parking, Intermodal, Car Rental	2.8
Singapore Changi	1990/2006	Shuttles	Terminals	0.8
Toronto	2006	Shuttle	Terminals, Parking	0.9
Paris–CDG	2007	Pinched Loop	Terminals, Parking, Intermodal	2.1
Atlanta	2009	Pinched Loop	Terminal, Car Rental, and Convention Center	1.4

source: ACRP Report 37 (2010)

APM Capacity Estimation

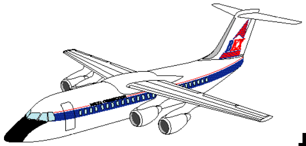


The basic equation for APM capacity usually predicated in terms of a minimum headway, h_{min}

h_{min} is usually dictated by APM station capacity since stops at stations would require between 30-45 seconds of stopped time under demanding flow conditions

h_{min} should be the least of station headway and guideway headway (this last one dictated by safety considerations) to make sure two TUs do not collide even if the leading TU stops instantaneously - brick wall analogy

APM Capacity Analysis



$$C = \frac{3600 C_v n}{h_{min}}$$

where:

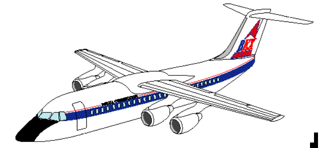
C is the hourly capacity of the APM system (passengers per hour)

C_v is the capacity of each vehicle (passengers per vehicle)

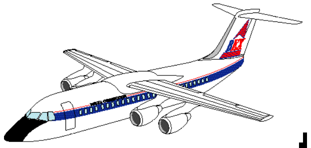
n is the number of vehicles per transit unit (in the APM)

and h_{min} is the minimum headway (seconds)

APM Capacity Fundamental Equations (Matlab Code)

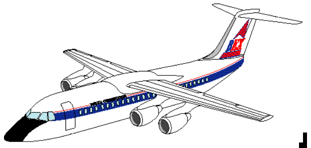


```
% Computation of APM capacity based on headway
% A. Trani (March 2000)
% Input parameters

Cv      = 40;% Capacity per vehicle
n       = 3;% Number of vehicles per TU

hlow    = 45;% Low headway (seconds)
hhigh   = 240;% High headway (seconds)
nn      = 15;% points on capacity curve
```

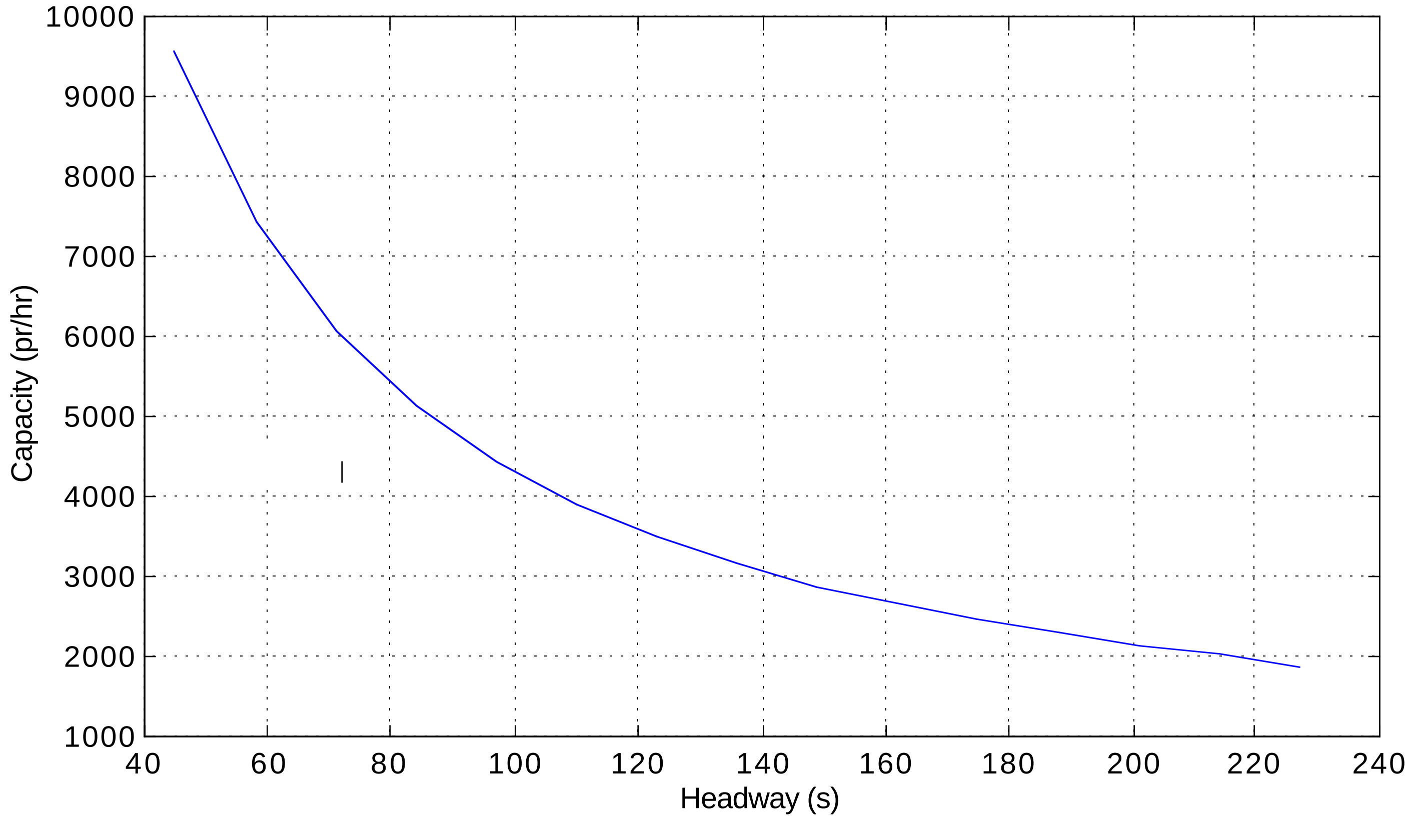


```
interval = round((hhigh-hlow)/nn);


i=1:1:nn

h(i) = hlow + interval * (i-1);

C(i) = 3600 * n * Cv ./ h(i);


plot(h,C)

xlabel('Headway (s)')

ylabel('Capacity (pr/hr)')

grid
```

