대한교통학회 제32회 학술발표회

공항터미널 형태에 관한 평가 및 설계에 대한 연구

- Methodology for Design and Evaluation of Airport Terminal Configuration -

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OUTLINE

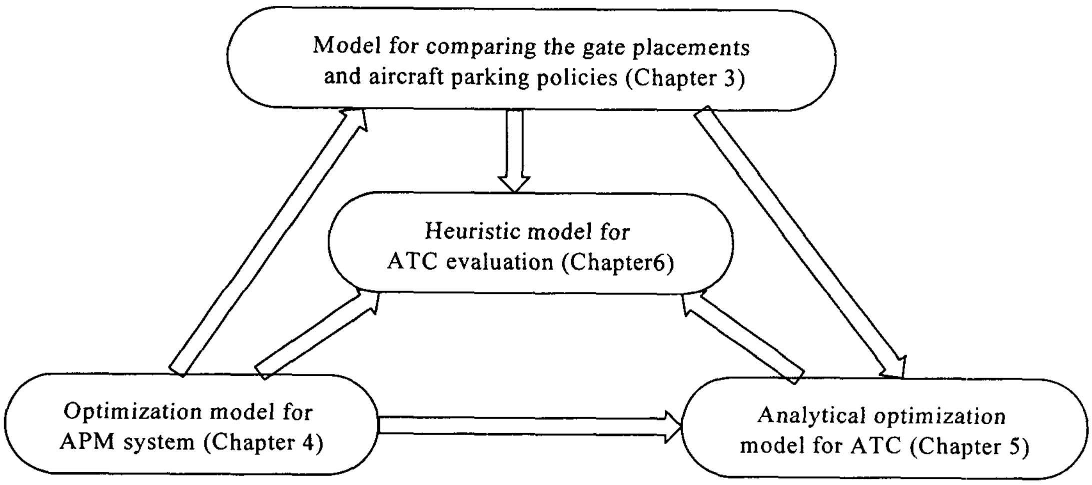
- ☐ Introduction
  - Background
  - Problem statement
  - Study objectives and scope
  - Literature review
- ☐ Model Formulation for Comparing Gate Placement and Aircraft Parking Policies
- ☐ Optimization Model for APM System
- ☐ Analytical Optimization Model for ATC
- ☐ Heuristic Method for Evaluating ATC
- ☐ Conclusions and Further Research

■ Background

- Airline Deregulation Act of 1978
- Airline companies emphasizing hub operations
- Significant traffic congestion at hub airports
- Growth of transferring traffic
- Expansion of landside and airside capacities
- New terminal configuration concepts (with APM system)

■ Questions Issued

- What kinds of airport terminal configurations (ATC) can best serve the future traffic?
- What kinds of design concepts should be applied?
- How can we evaluate and modify existing airport terminals with different kinds and levels of traffic?
- What kinds of APM system can best serve for the specific ATC.



Relation among the Proposed Models

■ Study Objectives and Scope

To develop a methodology for:

- optimizing airport terminal configuration

    - To comparatively evaluate the SCA(Smallest-aircraft Central Assignment) vs. LCA and NIP (Nose-in Parking) vs. ASP (Angled Satellite Parking)
    - To optimize Automated People Mover (APM) system
    - To develop an analytical optimization model
    - To develop a heuristic method for evaluating airport terminal configuration (ATC)

To be limited to deal with hub airports

■ Gate Placement Policies (SCA vs. LCA)

- Objective function

$$D = D_{LP} + D_{FP}$$

$$= \left(\sum_{i=1}^{n} P_{io} + \sum_{i=1}^{n} P_{oi}\right) d_{io} + \sum_{i=1}^{n} \sum_{j=1}^{n} P_{ij} d_{ij}$$

Where $D =$ Total passenger walking distance (pass.mile)

$D_{LP} =$ Local passenger walking distance

$D_{FP} =$ Transfer passenger walking distance

- SCA (Smallest aircraft Central Assignment)

