南京航空航天大学
Nanjing University of Aeronautics and Astronautics

Departure Scheduling in a Multi-airport System

Yanjun Wang, Minghua Hu
Nanjing University of Aeronautics and Astronautics
wangyj@nuaa.edu.cn, minghuahu@263.net

Contents

Contents

Why a departure scheduling?

- **The runway system capacity is one of the major constraints in the air transport system.**

- **Two ways to enhance the runway operation performance:**
  - Building new runways. It is expensive and sometime impossible.
  - Improving runway operations. The task is to optimally utilize runway capacity.

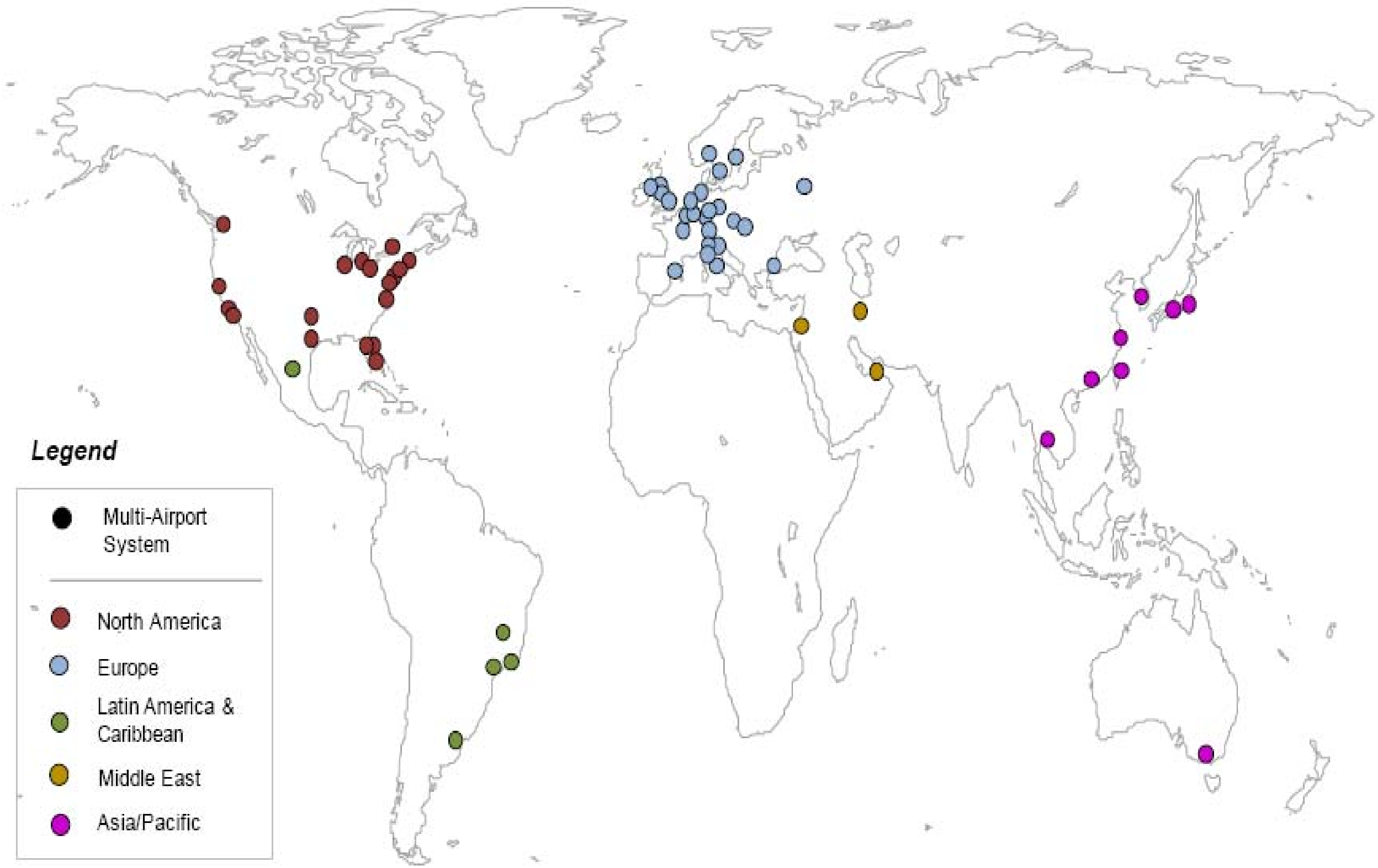
Why a multi-airport system?

- **The previous studies mainly focused on a single airport departure scheduling. (Bolender 2000, Atkin et al. 2007, Balakrishnan et al, 2007)**

- **A multi-airport system is : a set of significant airports that serve commercial transport in a metropolitan region, without regard to ownership or political control of the individual airport. (R. de Neufville, and A. Odoni, 2003)**

- **"The transition from single-airport to multi-airport systems is and will remain a key mechanism by which the air transportation system scales and will meet growing demand in the future." (P. A. Bonnefoy and R. J. Hansman, 2008)**

Multi-airport systems in the world



Geographical distribution of multi-airport systems worldwide (cite from Bonnefoy et al.)