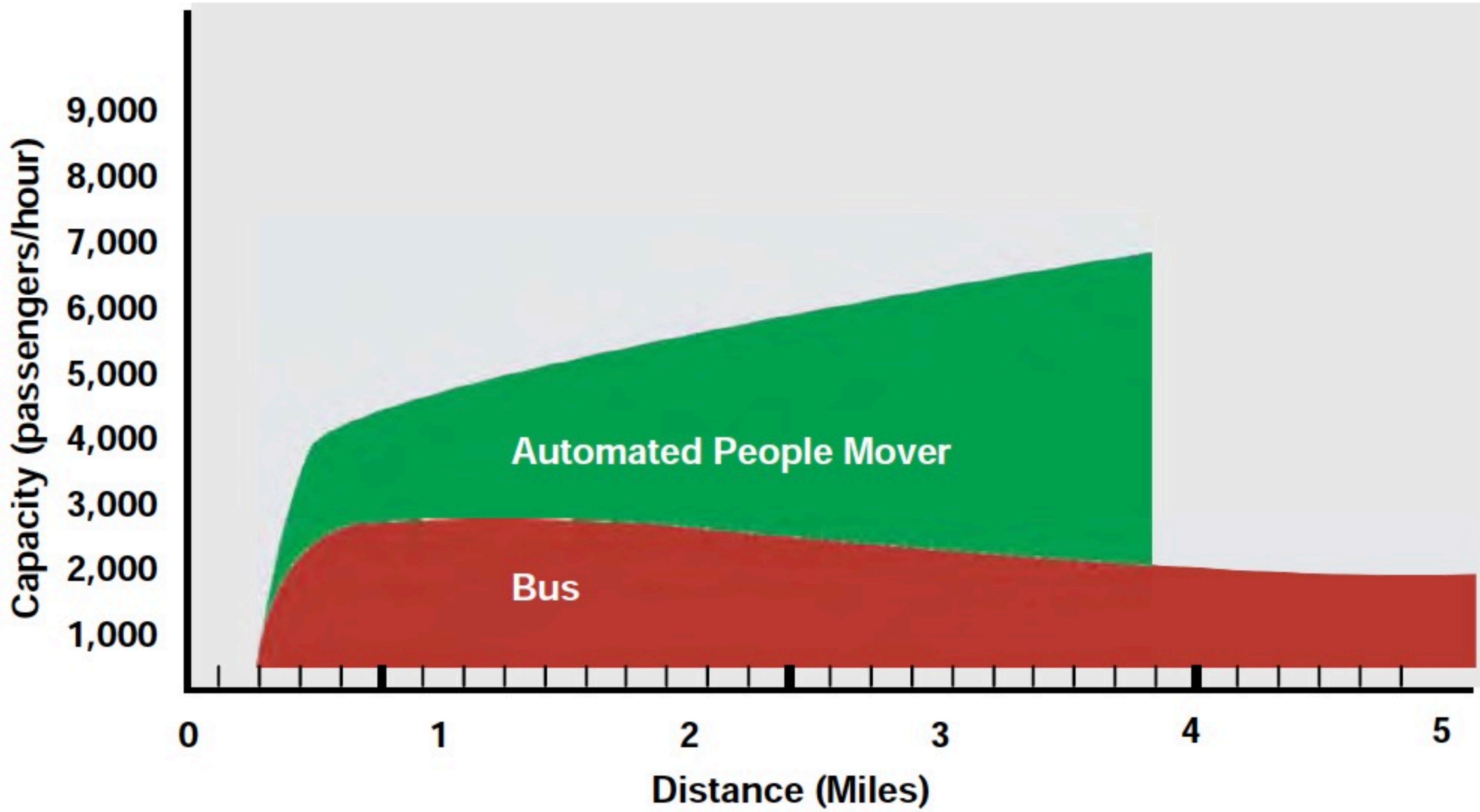
Sample APM Capacity Curve



Assumptions: n=3 vehicles/TU, Cv=40 pr/vehicle



Automated People Movers : Capacity



source: Lea + Elliott, Inc. and ACRP Report 37 (2010)

Automated People Movers : Database

Search the Airport APM System Inventory

INVENTORY OF AIRPORT APM SYSTEMS