- LCA (Largest aircraft Central Assignment)

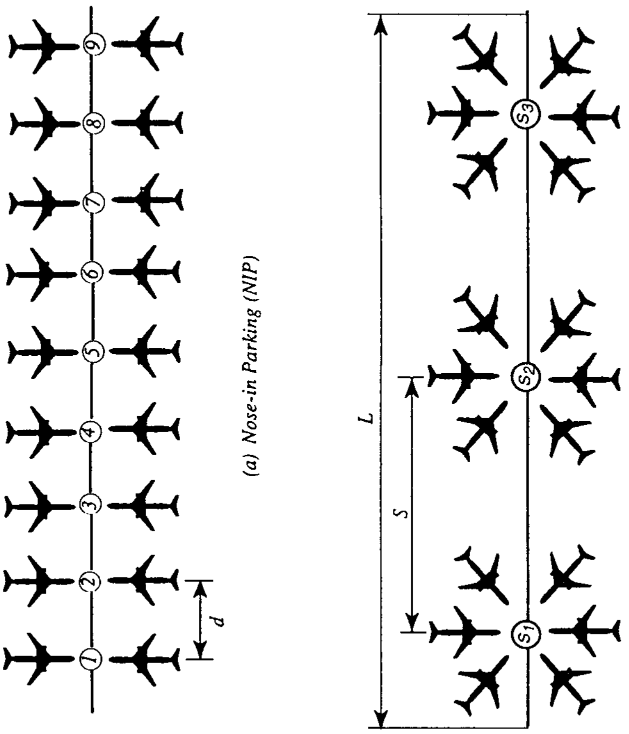
■ Aircraft Parking Policies (NIP vs. ASP)

- Objective function

$$D = D_{LP} + D_{FP}$$

- NIP (Nose-in Parking)

- ASP (Angled Satellite Parking)



(a) Nose-in Parking (NIP)

(b) Angled "satellite" Parking (ASP)

Aircraft Parking Policies

■ Optimization of APM System (One-route)

□ Objective function

$$\text{Min. } C = C_u + C_a$$
$$= C_{ux} + C_{uw} + C_{uiv} + C_{pm} + C_{ao} + C_{ac}$$

- Total cost (C), unit: $
- User cost (C_u):
  - user access cost between gate and APM station (C_{ux})
  - user waiting cost (C_{uw})
  - user in-vehicle cost (C_{uiv})
- Airport cost (C_a) ;
  - APM cost (C_{pm})
  - airport operating cost (C_{ao})
  - airport capital cost (C_{ac})

Table 4.1 Definition of Variables

Symbol	Units	Brief description	Base value
a	m/sec^2	APM acceleration.	1.3
b	m/sec^2	APM deceleration.	1.3
α	-	passenger transfer rate among hub flights	
d_{ij}	meters	distance between station i and station j.	
g_i	hours	aircraft ground time	
H	hours	headway of APM	5 minutes
i,j	-	index of APM station.	
k	-	index of station spacing.	
l	-	number of satellites	
L	meters	terminal or pier length	
L_k	meters	k[th] pier length	
M	car	number of cars in APM	
m	-	number of APM stations in terminal	
n	-	total number of gates	
p	$/meter.hour	airport operating cost(constant)	
q	$/meter.hour	airport capital cost (constant)	
P_{ij}	pass.	number of passengers from station i to station j.	
r		number of piers	
S_r	pass.	aircraft seat size	
s_k	meters	spacing between stations	
T	hours	time slot of hub operations	3 or 4
t_{ax}	hours	passenger access time from gate to station	
t_{bx}	hours	passenger access time from station to gate	
t_d	hours	APM dwell time at station.	30secs
u	km/hour	passenger walking speed	4
v	km/hour	APM travel speed.	40
V_c	$/car.hour	vehicle operation cost	100
V_g	$/seat.hour	ground time value of aircraft	
V_{in}	$/pass.hour	value of user in-vehicle time.	15
V_x	$/pass.hour	value of user access time	30
V_w	$/pass.hour	value of user waiting time	30