Objective

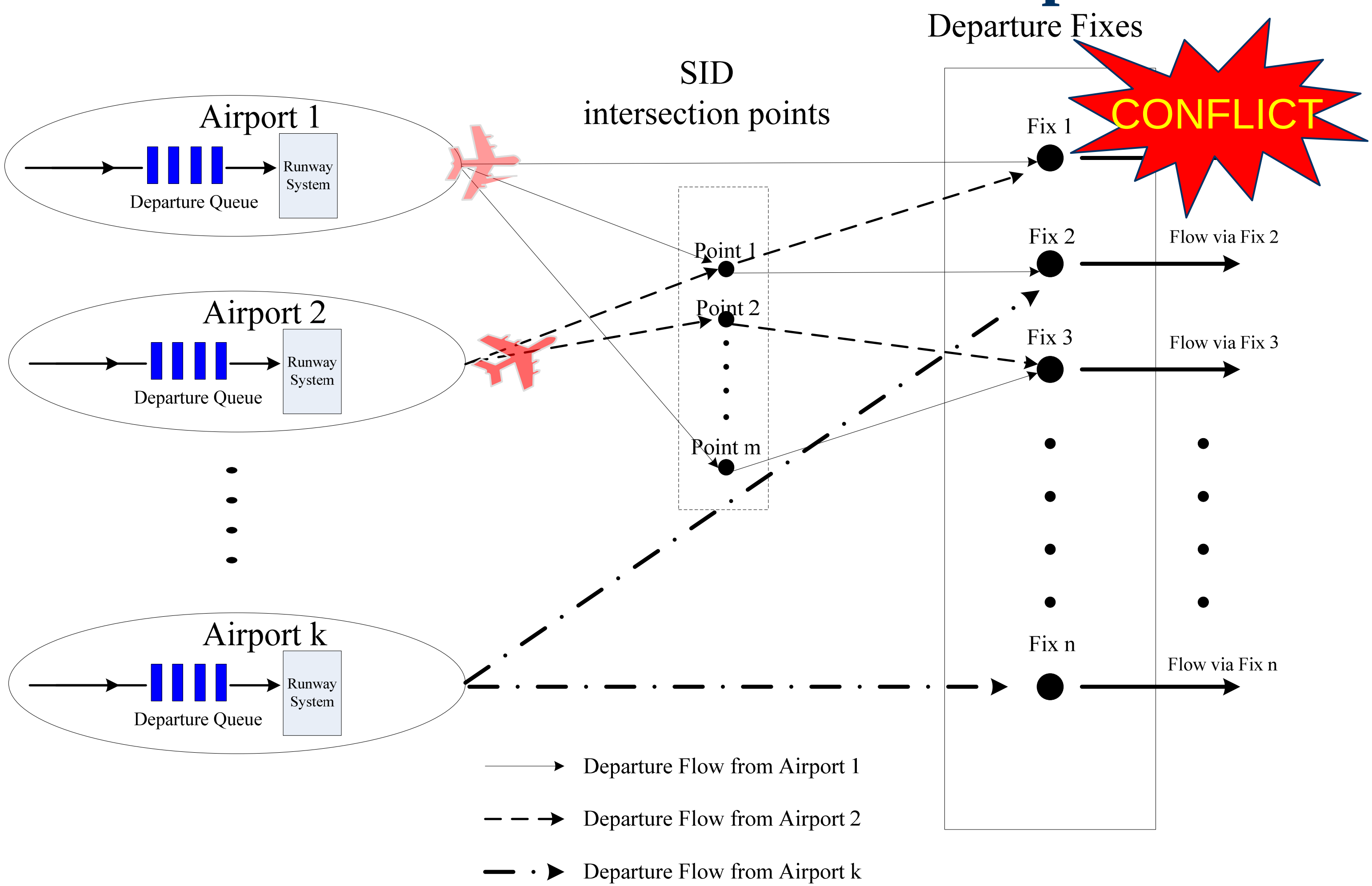
- **The purpose of departure scheduling in multi-airport is to determine an optimal sequence and takeoff time under different objectives.**
  - maximizing the runway/terminal throughput
  - minimizing the average delay
  - ensuring airlines’ or airports’ equities
  - Others……

Contents

Departure constraints

- A. Minimum Takeoff Separation
- B. Departure Time Window
- C. Position Shift Constraints
- D. Multi-runway Operation

E. Traffic Interaction between Airports



Contents

Constraints of scheduling model

$$d_i \geq e_i \quad \text{for all } i \in FL$$

$$d_i = e_i \quad \text{if } c_i = 1,\ i \in FL$$

$$d_j \geq \max_{i \in FL | c_i < c_j, a_i = a_j} (d_i + S_{ij})$$

$$b_i \leq d_i \leq l_i \quad i \in F^c$$

$$| c_i^j - o_i^j | \leq k \quad \text{for all } i \in F_j^a, j \in AD$$

$$\begin{cases} \left| (d_i + t_i^p) - (d_j + t_j^p) \right| \geq \tau^p \\ i, j \in FL, p \in PT \mid c_i > c_j, p_i = p_j = p \end{cases}$$

