一般財団法人　運輸総合研究所
研究報告会 2017年秋（第42回）

空港発着枠の最適配分に関する研究 -福岡空港を対象とした分析-

Analysis of Optimal Slot Allocation Problem for Fukuoka Airport

総合研究部
研究員 TIRTOM Huseyin

Contents

Contents

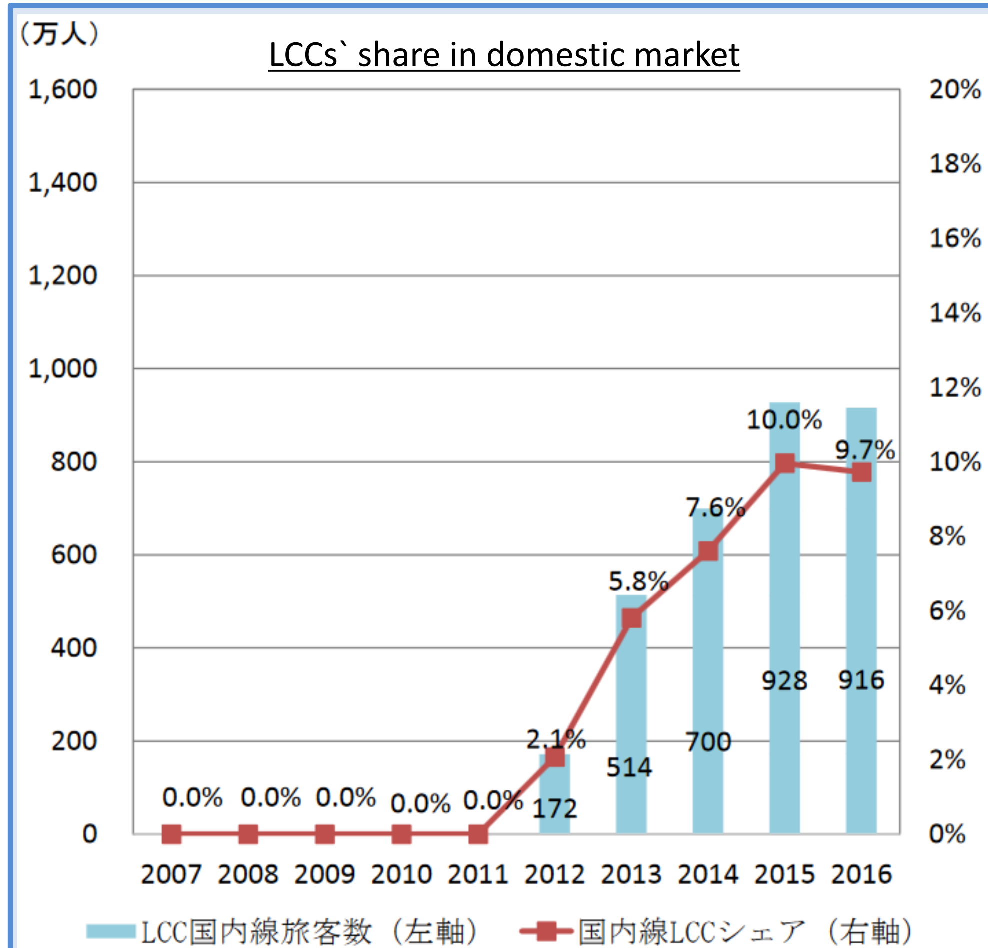
Introduction

What is LCC?

- A Low Cost Carrier is an airline that generally has lower fares with less comforts
- Studies indicated that LCC growth may increase Consumer Surplus
- Airport managers and local governments welcome LCC development as they generate new traffic in most cases
- Japanese Government also supports LCC development to stimulate air travel demand, increase tourist numbers and enhance regional economies.

Introduction LCC Growth in Japan

- In Japan, LCCs started as late as 2012, but managed a high growth rate and gained ~10% market share.



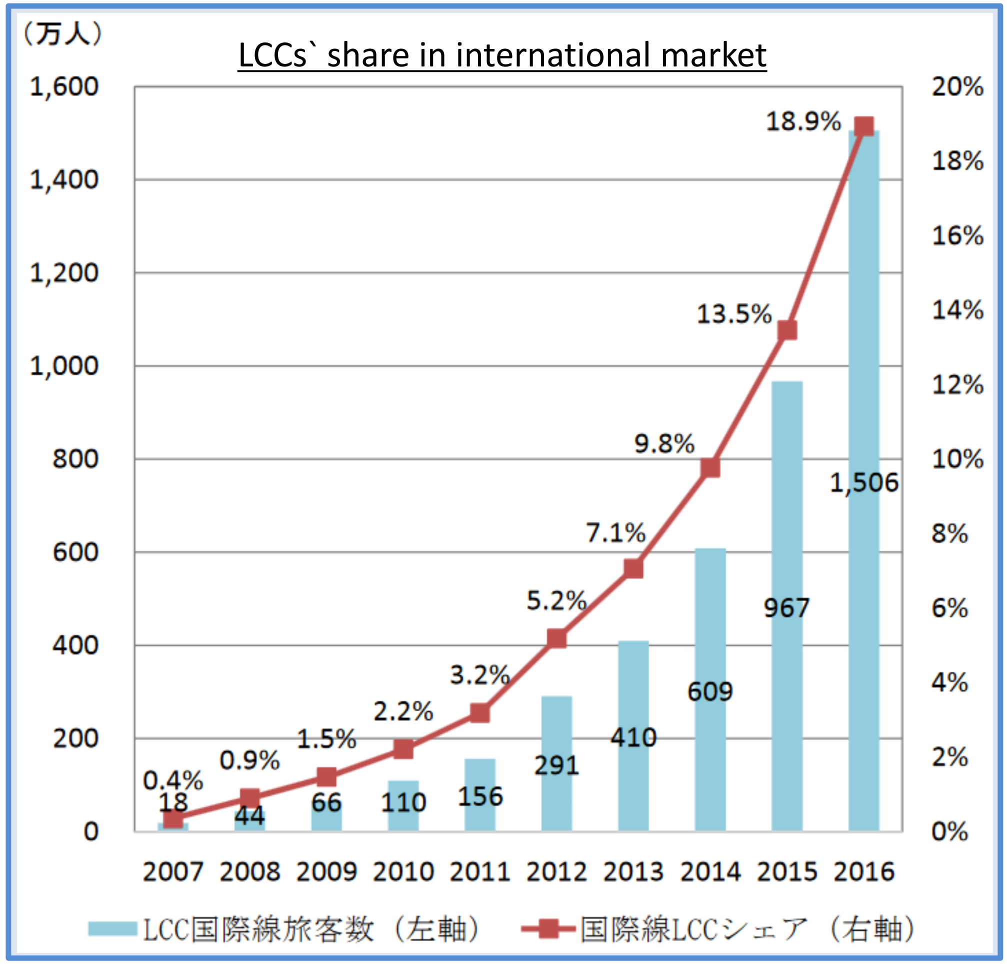
Source: Yoichi Hirotani, Development Bank of Japan

Source: Ministry of Land Infrastructure and Transport

Introduction Slowing Growth

- However, recently domestic LCC growth in Japan seems slowed down and their focus shifted to international lines.

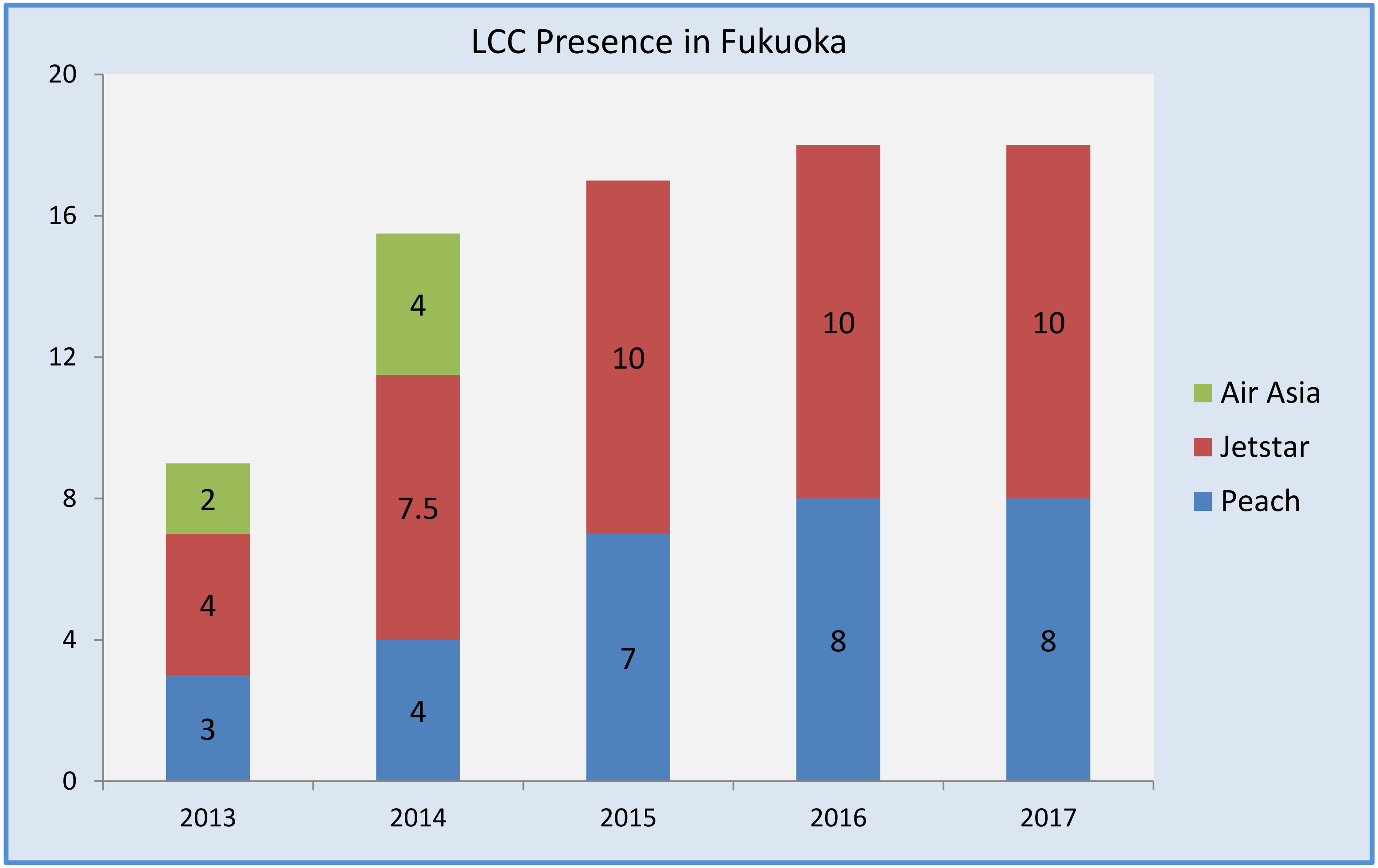
- Still, LCC operators have plans for domestic growth but they put forward several problems:
  - Increased competition
  - Airport access issues
  - Limited airport hours
  - Pilot shortage
  - Scarcity of slots



Source: Ministry of Land Infrastructure and Transport

Introduction Slowing Growth

- LCC growth affected by slot scarcity in Fukuoka



LCC routes to: Narita, Kansai, Chubu and Naha

Research Objective

- LCCs have the potential to increase social welfare but growth is slowing down.
- One likely solution: Increase LCC slots in congested airports. But… Is it possible? Is it feasible?