■ Optimization of APM System (One-route)

♦ **Objective function**

$$Min.C = 2\sum_{i=0}^{m}\sum_{j=0}^{m} P_{ij} t_{ax} V_x + \sum_{i=0}^{m}\sum_{j=0}^{m} P_{ij}(\frac{H}{2})V_w + \sum_{i=0}^{m}\sum_{j=0}^{m} P_{ij}[\frac{d_{ij}}{v} + |j-i|(\frac{v}{a}) + |j-i|t_d]V_{in}$$

$$+ \sum_{k=1}^{m-1}(\frac{s_k}{v} + \frac{v}{a} + t_d)(\frac{2M}{H})V_c + (p+q)\sum_{k=0}^{r} L_k$$

♦ **Objective function without cruise**

$$Min.C = 2\sum_{i=0}^{m}\sum_{j=0}^{m} P_{ij} t_{ax} V_x + \sum_{i=0}^{m}\sum_{j=0}^{m} P_{ij}(\frac{H}{2})V_w + \sum_{i=0}^{m}\sum_{j=0}^{m} P_{ij}(2\sqrt{\frac{d_{ij}}{a}} + |j-i|t_d)V_{in}$$

$$+ \sum_{k=1}^{m-1}(2\sqrt{\frac{s_k}{a}} + t_d)\frac{2M}{H}V_c + (p+q)\sum_{k=0}^{r} L_k$$

■ Optimization of APM System (One-route)

- ∂C/∂v=0,

$$v^* = \sqrt{\frac{\sum_{i=1}^{m}\sum_{j=1}^{m} P_{ij} d_{ij} V_{in} + 2\sum_{k=1}^{m-1} S_k(\frac{M}{H})V_c}{\sum_{i=1}^{m}\sum_{j=1}^{m} P_{ij}|j-i|\frac{1}{a}V_{in} + 2\sum_{k=1}^{m-1}\frac{M}{aH}V_c}}$$

- ∂C/∂H=0,

$$H^* = \sqrt{\frac{4\sum_{k=1}^{m-1}(\frac{s_k}{v} + \frac{v}{a} + t_d)MV_c}{\sum_{i=1}^{m}\sum_{j=1}^{m} P_{ij} V_w}}$$

♦ Objective function without APM

$$D = D_{LP} + D_{FPI} + D_{FPO}$$
$$= \sum\sum P_{ij}\, d_{ij}$$

$$D=2(1-\alpha)Q[b+\frac{x}{4}+\frac{(n-1)s}{2}]+\alpha\frac{Q}{n}(\frac{x}{3})+\alpha(1-\frac{1}{n})Q[\frac{s(n+1)}{3}+\frac{x}{2}]$$