Objective function of the model

Objective function of Model I:

$$J^{I}(d_i) = \frac{\sum_{i \in FL}(d_i - t_i)}{N}$$

The average delay of airport j:

$$D_j^a = \frac{\sum_{i \in F_j^a}(d_i - t_i)}{N_j^a}$$

Objective function of Model II:

$$J^{II}(d_i) = J^{I}(d_i) + \sum_{j \in AD} \left| D_j^a - J^{I}(d_i) \right|^{\alpha_j}$$

Solution to the problem

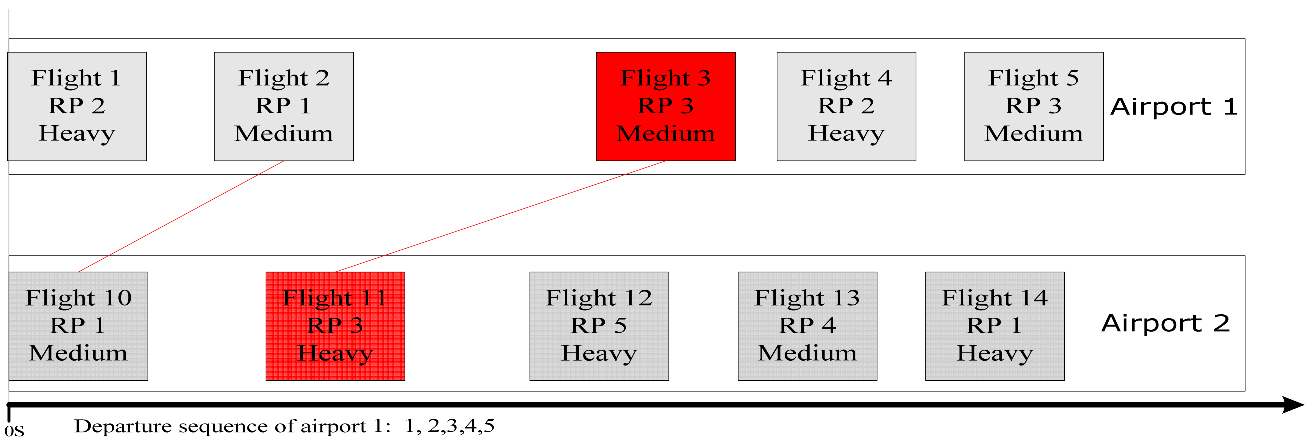
- **Aircraft scheduling problem is known as an NP-hard problem.**

- **Various algorithms have been developed to solve this problem, such as GA algorithms (Xiao-bing Hu et al. 2005, 2008), dynamic programming based approach (Balakrishnan et al.,2006, 2007)**

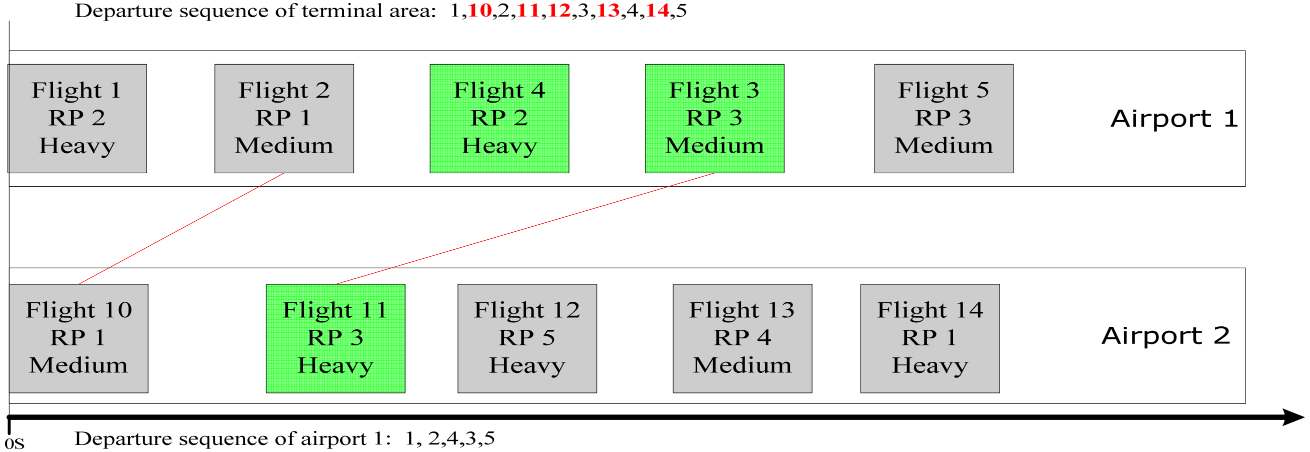
A tabu search (TS) algorithm

- **There are five essentials of the TS algorithm:**
  - (1) Initial solution;
  - (2) Neighborhood searching;
  - (3) Tabu list;
  - (4) Measuring function;
  - (5) Stop condition.