My objective is to investigate possibility and feasibility of introducing new slot distribution rules favoring LCCs to increase social welfare.

Contents

Airport Slot Allocation System

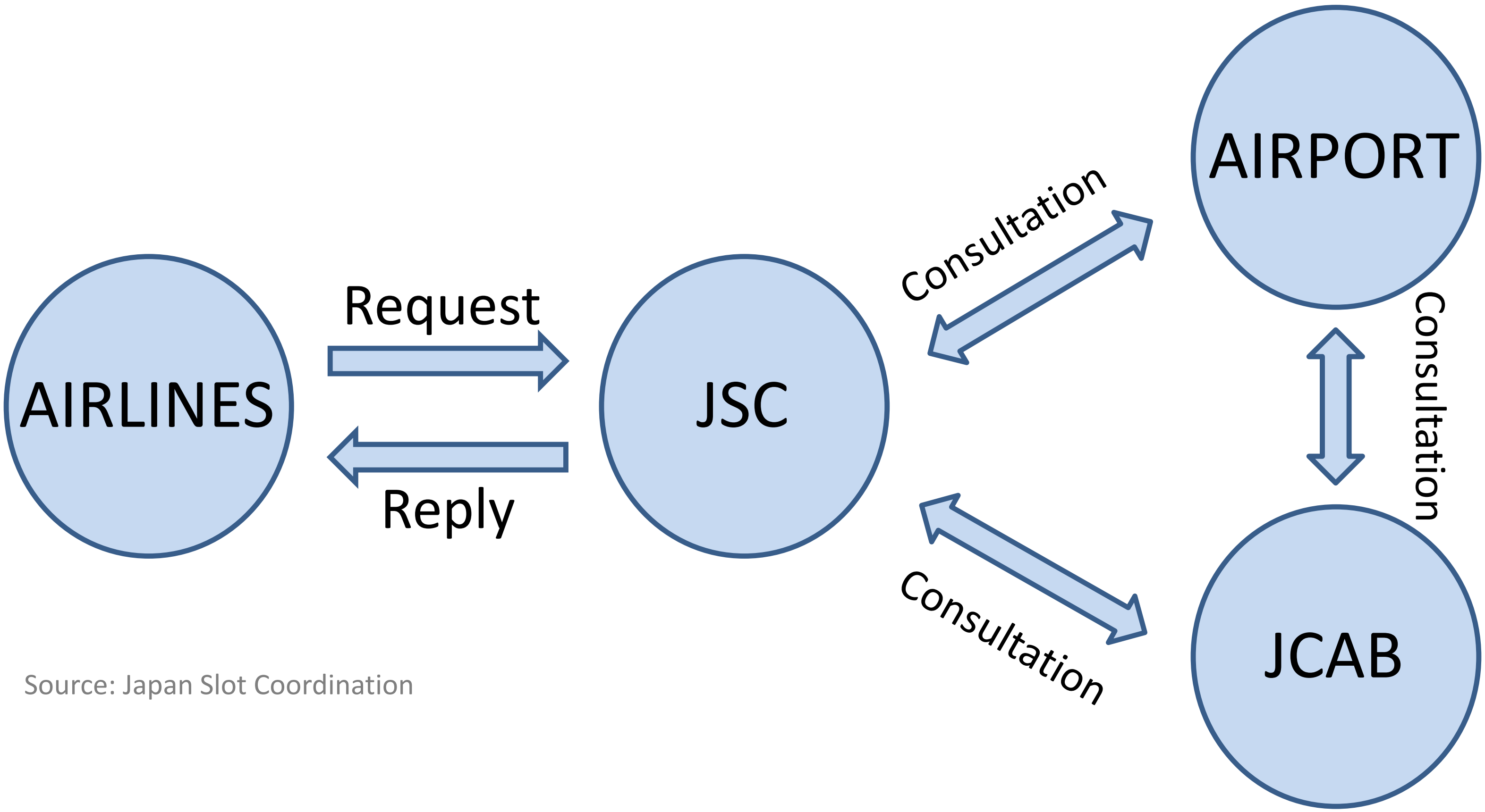
- Airport slots are specific time periods allotted for an aircraft to land or take off at an airport.

- If demand for slots at an airport exceeds the capacity, the airport is considered as “capacity-constrained”, and “slot allocation” process is implemented.

- There are two approaches to slot allocation:
  1. Administrative:
     - Airport owner sets up rules and distributes slots accordingly
  2. Market based:
     - Congestion pricing, slot auctions, secondary trading etc.

Slot Allocation in Japan

- Slot distribution of 5 congested airports (Narita, Kansai, Haneda, Shin-Chitose and Fukuoka) are controlled by Japan Schedule Coordination (JSC), an independent, nonprofit organization.

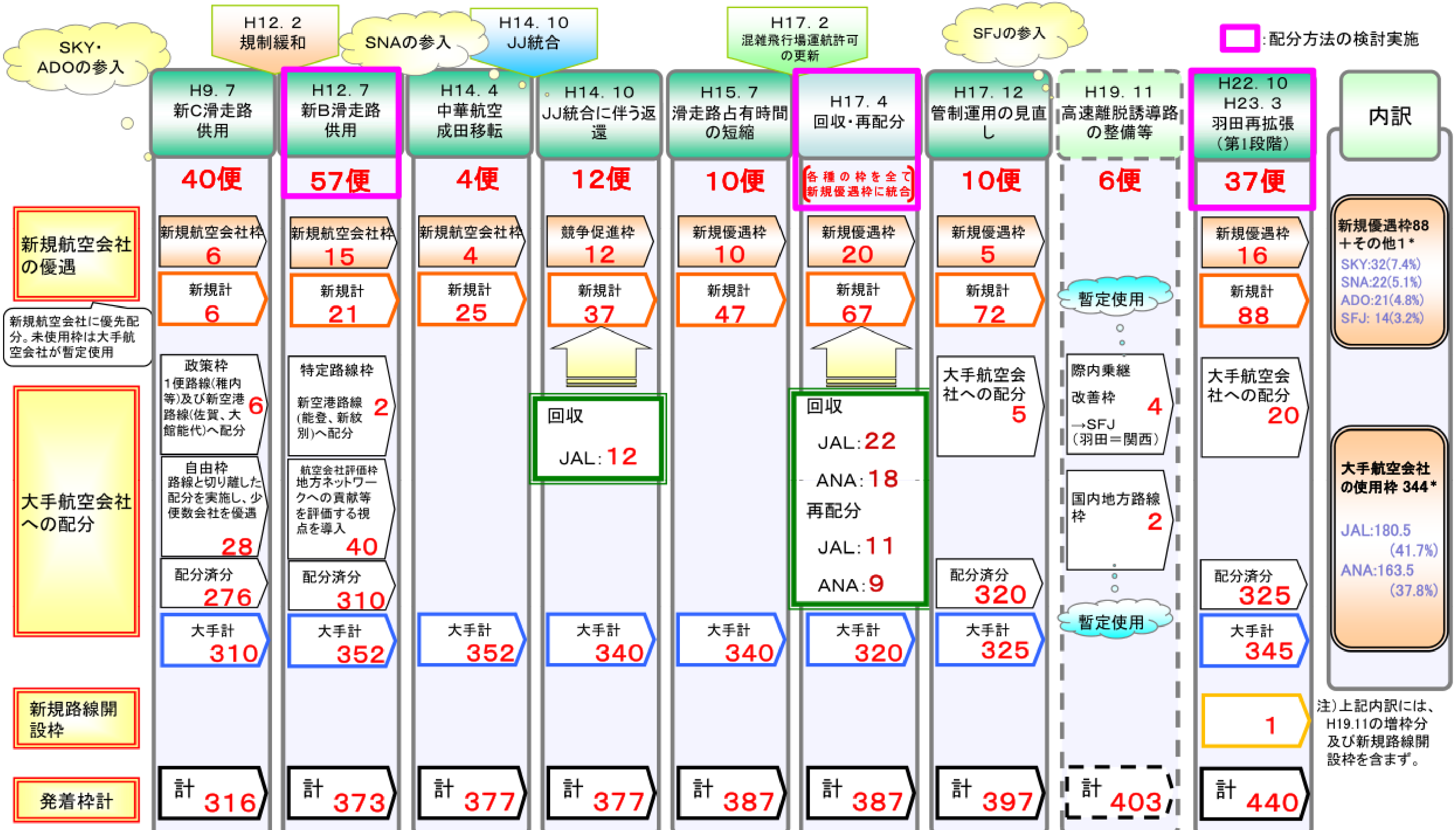


Source: Japan Slot Coordination

- JSC follows IATA Guidelines based on <u>grandfather rights</u> and <u>use it or lose it</u> rule.

Past Practices at Haneda Airport

Chronology of Haneda Slot Distributions



＊：羽田再拡張（第1段階）で大手に配分した20便のうち4便分について、出発4便をANAに、到着1便をJAL、1便をANA、2便をSFJに配分し、それぞれ1便を0．5枠としてカウント。

Source: MLIT Civil Aviation Bureau (2007)

Past Practices at Haneda Airport

Competitive Forces

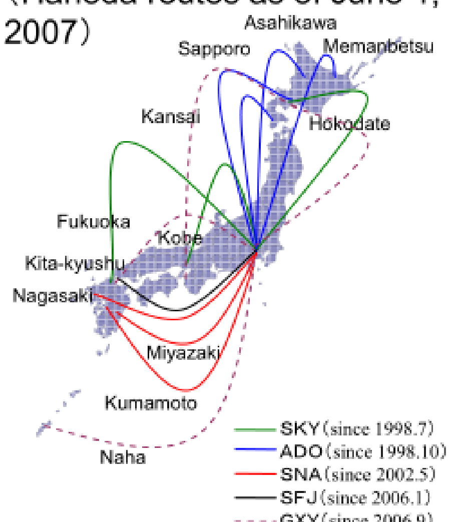
○In order to promote competition, new entrants are given priority in slot allocation at Haneda Airport, Tokyo's domestic hub airport.