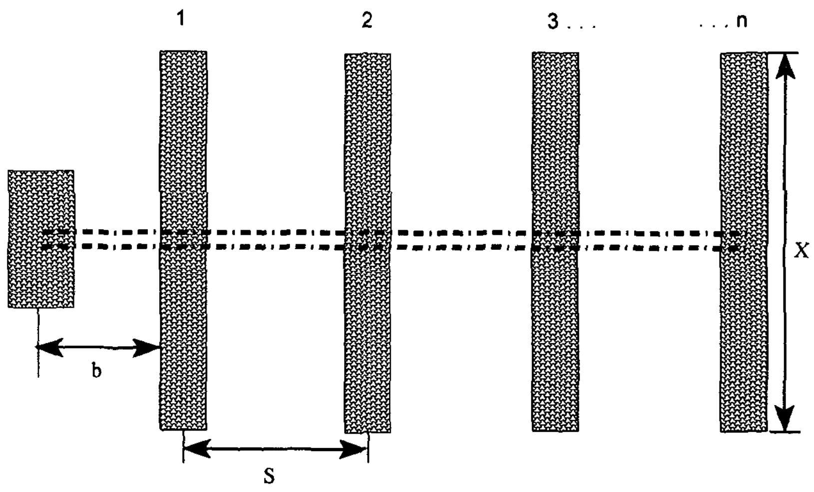


Figure 5.1 Parallel Pier Type Airport Terminal Configuration

Figure 5.5a Average Cost for Various Transfer Rates

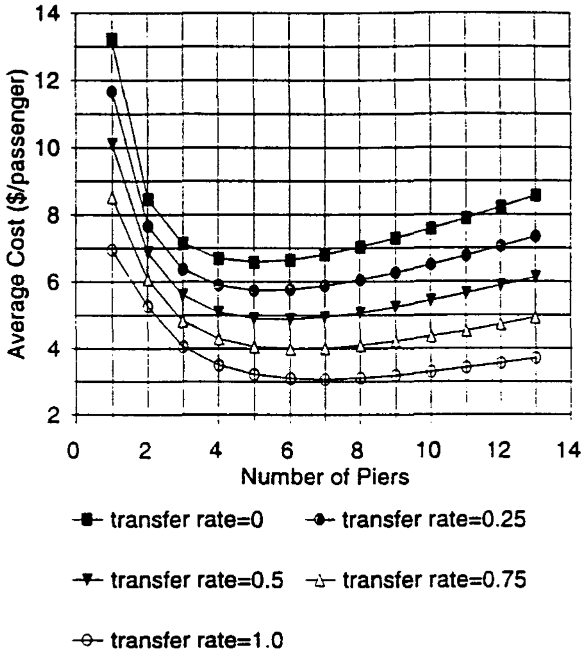
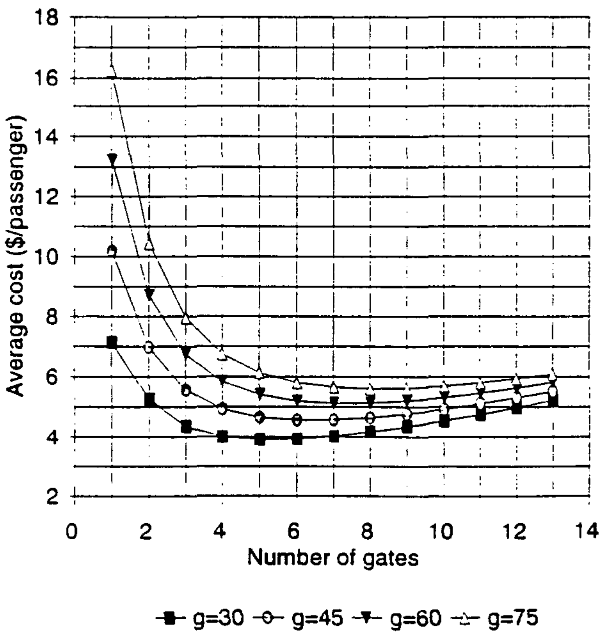


Figure 5.5b Average Cost for Various Gate Sizes



♦ Objective function with APM

$$C=C_u + C_{ap}$$

$$C=2(1-\alpha)Q[\frac{x}{4}\frac{V_x}{u}+((b+\frac{(n-1)s}{2})\frac{1}{v}+\frac{(n+1)}{2}(\frac{v}{a}+t_d))V_{in}+\frac{H}{2}V_w]+\alpha\frac{Q}{n}(\frac{x}{3})\frac{V_x}{u}$$

$$+\alpha\frac{Q}{n}[(\frac{s}{v}+\frac{v}{a}+t_d)\frac{(n^2-1)}{3}V_{in}+\frac{(n-1)x}{2}\frac{V_x}{u}+\frac{H}{2}V_w]$$

$$+[\frac{(n-1)s+b}{v}+n(\frac{v}{a}+t_d)](\frac{2M}{H})V_c+n(p+q)x$$

- $\partial C/\partial x = 0, \Rightarrow x^*, n^*$

Numerical examples

Optimal number of piers (n*) and pier length (x*)