- **A sequence in order of ascending ETD with several adjustments will be the starting point for TS.**

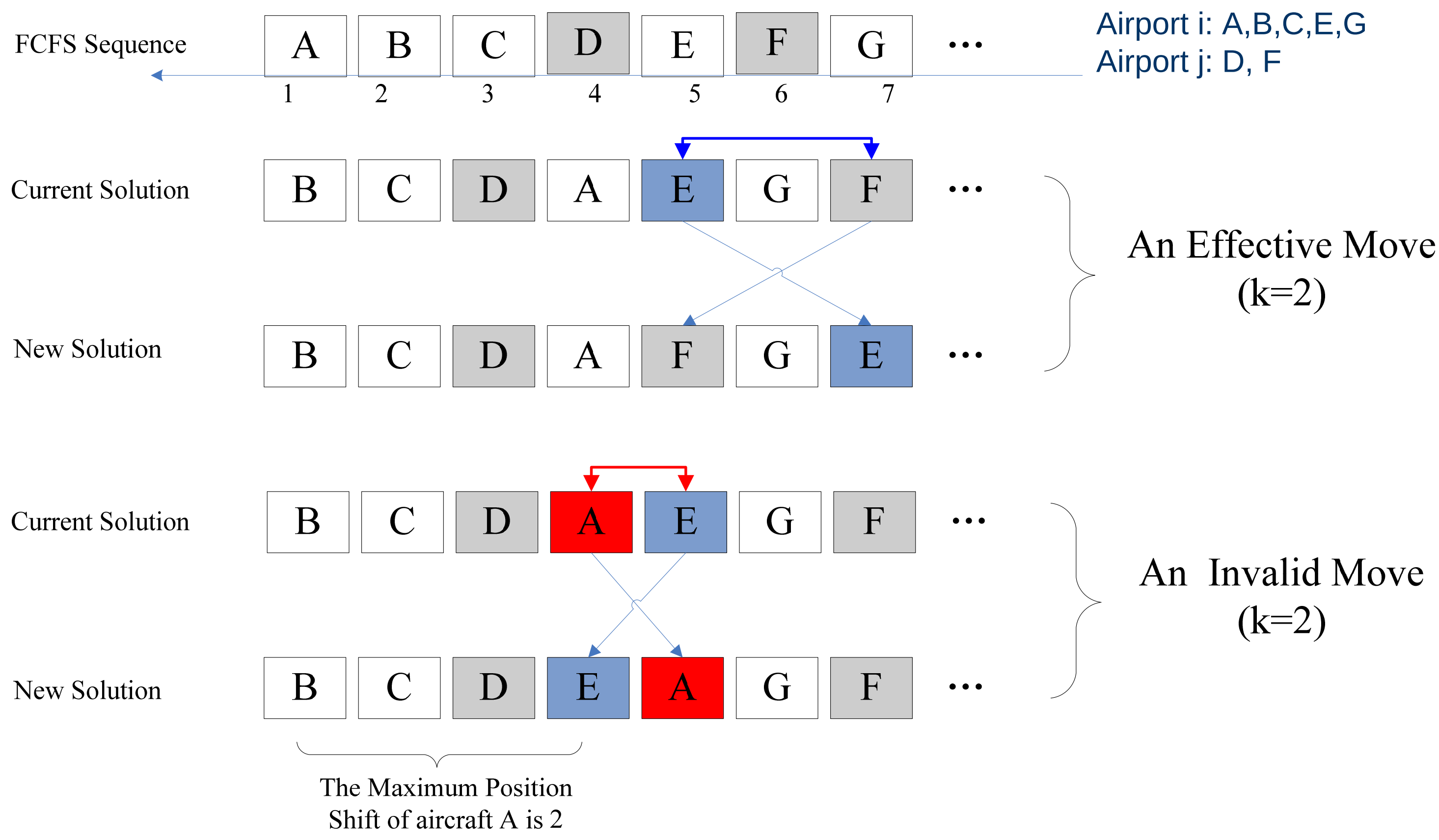


Departure sequence of airport 1: 1, 2,3,4,5
Departure sequence of airport 2: 10,11,12,13,14
Departure sequence of terminal area: 1,**10**,2,**11**,**12**,3,**13**,4,**14**,5



Departure sequence of airport 1: 1, 2,4,3,5
Departure sequence of airport 2: 10,11,12,13,14
Departure sequence of terminal area: 1,**10**,2,**11**,4,**12**,3,**13**,**14**,5

- **A neighbor is generated by swapping the positions of two aircraft in *X* while complying with the CPS.**



(3) Tabu List

- **The last 20 moves of each aircraft are stored in the tabu list.**

- **Two aspiration criteria :**
  - when all solutions in candidate set are forbidden, then the solution with minimal objective value is chosen to unbind.
  - Although one solution is forbidden but its measuring function value is better than the value of the current best solution, then this solution can be unbound and return to the candidate set.