・Priority given when additional landing slots are made available

・Some slots are withdrawn from the incumbents and re-allocated to new entrants when five-year duration period of the approval ends.

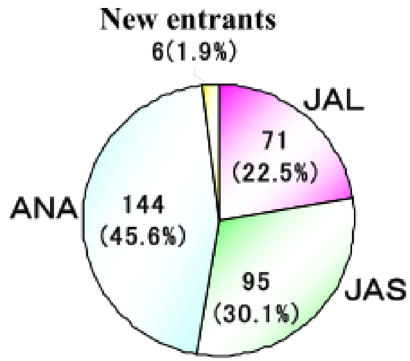
New Entrants since 1998

(Haneda routes as of June 1, 2007)



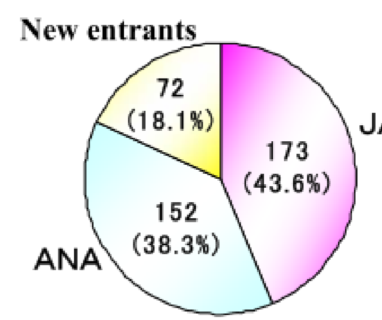
Change in slot allocation at Haneda Airport

February 1, 2000



【Total landing slots：316】

June 1, 2007



【Total landing slots：397】

Source: MLIT Civil Aviation Bureau (2007)

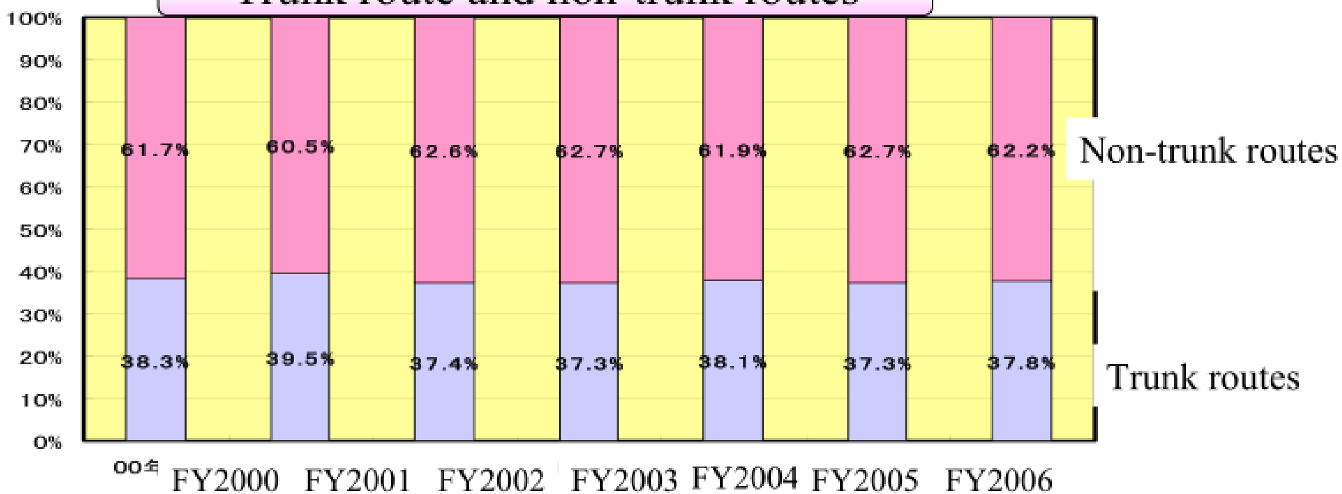
Diversity of Networks

○Incremental slot allocation is provided to airlines that contribute to diverse nation-wide networks

- ・Appraisal of historic operation is reflected to slot allocation to incumbent carriers
- ・Criteria for appraisal includes diversity of nation-wide networks

Criteria for diversity of nation-wide networks	
①Contribution to network diversity	
	Increase in low-density routes in past five years
	Increase in airports with over-night aircraft stay
②Contribution to accessibility to local airports	
	Percentage of non-trunk routes at Haneda airports exceeds 50%
	Percentage of landing slots in the recent allocation case used for non-trunk routes exceeds 50%

Trunk route and non-trunk routes



Trunk route: routes between Haneda, Sapporo (New-Chitose), Itami, Kansai, Fukuoka and Naha

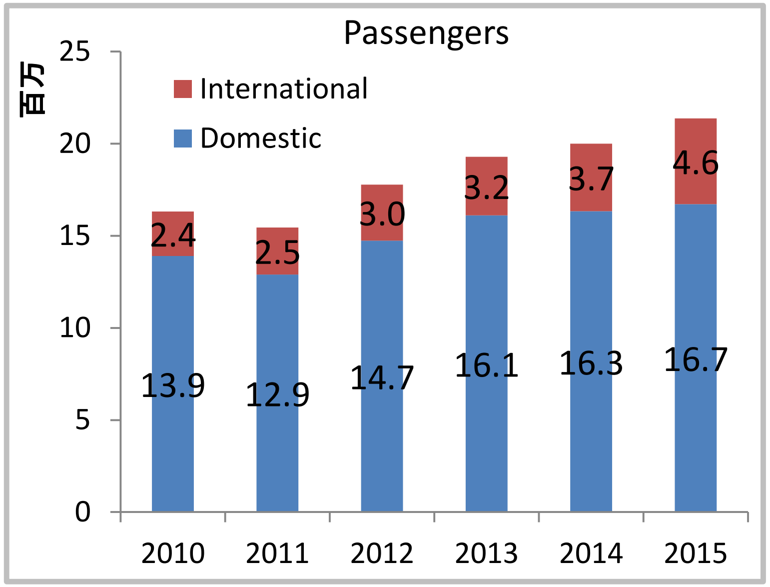
Source: MLIT Civil Aviation Bureau (2007)

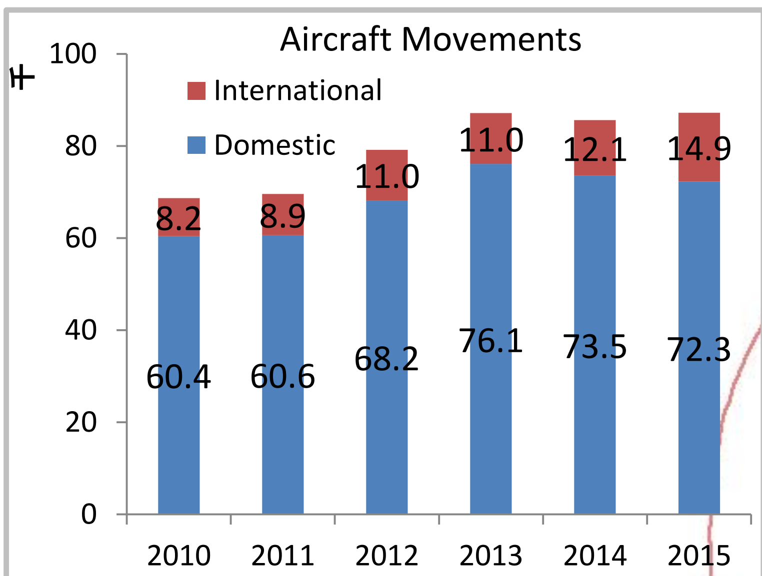
Conclusions for Part 1

- Airport slots belong to public not to airlines.
- Past practices indicate that in certain times slots were taken from incumbent operators and given to new entrants to increase competition and diversity.
- Therefore, it is worth considering to do the same for LCCs if it improves social welfare.