Case	Trans-fer Rate (α)	No. of Gates (G)	Spacing, m, (s)	Gate Size,m (g)	Distan-ce,m (b)†	Opt. No. Of Piers (n*)	Opt. Pier Length m, (X*)	Average Cost,$ (C)
1	0	250	200	50	0	8	781.25	8.27
2	0.5	250	200	50	0	9	694.44	6.31
3	1.0	250	200	50	0	11	568.18	4.24
4	0.5	200	250	45	100	8	562.5	5.76
5	0.5	100	350	50	100	5	500.0	4.86
6	0.7	200	350	50	100	8	625.0	5.48
7	0.7	300	250	50	0	10	750.0	6.13
8	0.3	200	250	50	0	8	625.0	6.71
9	0.1	250	200	50	0	8	781.25	7.89
Atlanta	.65	138	305	40	0	6(5†)	460.0	4.35
Denver	.6	107	450	40	170	5(3†)	428.0	4.45

♦ Case Study

Evaluation Results for ATC without APM System (60 gates case)

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	ATC of BWI
Number of gates	60	60	60	60	60	60 (58)
ATC Type	linear (2 sides)	2-parallel piers	2-parallel piers	3-parallel piers	3-finger	5-finger
Total Cost (pass.m)	120,855	103,288	102,567	109,321	130,847	104,717 (130,747)