(4) Measuring Function

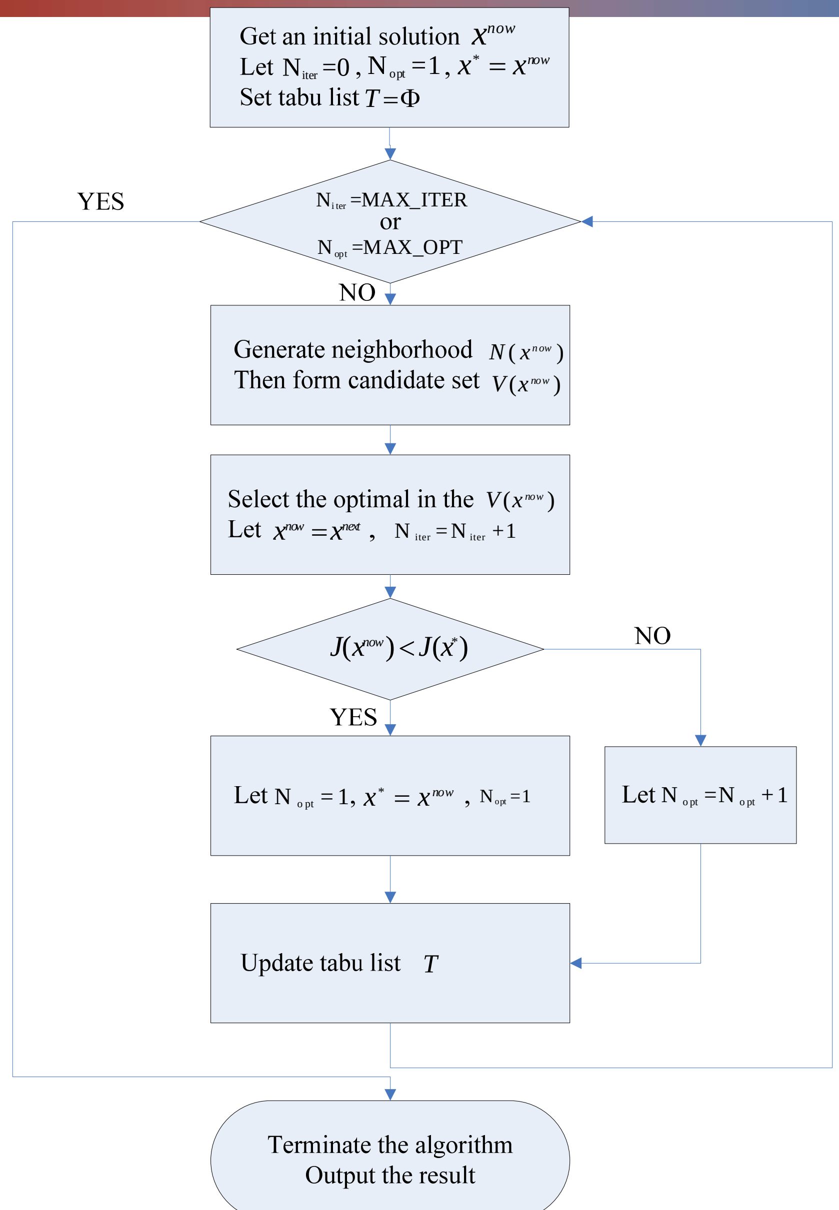
- **A new starting point will be selected from candidate set through the measuring function.**
  - We take the objective function as the measuring function.

(5) Stop Condition

- **Condition 1: the algorithm has run for a predetermined number of iterative steps MAX_ITER.**

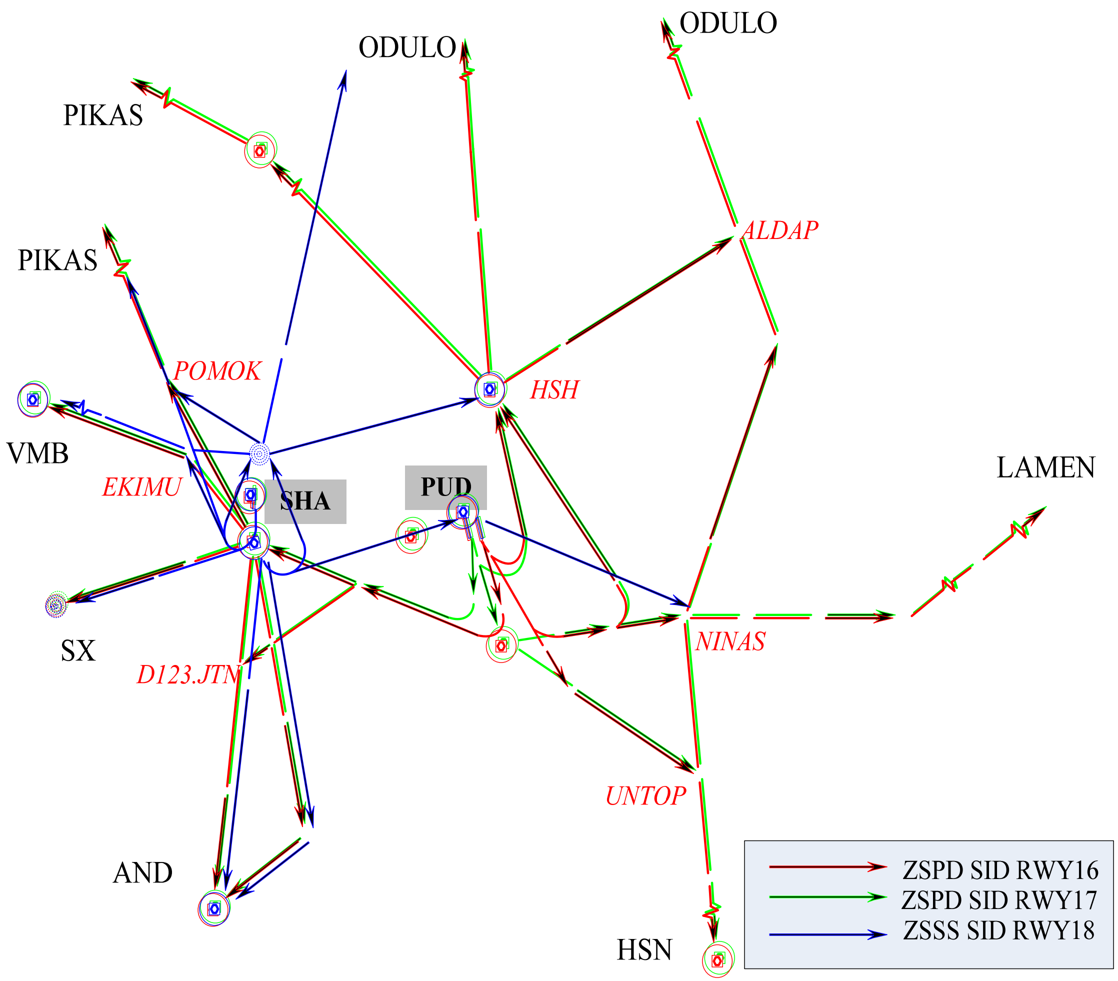
- **Condition 2: the objective value does not decrease in limited steps MAX_OPT.**