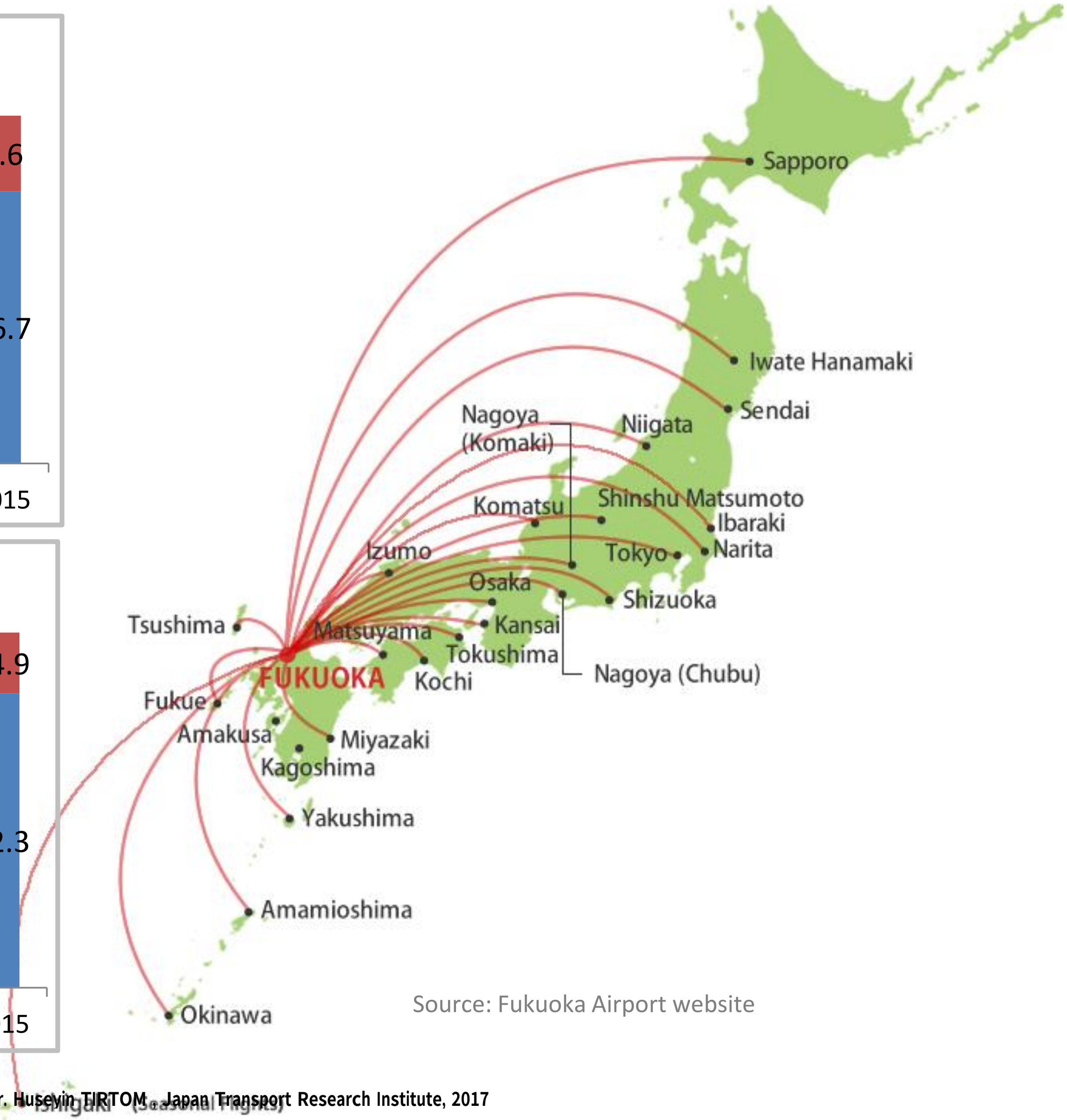
Contents

Capacity Constraints at Fukuoka Airport





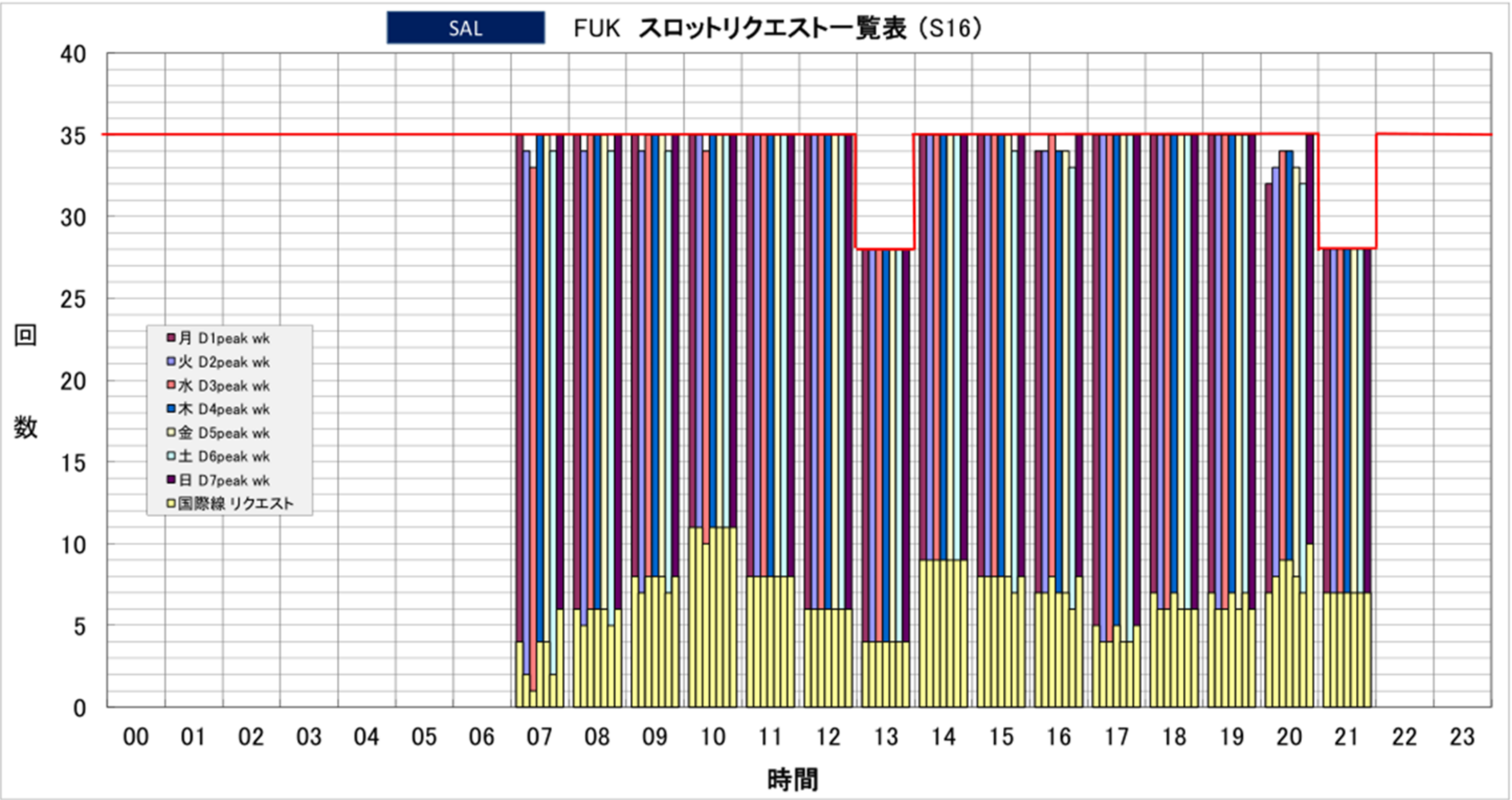
Source: Japan Slot Coordination



Source: Fukuoka Airport website

Capacity Constraints at Fukuoka Airport

- In 2015 Fukuoka Airport was designated as “congested airport” by MLIT and operations were restricted to 35 take-off/ landing per hour

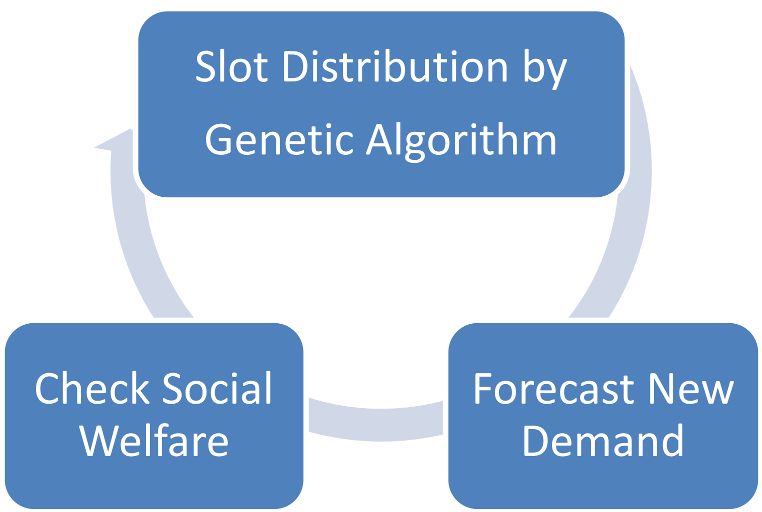


Source: Japan Slot Coordination

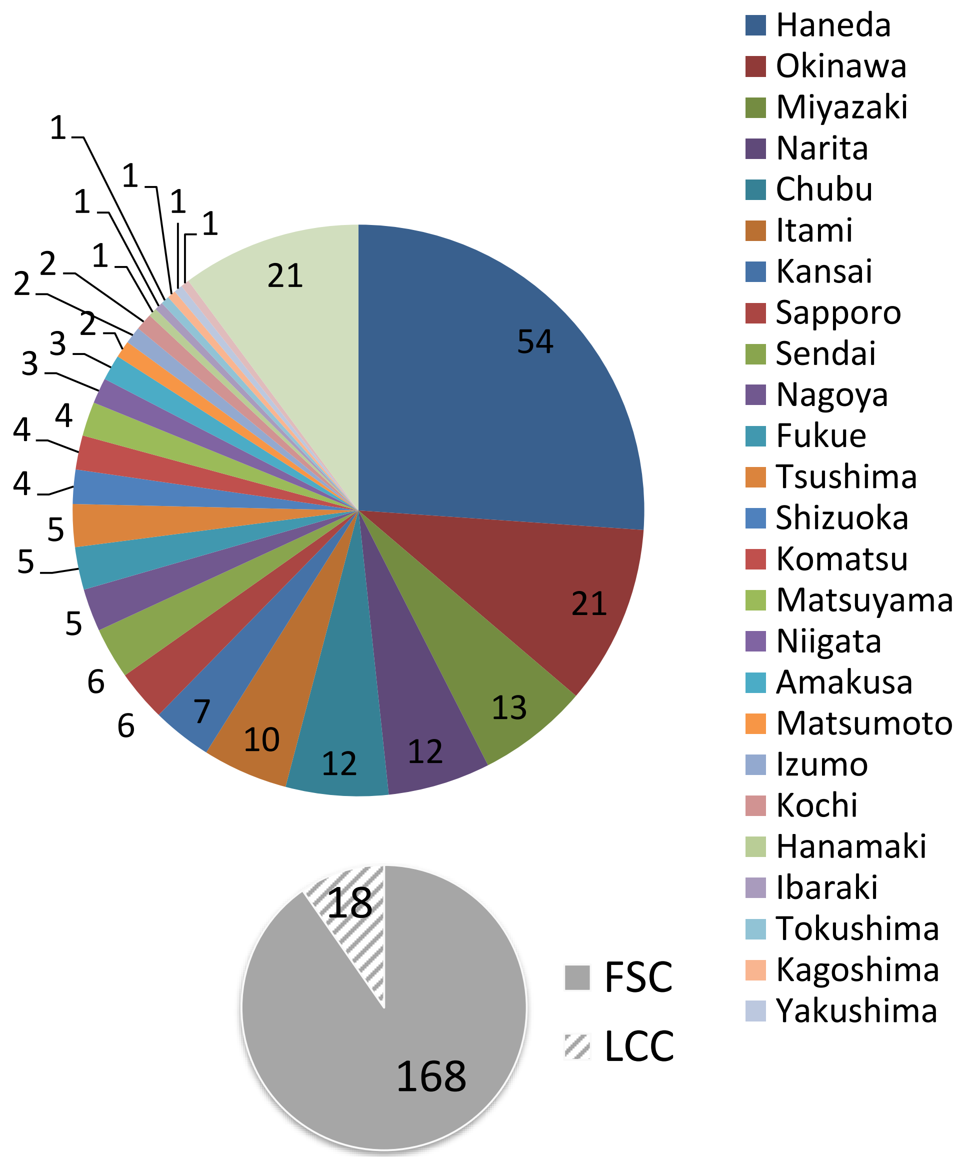
Optimization Methodology

Objective: Finding optimal slot distribution to maximize social welfare (consumer surplus + operator surplus)