■ Heuristic Method for Evaluating ATC without APM

♦ Development of Model

♦ Objective Function

$$D = D_{LP} + D_{FP}$$

♦ Case Studies

- 20 gates case

- 60 gates case

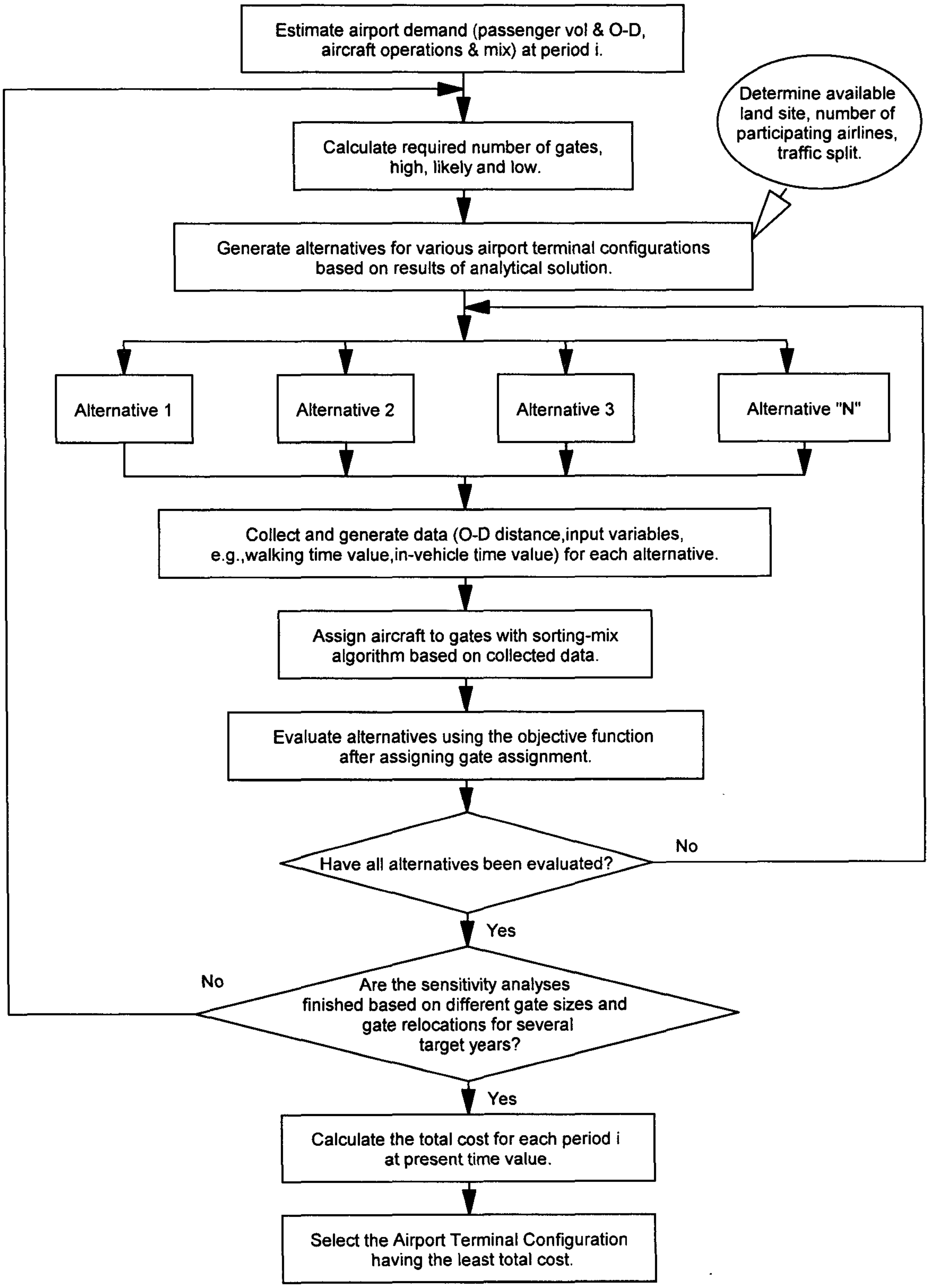