(6) The Algorithm Procedure



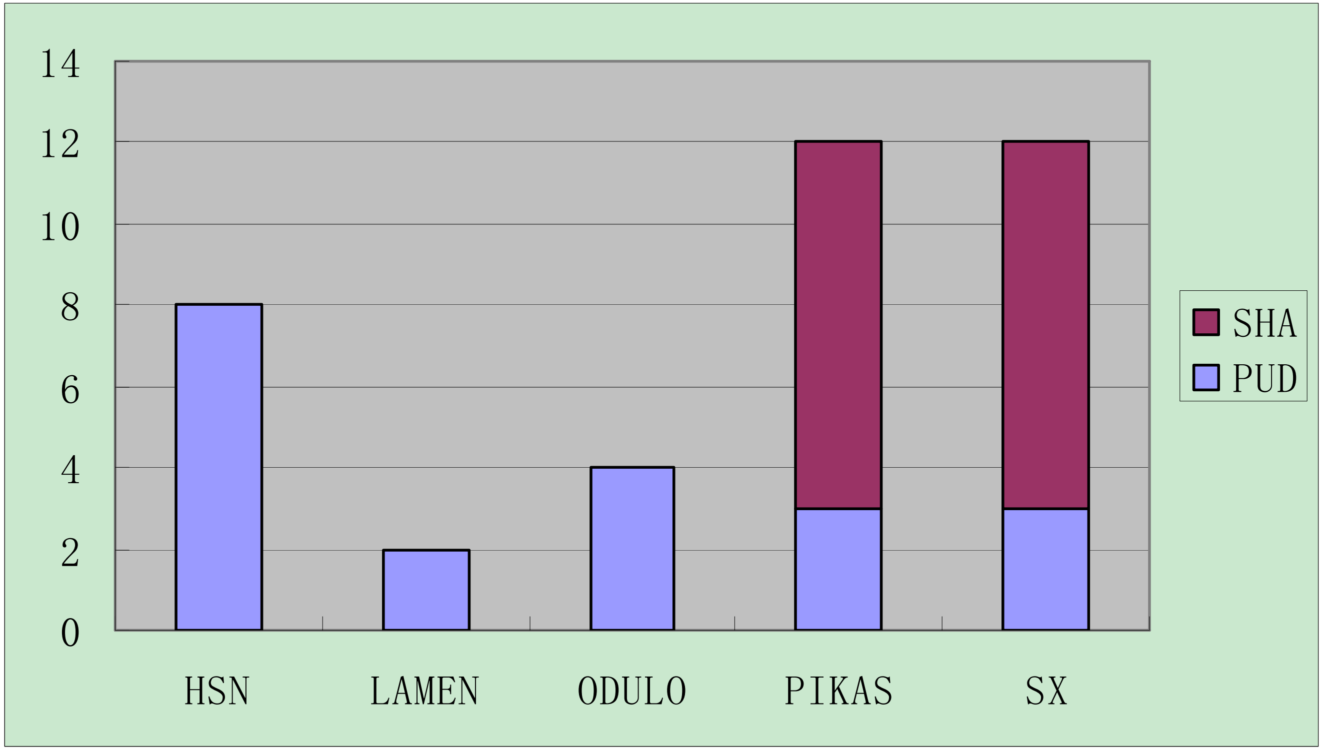
Contents

Scenario: the Shanghai Terminal Area



Input data

- **Flight data used in the experiment was drawn from the Operations Management Centre of Air Traffic Management Bureau, CAAC.**



Statistics result on number of departure flights from 15:00 to 16:00

Separation requirements

- **The minimum runway separation is 2 minutes as all aircraft types in experiment are either heavy or medium.**

Minute-In-Trail requirement at departure fixes

Fix	Minute-In-Trail Separation
HSN	Flights to Hong Kong and Macao require an 8 minutes distance; others 5 minutes
PIKAS	7 minutes
SX	Flights which depart from the same airport require a 7 minutes distance； otherwise 3 minutes
ODULO	8 minutes
LAMEN	5 minutes

Three cases

- **Case A: PUD is open while SHA is closed.**
- **Case B: SHA is open while PUD is closed.**
- **Case C: Both PUD and SHA are open during the period.**