Methodology:

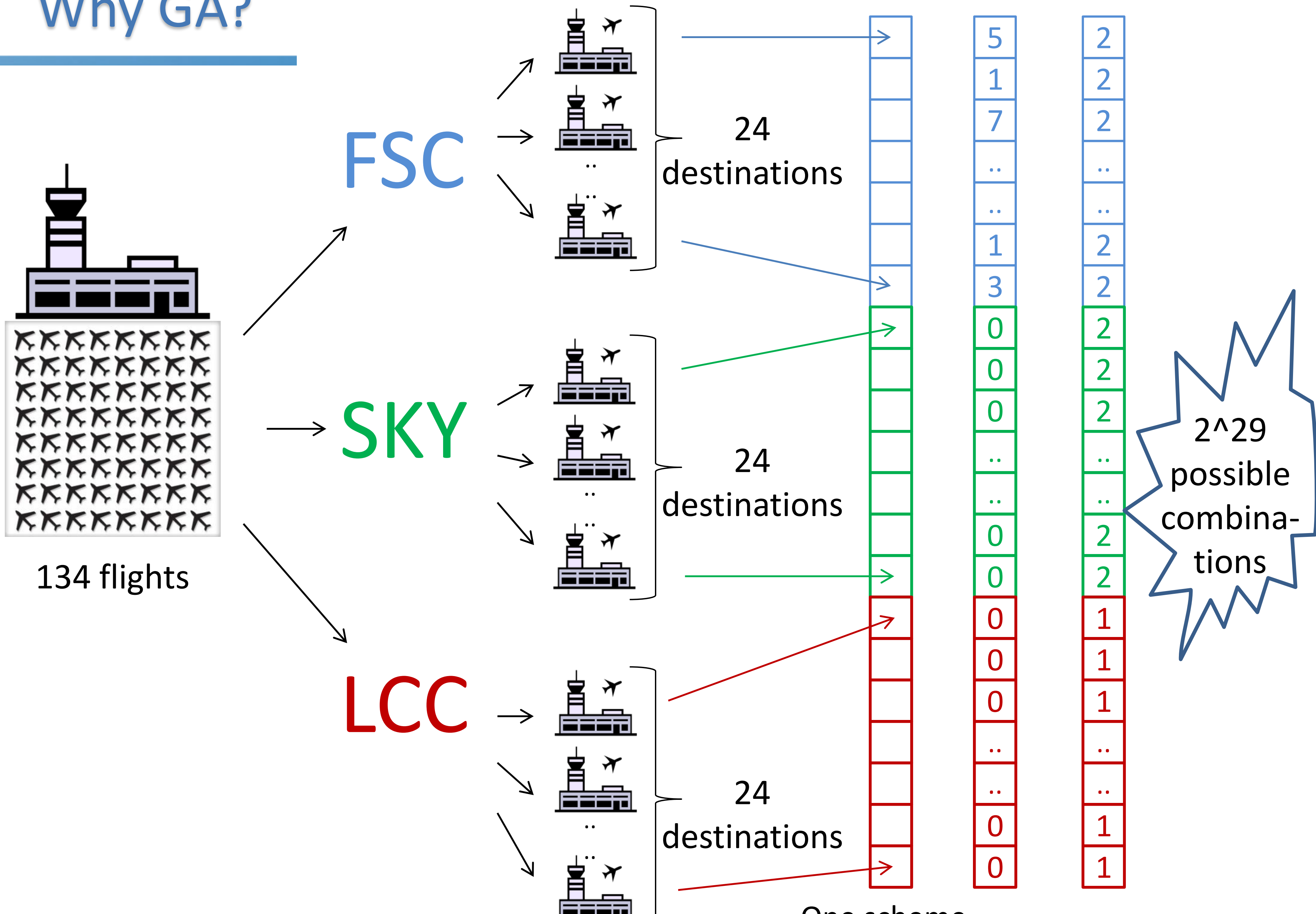


Considerations: Aircraft limitations



Fukuoka Airport slot distribution in summer 2016

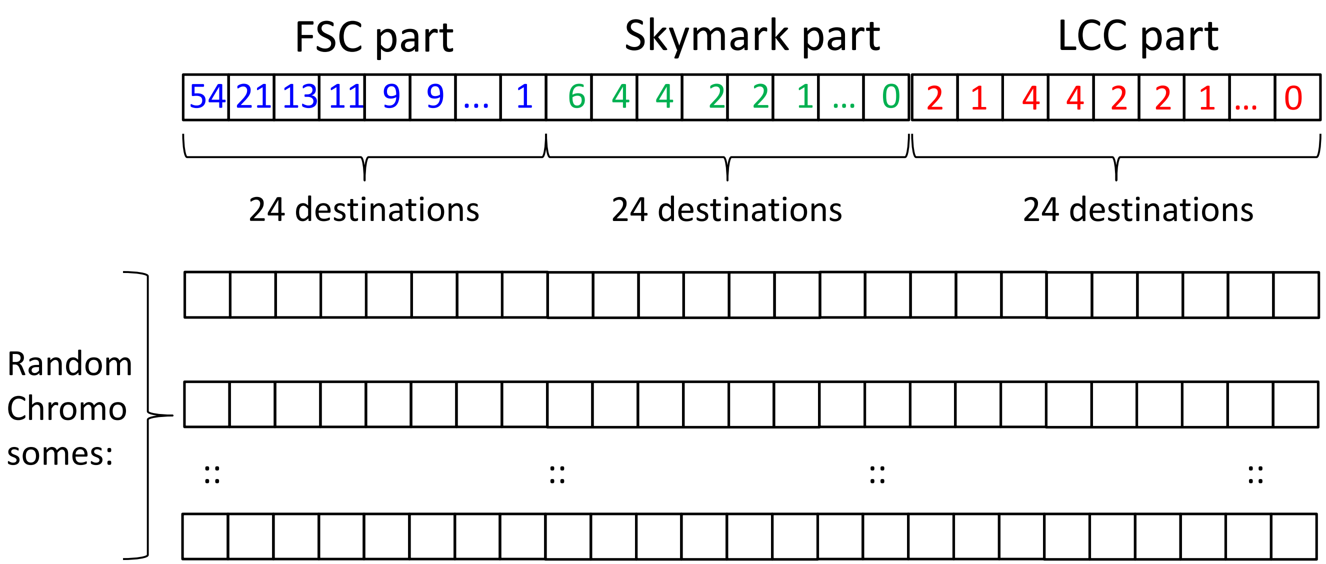
Why GA?

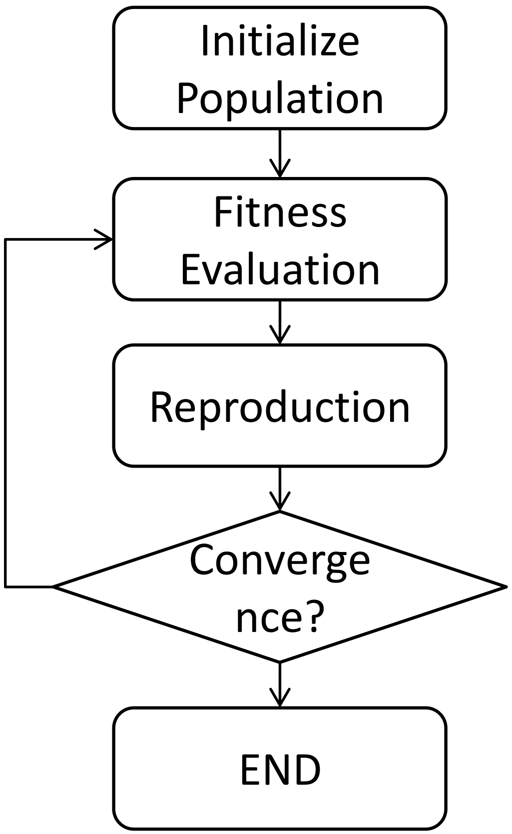


134 flights
FSC
SKY
LCC
24 destinations
24 destinations
24 destinations
5 1 7 .. .. 1 3 0 0 0 .. .. 0 0 0 0 0 .. .. 0 0
2 2 2 .. .. 2 2 2 2 2 .. .. 2 2 1 1 1 .. .. 1 1
2^29 possible combina-tions
One scheme

Genetic Algorithm

- Each chromosome consist of three parts to represent FSC, Skymark and LCC frequencies to 24 destinations
- Fitness evaluation is done by checking social welfare





Airline Choice Model

Indirect Utility Function:

$$u_{ij} = x_j * \beta_i + \alpha_i p_j + \xi_j + \epsilon_{ij}$$

Observable Mode Characteristics

Fare

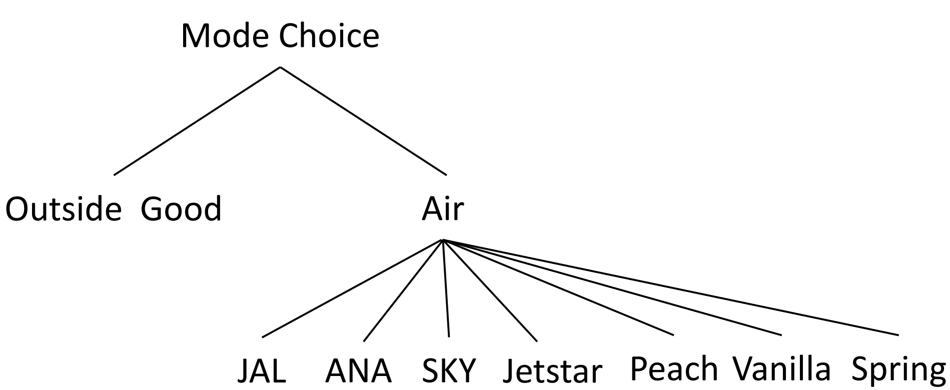
Unobservable Mode Characteristics

Error Term

where; i:individual, j:product

Mean Utility Function:

$$\delta_j = \alpha * Fare + \beta_0 + \beta_1 * Log(Frequency) + \beta_2 * Rail\ Time + \beta_3 * Log(Seats) + \beta_4 * SKY + \beta_5 * LCC + \xi_j$$