System Name: | Supplier Name:
System Type: | Model Name:
Airport Name: City Name: | Peak Link Capacity (pphpd) Min: To Max:
Guideway Length (mi) Min: To Max: | Fleet (Cars) Min: To Max:
Guideway Length (km) Min: To Max: | Conveyance (Airside/Landside):

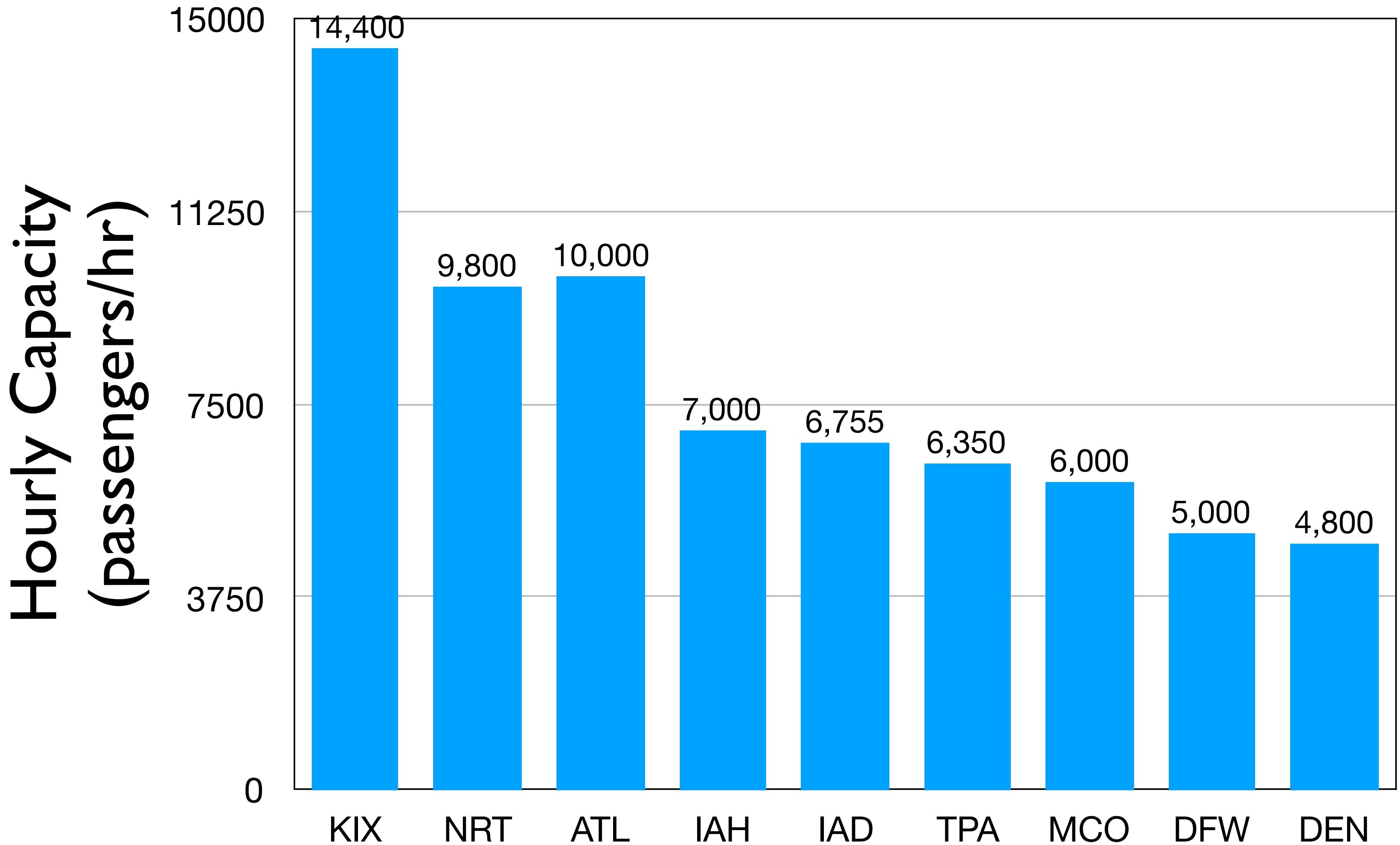
Search | Clear | View Report | Print Report | Help | Exit