Average flight delay

Comparative results on aircraft delay under different cases and policies
(in minute per aircraft)

Fix/Airport	Case A		Case B		Case C	
	FCFS	Model I.	FCFS	Model I.	FCFS	Model I.
HSN	7	1	—	—	18.375	8
LAMEN	4	4	—	—	14.5	7
ODULO	7	10.5	—	—	14.5	11.75
PIKAS	5.67	1.33	20	5.44	**27.17**	**12.92**
SX	4.33	1.67	19.44	12.56	**23.58**	**15.5**
ZSPD	6.1	2.95	—	—	15.95	10.25
ZSSS	—	—	19.72	9	29.11	14.5
Terminal	6.1	2.95	19.72	9	22.18	12.26

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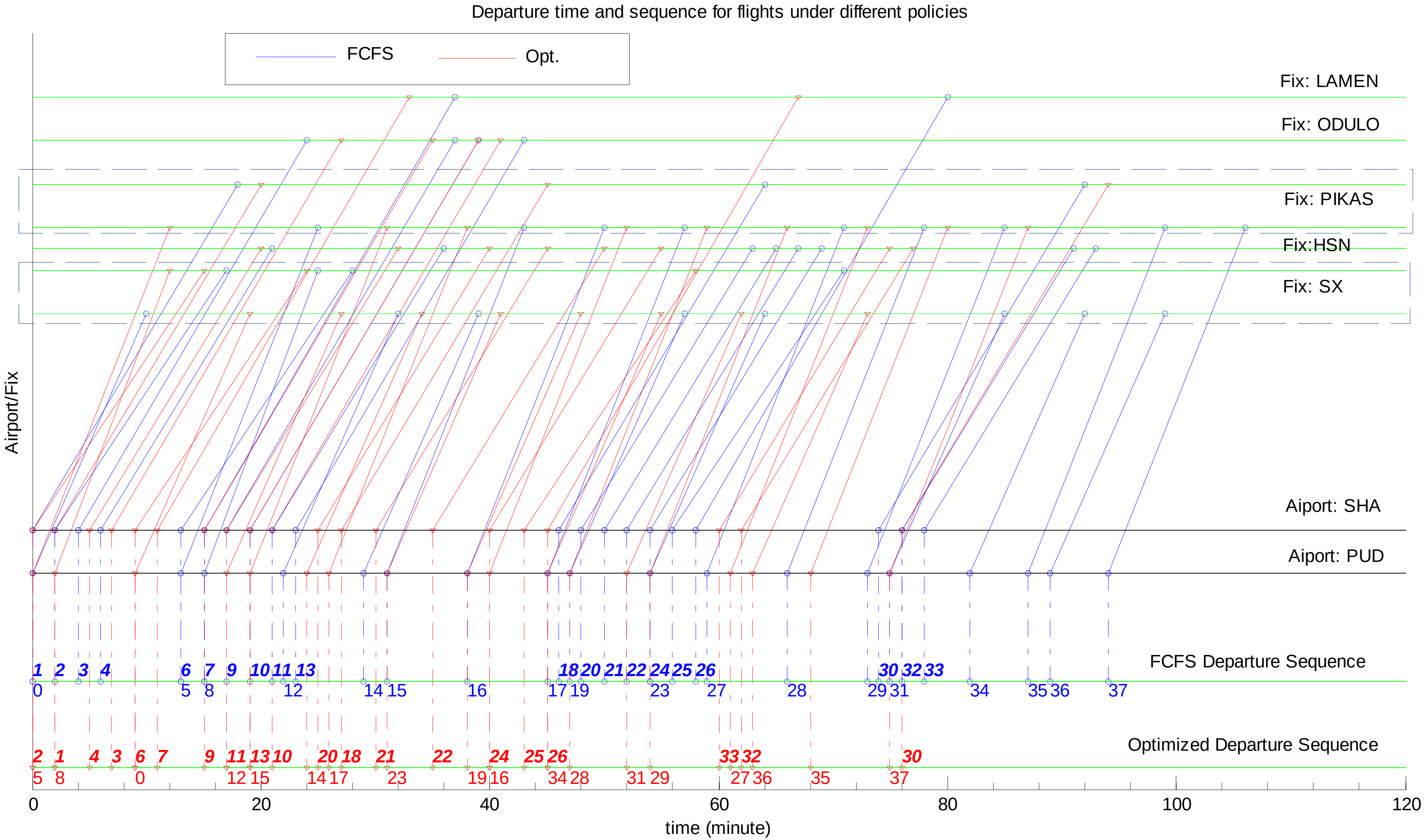
Average time intervals

Fix/Airport	Case A		Case B		Case C	
	FCFS	Model I.	FCFS	Model I.	FCFS	Model I.
HSN	8.43	8.43	—	—	9.43	8.57
LAMEN	41	35	—	—	25	24.5
ODULO	9	15	—	—	12.33	14
PIKAS	**27**	**23**	**9.75**	**7.25**	**8**	**7.09**
SX	**22.5**	**21**	**9.75**	**7.75**	**8.09**	**5.82**
ZSPD	3.42	3.42	—	—	4.26	3.78
ZSSS	—	—	4.71	3.65	5.53	4.18