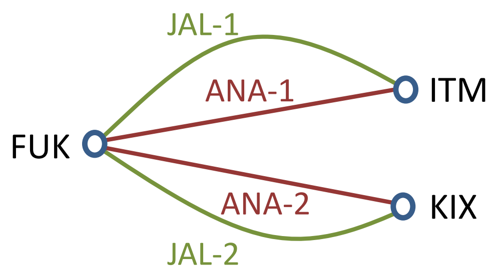
Upper Level Share: $M_m = \dfrac{e^{\lambda \delta_m}}{\sum_n e^{\lambda \delta_n}}$

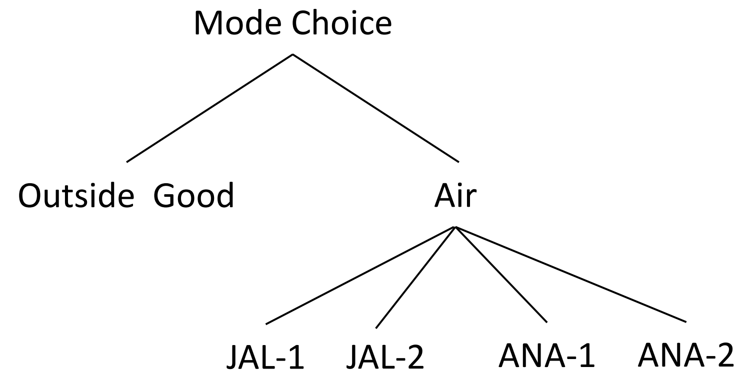
Lower Level Share: $M_k = \dfrac{e^{\gamma \delta_k}}{\sum_j e^{\gamma \delta_j}} * M_{Air}$

Air Utility: $\delta_{Air} = \dfrac{1}{\gamma} \ln\left(\sum_j e^{\gamma \delta_j}\right)$

Airline Choice Model

In the case of multiple airports:





Assuming λ=1 and normalizing outside good`s utility as $\delta_{Outside} = 0$;

$$M_{Outside} = \frac{1}{1 + e^{\delta_{Air}}}$$

$$M_{Air} = \frac{e^{\delta_{Air}}}{1 + e^{\delta_{Air}}}$$

$$\ln(M_k) - \ln(M_{Outside}) = \delta_k + \underbrace{\left(1 - \frac{1}{\gamma}\right)}_{\text{Sigma}} ln\left(M_{k/Air}\right) + \xi_j$$

Consumer Surplus Calculation

A person's consumer surplus is the utility, in monetary terms, that the person receives in the choice situation:

$$E(\mathrm{CS}_n) = \frac{1}{\alpha_n} E[\max_j (V_{nj} + \varepsilon_{nj})] \quad \Rightarrow \quad E(\mathrm{CS}_n) = \frac{1}{\alpha_n} \ln\left(\sum_{j=1}^{J} e^{V_{nj}}\right) + C$$

marginal utility of income

Utilities

Error Term

Consumer Surplus Change for one person in MNL:

$$\Delta E(\mathrm{CS}_n) = \frac{1}{\alpha_n}\left[\ln\left(\sum_{j=1}^{J^1} e^{V_{nj}^1}\right) - \ln\left(\sum_{j=1}^{J^0} e^{V_{nj}^0}\right)\right]$$

Total Consumer Surplus Change in NL with fixed total demand

$$\boxed{\Delta E(CS) = \frac{T}{\beta}\left[\ln\left(e^{\delta_{Air}{}^{1}} + 1\right) - \ln\left(e^{\delta_{Air}{}^{0}} + 1\right)\right]}$$

$T: Outside\ Good + Airline\ demand$

Data

- Standard Airfare, Frequency and Seat information are taken from timetables (2013-2016)
- Air passengers data is taken from 航空輸送サービス係る情報 (2013-2016)

(2) 路線別データ

	区間	区間距離 (Km)	平成27年度 年度計 旅客数	座席数	座席利用率 (%)
1	東京－札幌	894	9,016,082	12,463,673	72.3
2	東京－大阪	514	5,194,556	7,255,909	71.6
3	東京－関空	678	1,150,833	1,747,750	65.8
4	東京－福岡	1,041	8,158,953	11,322,294	72.1

	輸送人員(人)	旅客収入(百万円)
日本航空(注3) (法人番号 7010701007666)	27,213,377	433,122
全日本空輸(注3) (法人番号 1010401099027)	42,753,163	674,954
日本トランスオーシャン航空 (法人番号 3360001001727)	2,733,449	34,366
スカイマーク (法人番号 7010801019529)	6,015,948	70,381
AIRDO (法人番号 6430001021797)	1,825,963	28,057

- Ticket Type data is taken from 航空旅客動態調査 (2013, 2015)

路線名			航空券の種類 普通運賃	%	往復割引	%	乗継割引	%
新千歳	—	羽田	1,681	15.5	1,992	18.4	122	1.1
羽田	—	伊丹	1,173	12.5	1,779	18.9	81	0.9
羽田	—	福岡	1,821	16.2	1,936	17.2	70	0.6
羽田	—	那覇	732	13.6	669	12.4	54	1.0
新千歳	—	伊丹	102	15.6	93	14.2	6	0.9
伊丹	—	福岡	194	14.1	176	12.8	17	1.2

- Total Demand (including no travel) is calculated as geometric average of city populations

Model Calibration

- Parameters were calibrated with 2SLS method using HHI index, distance and monopoly dummy as instrument variables
- Test results show that coefficients are meaningful and significant
- R-squared is acceptable

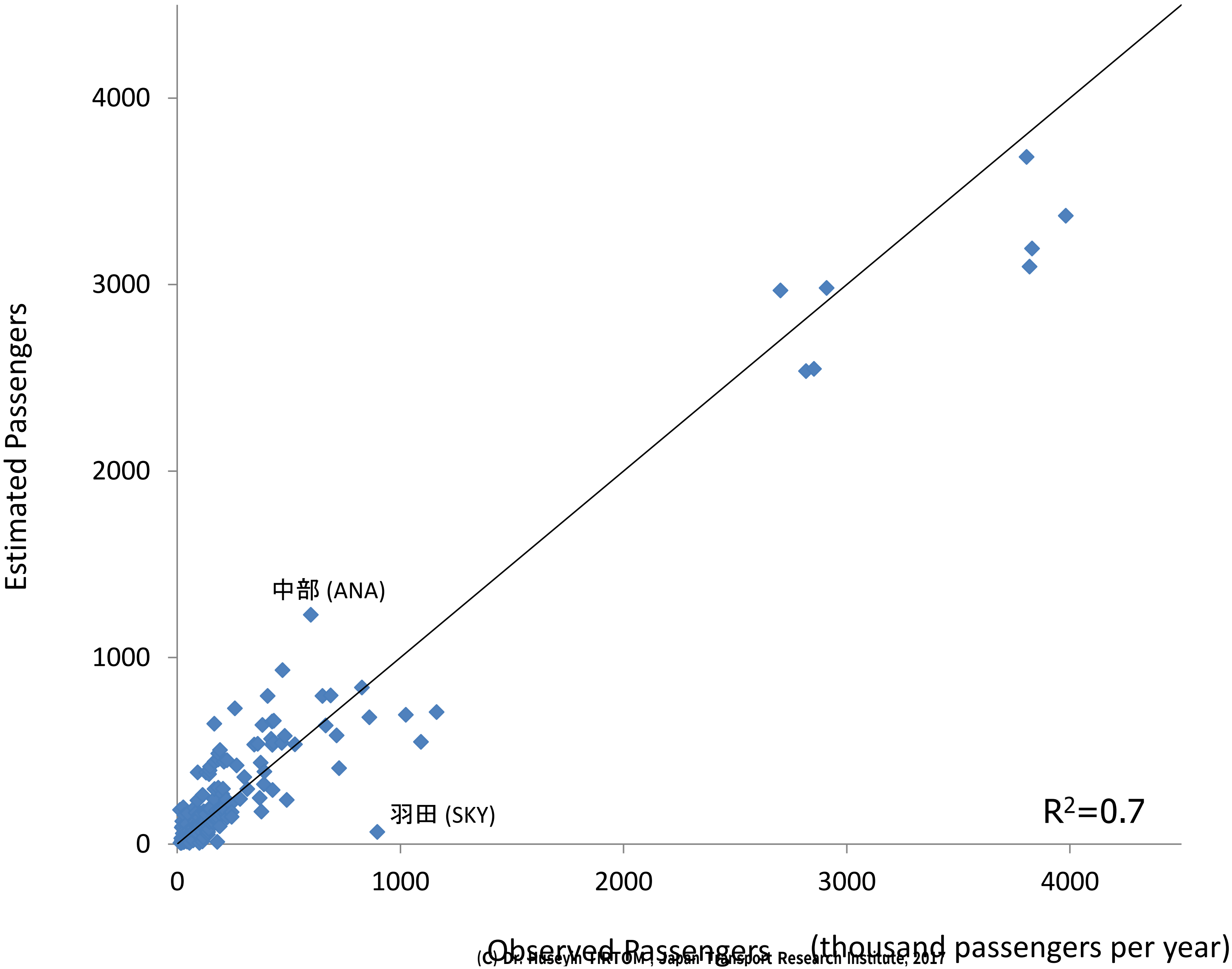
Variable	Coefficient	t-stat
Intercept	-8.24	-19.91
Log (Frequency)	0.94	13.18
Fare (10,000 ¥)	-1.12	-6.50
Log (Average Seats)	0.97	8.86
Sigma	0.25	3.82
LCC dummy	-0.68	-2.72
SKY dummy	-0.70	-3.42
Rail Time	0.71	11.20
Adj. R^2	0.71	
Observations	208	

*Airline classification:

Airline	Unit Revenue (¥/pax-km)	Group
Jetstar	7.7	LCC
Peach	7.8	LCC
SKY	10.0	SKY
JTA	12.8	FSC
JAL	16.9	FSC
SFJ	17.0	FSC
ANA	17.3	FSC
IBX	20.2	Regional
FDA	22.6	Regional
AMX	34.8	Regional
JAC	35.2	Regional
ORC	49.3	Regional

*Rail time is categorized as;
1: less than 200min.
2: between 200-400 min.
3: between 400-600 min.
4: over 600 min.