Figure 6.1 Heuristic Method for Evaluating Airport Terminal Configurations

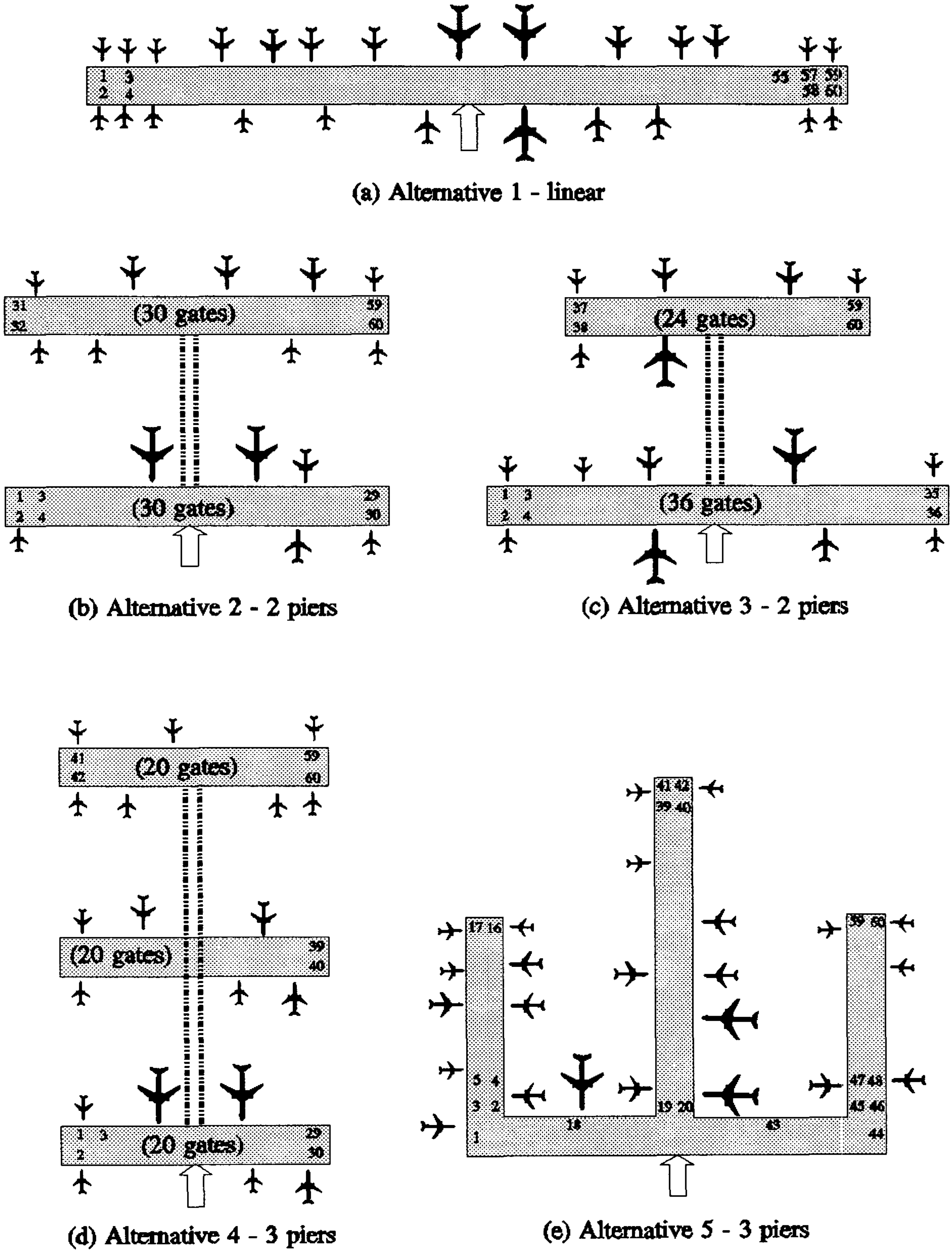


Figure 6.3 Alternatives for APC without or with APM System (60 gates)