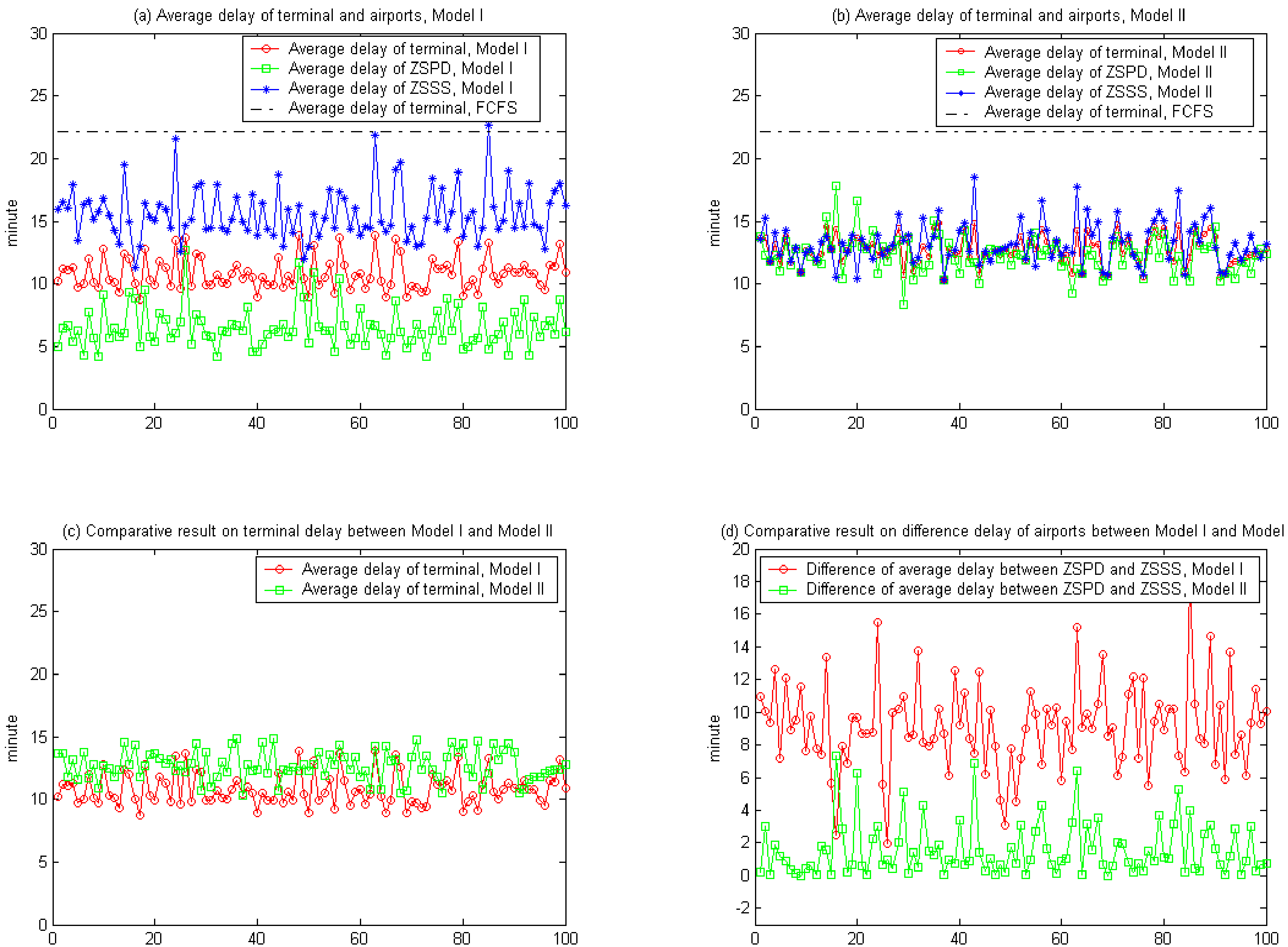
Time intervals at PIKAS & SX

	PIKAS		SX	
	FCFS	Model I	FCFS	Model I
1	7	8	7	3
2	**18**	7	8	4
3	7	7	3	8
4	7	7	4	7
5	7	7	7	8
6	7	7	**18**	6
7	7	7	7	7
8	7	7	**16**	7
9	7	7	5	7
10	7	7	7	3
11	7	7	7	4
Average	**8**	**7.09**	**8.09**	**5.82**

Departure time and sequence



Comparison of Model I and Model II



Contents

- Ⅰ. Motivation & objectives
- Ⅱ. Operational constraints of a multi-airport departure scheduling
- Ⅲ. Mathematical model & algorithm
- Ⅳ. Experimental results
- **Ⅴ. Conclusions**

Conclusions

- The limited capacity of departure fixes is the main factor confining the growth of departure flow in multi-airport system.
- Optimizing the utilization of the shared departure fixes will result in an enhancement of terminal capacity.
- Interaction of departure traffic between airports can bring the inequality among airports. Fortunately this can be eliminated by a reasonable departure control strategy.

Future Research

- **Some improvement to the departure scheduling may be including the airliners' preferences in the model.**

- **Integrating the scheduling of departure and arrival flows in terminal area will be another challenging aspect in ATFM field.**

Thank You！