Observed vs Estimated Passengers



We try to estimate fare as a function of distance for two cases:

$$y = a + b*distance$$

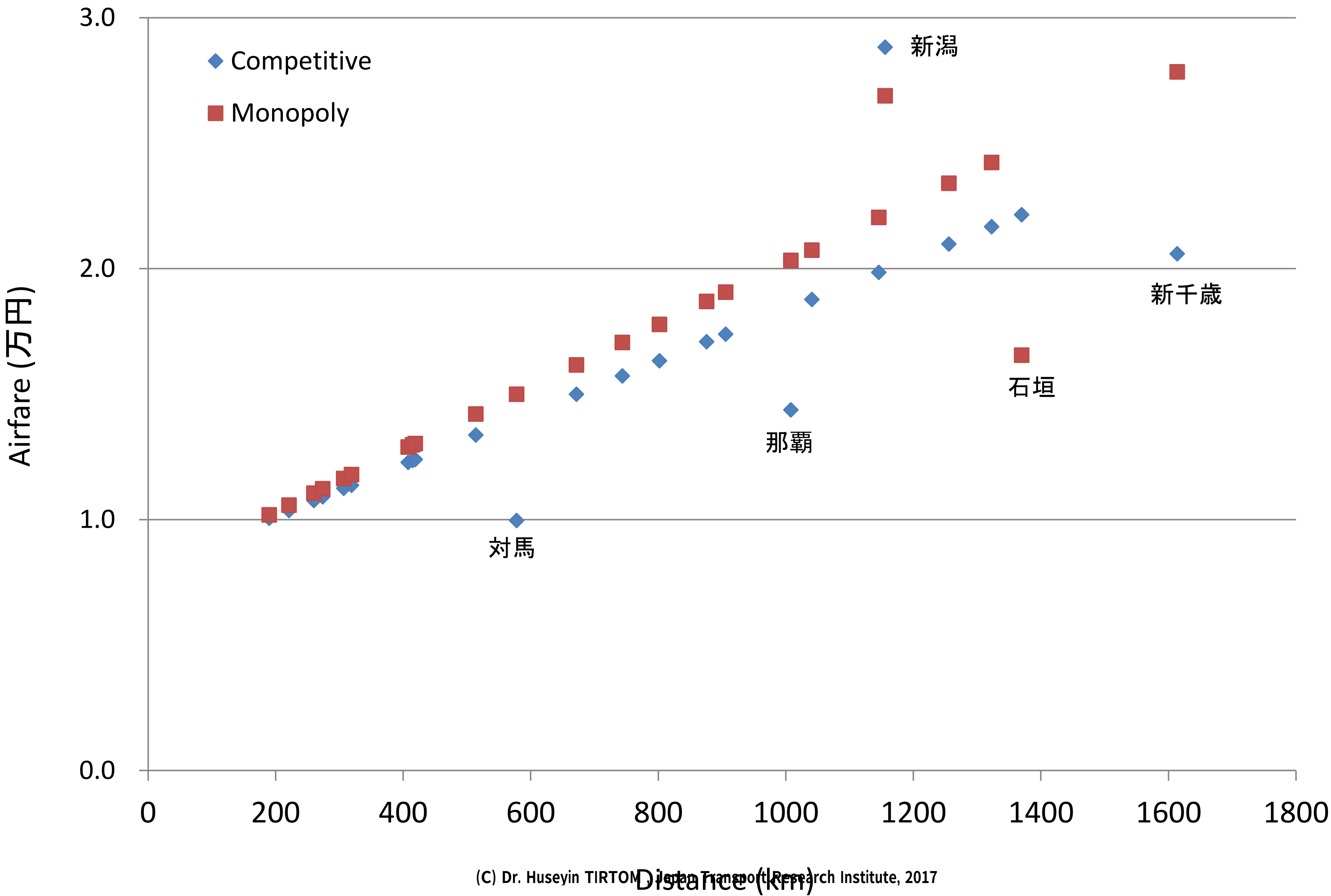
a) In the case of competition:

- using average fares from competitive routes

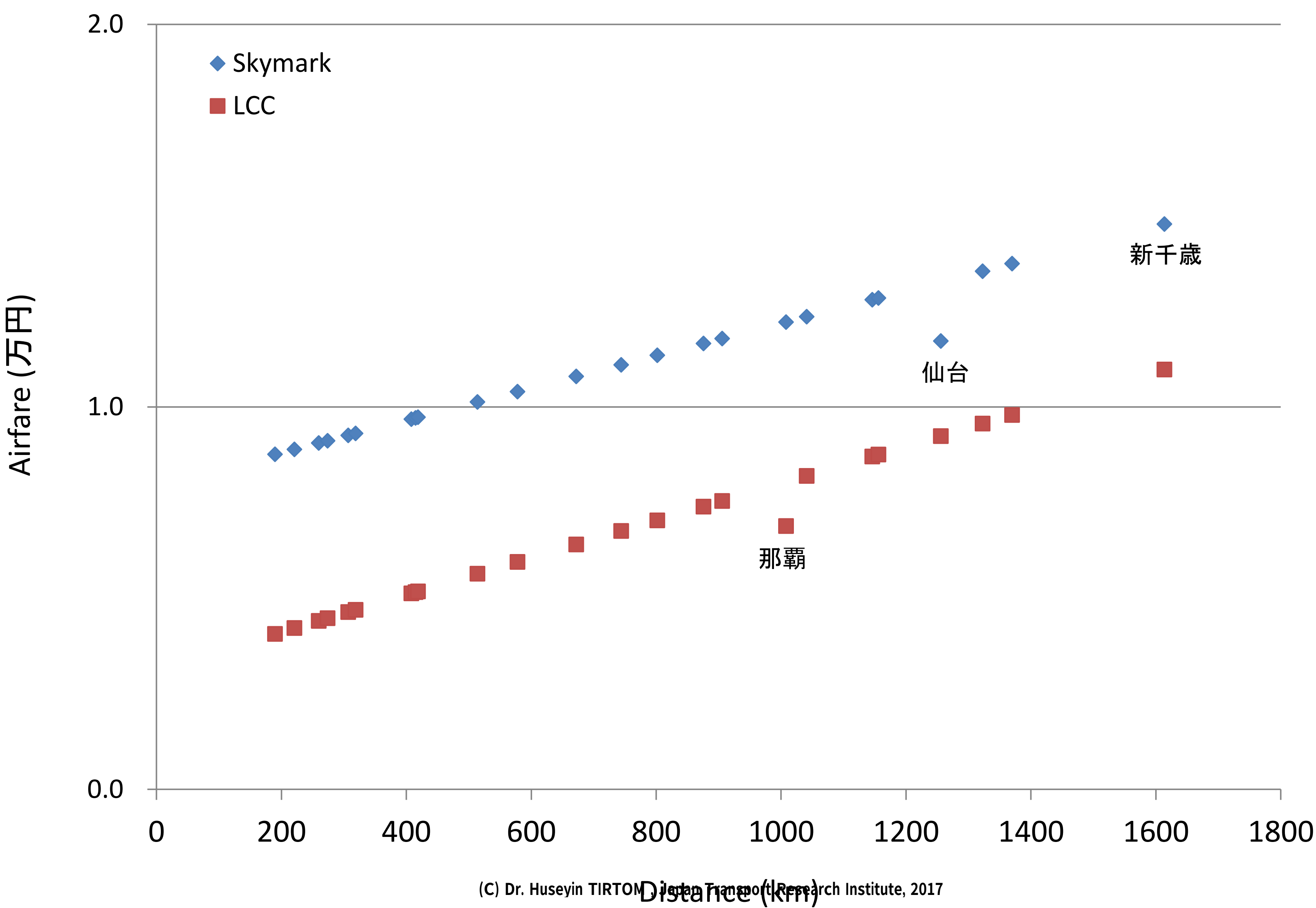
b) In the case of monopoly:

- using average fares from monopoly routes

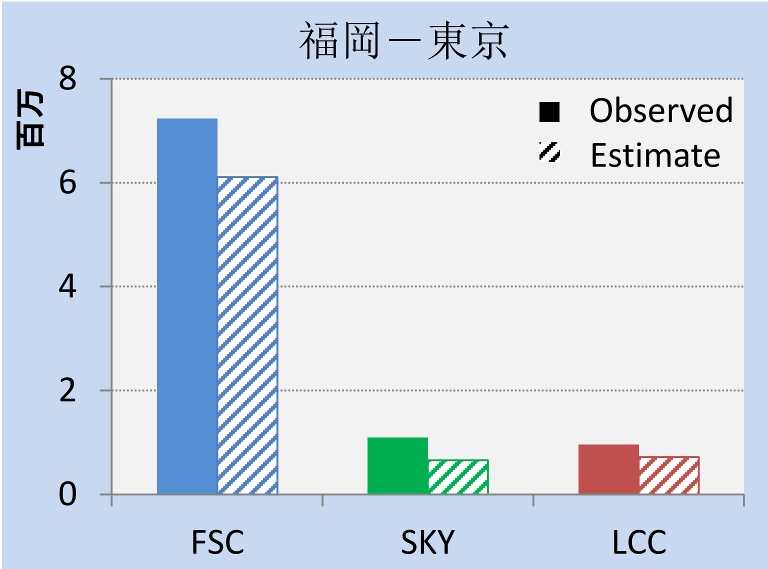
Airfare Calculation (FSC)

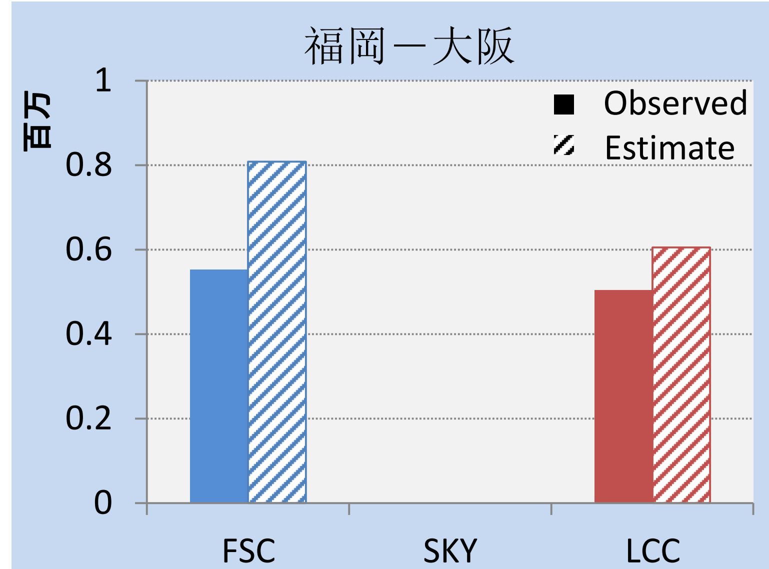


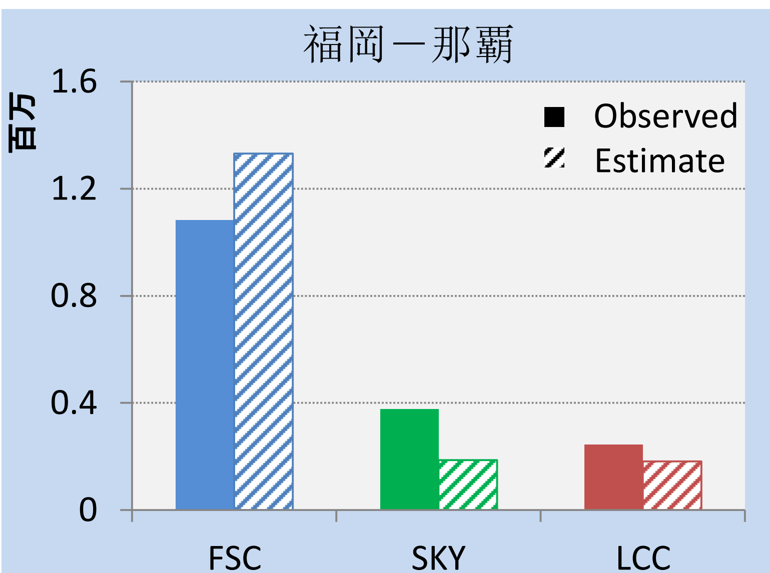
Airfare Calculation (Skymark & LCC)