City	Supplier Name	Model	System Type	Capaci	Length(mi)	Length(km)	Fleet	Conveyance
Atlanta	Mitsubishi Heavy Industries	Crystal Move	Pinched Loop, Elevatec	2,700	1.4	2.3	12	Landside
Atlanta	Bombardier	CX-100	Pinched Loop, Undergr	10,000	1	1.6	49	Airside
Beijing	Bombardier	CX-100	Pinched Loop, At-grade	4,100	1.2	2	11	Airside
Birmingham	DCC Doppelmayr	Cable Liner S	Dual Lane Shuttle, Elev	1,608	0.4	0.6	4	Landside
Chicago	Siemens	VAL 256	Pinched Loop, Primarily	2,400	2.7	4.3	15	Landside
Cincinnati	Poma-Otis	Hovair	Dual Lane Shuttle, Und	5,700	0.2	0.4	6	Airside
Dallas/Fort Worth	Bombardier	Innovia	Dual Lane Loop, Elevat	5,000	4.9	7.9	64	Airside
Denver	Bombardier	CX-100	Pinched Loop, Undergr	8,300	1.2	1.9	31	Airside
Detroit	Poma-Otis	Hovair	Single Lane Shuttle, El	4,000	0.7	1.1	4	Airside
Dulles	Mitsubishi Heavy Industries	Crystal Move	Pinched Loop, Undergr	6,755	1.5	2.3	29	Airside
Düsseldorf	Siemens	H-Bahn	Pinched Loop, Elevatec	2,000	1.6	2.5	12	Landside
Frankfurt	Bombardier	CX-100*	Pinched Loop, Elevatec	4,500	2.4	3.8	18	Airside
Hong Kong	Sumitomo/Mitsubishi & IHI/I	Crystal Move	Mixed, Underground	4,500	0.8	1.3	28	Airside
Houston	Bombardier	CX-100	Pinched Loop, Elevatec	7,000	0.7	1.2	12	Airside
Houston	Bombardier	WEDway Pe	Single Lane Loop, Und	720	2	3.2	24	Landside
Kuala Lumpur	Bombardier	CX-100**	Dual Lane Shuttle, Elev	3,000	0.8	1.3	4	Airside
Las Vegas	Bombardier	C/CX-100	Dual Lane Shuttle, Elev	6,900	0.8	1.4	10	Airside
London	Bombardier	C/CX-100	Dual Lane Shuttle, Elev	4,200	0.7	1.2	6	Landside
London	Bombardier	Innovia	Dual Lane Shuttle, Und	6,500	0.4	0.7	6	Airside

Record: 1 of 44 | Unfiltered | Search

source: Lea + Elliott, Inc. and ACRP Report 37 (2010)

Automated People Movers : Capacities

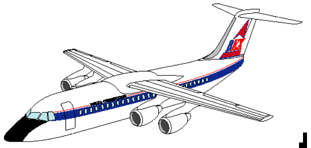


source: Lea + Elliott, Inc. and ACRP Report 37 (2010)

APM Requirements Analysis

- Level of Service Analysis
- APM Demand Analysis
- Capacity Analysis
- Flow Analysis
- Energy Consumption Analysis

References



1) Lin,Y. *A Simulation Model of an Automated People Mover at Airports*. M.S. Thesis. Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.

2) Kulkarni, M. *Development of a Landside Terminal Simulation Model*. M.S. Thesis. Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.

3) Fruin, J.J. *Designing for Pedestrians*. in Public Transportation Systems. Hoel and Gray: Editors. John Wiley and Sons, New York, 1993.

4) IATA. *Airport Development Reference Manual: 8th Edition*. International Airline Transport Association, Montreal, 1995.