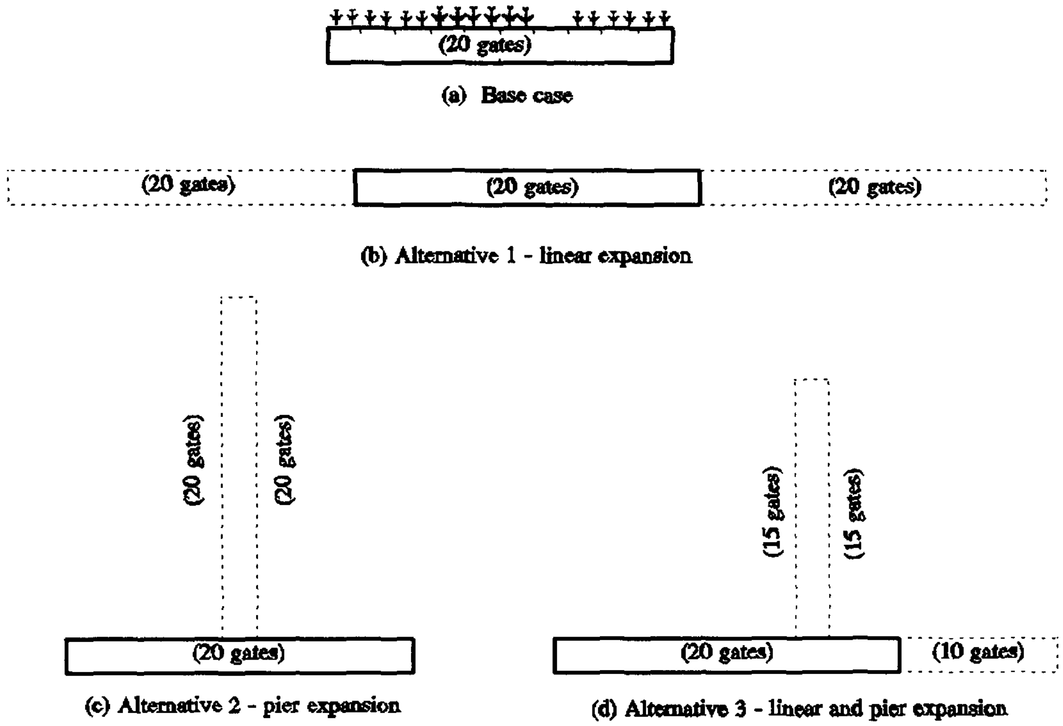


Figure 6.4 Alternatives for Expansion of Existing Airport Terminal

■ Heuristic Method for Evaluating ATC with APM

♦ Objective Function

Min. Total cost = User cost + Supplier cost

$$\text{Min. } C=(C_{ux} + C_{uw} + C_{v}) + (C_{PM} + C_{SM} + C_{SC})$$

♦ Case study

Evaluation Results for ATC with APM System (60 gates case)

	Alternative 2	**Alternative 3**	**Alternative 4**
Number of Gates	60	60	60
ATC Type	2-pier parallel	2 different pier parallel	3-pier parallel
Total Cost ($)	15,723.09	15,506.98	16,595.12

Heuristic Method for Evaluating the Existing Airport Terminals

♦ Objective Function

$$D = D_{LP} + D_{FP}$$

♦ Case study

Evaluation Results for Expansion (40 gates) of Existing AT(20 gates)

	Base Case	**Alternative 1**	**Alternative 2**	**Alternative 3**
Number of Gates	(20)	20+(20)+20	(20)+20+20	(20)+10+15+15
Expansion of ATC	linear type	linear expansion	pier expansion	linear and pier expansion
Total Cost		241,655	151,246	149,672

■ Conclusions

- Comparisons for Gate Placements (LCA and SCA) and Aircraft Parking Policies (NIP and ASP).
  - The LCA is superior to the SCA in hub operations.
  - The ASP is a better parking policy than the NIP, when APM or side walk system is operating.
  - The LCA with flight sequencing is superior to the SCA.
- Optimization Models for APM System.
  - The optimal headway is proportional to the square root of the vehicle round trip operating cost, and is inversely proportional to the square root of the passenger waiting time value.
  - The optimal speed is proportional to the square root of the APM route length and acceleration.
  - The optimal route spacing is proportional to the square root of the vehicle round trip operating cost and inversely proportional to the square root of the passenger access walking cost.

■ Conclusions (continued)

- Analytical optimization models for ATC

  The optimal number of piers:
  - Increases as passenger transfer rate, required number of gates and gate size increase for ATC w/o APM.
  - Increase as the APM headway, ratio of the user access value to in-vehicle value for ATC with APM.
  - Is sensitive to the ratio of the user access to in-vehicle time value, however is not sensitive to the speed and acceleration of APM.

  The optimal configurations is compact square ... & elongated rectangular....
- Heuristic model for evaluating an ATC
  - A linear ATC is the best for a small airport and an ATC with unequal parallel piers is the best for large airport.
  - Results of analytical optimization model can be a preliminary input for a heuristic method.
  - The proposed heuristic model can evaluate: the expansion of existing airport terminals, other type of ATC, pier finger or satellite type.

Future Research

- Short term research
  - Non-uniform passenger demand density along pier for multi-route APM system.
  - Analytical optimization model for ATC with multi-route APM
  - Improvement of gate assignment model
  - Flight sequencing can be considered in ATC
- Long term research
  - Apply to other modes such as bus terminal configurations, truck terminals and rail transfer stations.
  - Consider runway configurations, taxiway distance and airport ground access system.
  - When and how can an APM system be added to an existing airport terminal.

Contributions

- Provide the guidance to the planner and designer about the gate placement and parking policies
- Prove the superiority of LCA in specified conditions
- Optimize the APM headway, speed and number of routes in specific ATC.
- Optimize the parallel pier ATC analytically with and without APM
- Evaluate a more complex ATC with heuristic method
- Evaluate expansion options for an existing ATC