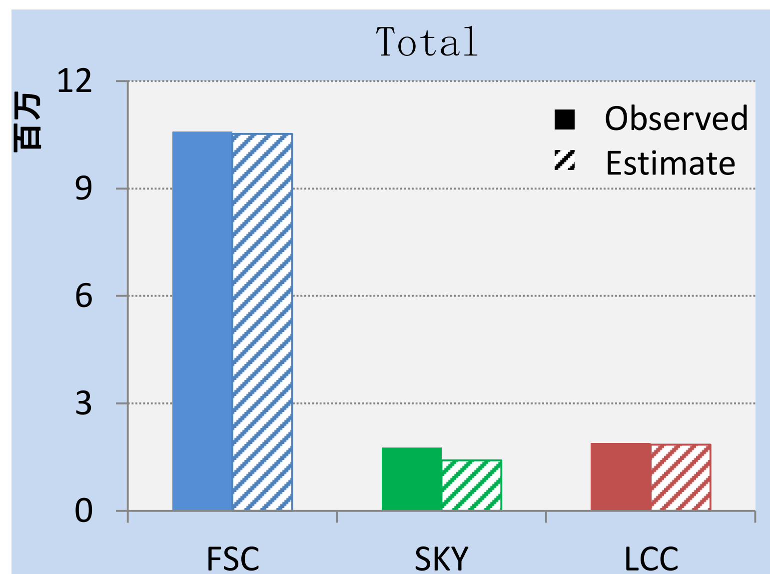


Performance of the Model









Part 2 Optimization Model

Definitions:

$$\delta_j = \alpha * Fare + \beta_0 + \beta_1 * Log(Frequency) + \beta_2 * Rail\ Time + \beta_3 * Log(Seats) + \beta_4 * SKY + \beta_5 * LCC$$

$$\delta_{Air\_od} = \frac{1}{\gamma} \ln\left(\sum_n e^{\gamma \delta_{nod}}\right)$$

$$P_{jod} = \begin{cases} a_1 + b_1 * D_{od} & if\ there\ is\ competition \\ a_2 + b_2 * D_{od} & if\ there\ is\ no\ competition \end{cases}$$

$$Q_{jod} = T_{od} * \frac{e^{\gamma \delta_{jod}}}{\sum_n e^{\gamma \delta_n}} * \frac{e^{\delta_{Air\_od}}}{1 + e^{\delta_{Air\_od}}}$$

$$CS_{od} = \frac{T_{od}}{\alpha}\left[\ln\left(e^{\delta_{Air\_od}{}^1} + 1\right) - \ln\left(e^{\delta_{Air\_od}{}^0} + 1\right)\right]$$

$$OS_{od} = \sum_j \left[\left(Q_{jod} * P_{jod}\right) - \left(Fr_{jod} * S_{jod} * D_{od} * c_j\right)\right]$$

CS	Consumer Surplus
OS	Operator Surplus
T	OD Demand (including outside option)
δ	Utility Function
Q	Passengers
P	Airfare
Fr	Frequency
S	Number of Seats
D	OD Distance
c	Unit costs (¥/seat-km) FSC:9.3, SKY:8.9, LCC:7.7

Objective Function:

$$Max \sum_{od} (CS_{od} + OS_{od})$$

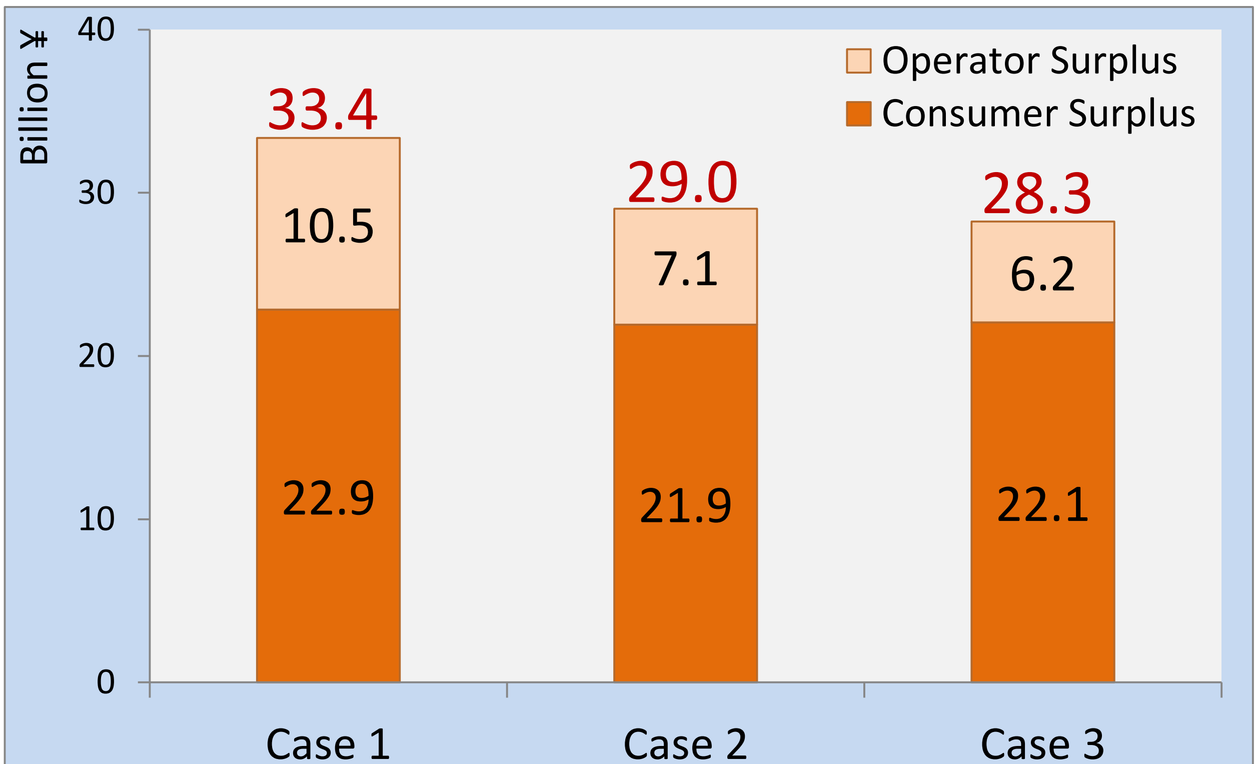
Constraints:

$$\sum_{jod} Fr_{jod} = Fr_{od,total} \quad , \quad \sum_{od} Fr_{jod} = Fr_{j,total}$$

Contents

Preliminary Results Comparison of 3 Cases

Case 1	- Total flights to each destination is fixed	No consideration of aircraft numbers
Case 2	- Total flights to each destination is fixed - Total flights of each group is fixed (FCC:99,SKY:18,LCC:17)	Similar to actual conditions
Case 3	- Total flights to each destination is fixed - FSC flights decreased by 10% and distributed to SKY and LCC - Total flights of each airline is fixed (FSC:89,SKY:23,LCC:22)	LCC flights increased to the detriment of FSC



FLIGHTS	FSC	SKY	LCC
Case 1	117	4	13
Case 2	99	18	17
Case 3	89	23	22

Preliminary Results Case Comparisons

			Actual Situation				Case 1			Case 2			Case 3		
No	Destination	Total Fr.	Reg	FSC	SKY	LCC	FSC	SKY	LCC	FSC	SKY	LCC	FSC	SKY	LCC
1	新千歳	5		3	2		3		2	1		4			5
2	花巻	1		1			1					1			1
3	仙台	5	1	4			2		2		3	1			4
4	茨城	1			1				1		1		1		
5	東京	65		46	11	8	64		1	64		1	62	1	2
6	新潟	3	1	2			1	1				2			2
7	小松	4	3	1					1			1	1		
8	松本	2	2												
9	静岡	4	4												
10	名古屋	17	6	9		2	10		1	11			11		
11	伊丹	16	2	9		5	14			13	1		14		
12	出雲	2	2												
13	徳島	2	2												
14	松山	5	5												
15	高知	4	4												
16	福江	4	2	2			1	1		1	1			1	1
17	対馬	4		4			2	2			4			4	
18	天草	2	2												
19	宮崎	14	11	3					3			3		2	1
20	鹿児島	2	2												
21	屋久島	1	1												
22	奄美大島	1	1												
23	那覇	20		14	4	2	19		1	8	8	4		15	5
24	石垣	1		1					1	1					1
Total		185	51	99	18	17	117	4	13	99	18	17	89	23	22

	Case 1	Case 2	Case 3
CS+OS	33.4 billion ¥	29.0 billion ¥	28.3 billion ¥

Contents

Conclusions

There are some limitations in this study such as:

- Model parameters were calibrated using aggregate data
- Effect of departure time was not taken into account

Still, results indicate that:

- Better distributions are possible
- Assigning more slots to LCCs increases Consumer Surplus, but not necessarily improves Social Welfare
- LCC slots are better utilized at distant destinations.

Future Works

Improvement of airline choice model
- using individual survey data
- including departure time as an explanatory variable

Consideration of variable slot assignments to destinations

Consideration of costs that will be incurred by each airline in the case of a slot distribution change

Thank you for your kind attention