ASSESSMENT OF LOW COST TERMINAL LOCATION AND CONFIGURATION IN AIRPORT

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1. Introduction

The entry of low-cost carriers (LCCs) brings competition to the air transportation industry. In many instances, the entry has been influential because LCCs offer low prices to the market thus affecting almost all aspects of the business. Airport is one of the elements that are influenced heavily by LCCs. One of the reasons is because LCCs have distinct business model that requires different airport services than the ones usually offered to full-service airlines. Barret (2004)[1)] identified seven airport requirements needed to serve the low-cost carriers: (1) low airport charges, (2) quick 24-minute turnaround time, (3) single story airport terminal, (4) quick check-in, (5) good catering and shopping at the airport, (6) good facilities for ground transport, and (7) no executive/business lounge.

Several airports have constructed low-cost terminal (LCT) to address the issues. LCT is an airport terminal specially designed to accommodate LCCs, the concept of which emphasizes on cost and time reduction. Developing a specialized terminal for LCCs is a considerable alternative for airports to avoid conflicting needs between full-service airlines and LCCs (Graham, 2008)[2)]. Besides, construction of LCT in the airport is believed to be powerful to attract LCCs and produce a strong, positive impact on traffic volume for the airport (Zhang, et al., 2008)[3)].

This study addresses two main subjects: configuration and location of LCT in airport. These are considered as two of main factors that would influence the success of LCT. The configuration of LCT affects passenger walking distance, while the location of LCT towards runways affects aircraft taxiing distance. Both passenger walking distance and aircraft taxiing distance influence time spent by aircrafts and passengers in airport, thus affecting efficiency of LCC operations.

2. Present State of Low Cost Terminal

(1) Low Cost Terminal

The number of LCTs development throughout the world is increasing from time to time. It shows that airports were keen to see the growth of LCCs and recognized that the current facilities provided are not appropriate for LCCs. The main airports have responded by either redeveloping existing facilities (old passenger terminal and old cargo terminal) or building new facilities.

The LCT developments throughout the world are different from one area to another. In Europe, even though LCCs already have extensive choices of uncongested secondary airports, the development of LCT in main airports keeps increasing and it triggered by the rapid growth of LCCs in the European market. Most LCTs are located in Europe and less of them are located in United States and Asia Pacific. In Asia, airlines for the most part do not have the secondary airport option, with the result that most services are between primary airports. Implementation of LCT in Asia was started in 2006, pioneered by Kuala Lumpur International Airport (KLIA) in Malaysia and Changi Airport in Singapore.

There are several LCTs currently in the process to be opened to accommodate growing traffic from LCCs. According to CAPA (2009)[4)], CPH Swift Terminal in Copenhagen Airport will be opened before the end of 2010 and LCT in Brussels International Airport is planned to be opened in April 2011. There are also several new

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proposed plans for LCT development, such as LCT in Kiev Borispool International Airport and Xiamen Airport. Table 1 shows the list of existing LCTs worldwide.

Table 1: List of LCTs worldwide

Low Cost Terminal	Opening Year	LCCs Operating	Description
Terminal 2 in Tampere Pirkkala (Finland)	2003	Ryanair, Wizz Air	Conversion of cargo terminal
Terminal 1 in Budapest Ferihegy Airport (Hungary)	2005	Ryanair, EasyJet, Wizz Air, Norwegian Air Shuttle, Germanwings, Jet2	Refurbished old terminal
Pier H & M in Schiphol Airport (Netherlands)	2005	BMIbaby, Flybe, EasyJet, Jet2, Air Berlin	Piers off existing terminal
Concourse A/B in Baltimore – Washington Airport (USA)	2005	Southwest, Jet Blue	Renovation and extension of old concourse
Terminal 2 in Marseille Provence Airport (France)	2006	Ryanair, Jet4you, Germanwings, EasyJet, Pegasus Airlines	Conversion of cargo terminal
Terminal 2 in Milan Malpensa Airport (Italy)	2006	EasyJet, Germanwings	Refurbished old terminal
Low Cost Carrier Terminal in Kuala Lumpur Airport (Malaysia)	2006	Air Asia, Lion Airways, Tiger Airways, AirAsia X, Jetstar	Newly built terminal
Budget Terminal in Changi Airport (Singapore)	2006	Tiger Airways, AirAsia, Thai AirAsia, Jetstar	Newly built terminal
Terminal 3 in Lyon Saint Exupery Airport (France)	2008	EasyJet, Transavia France	Conversion of old passenger terminal
Terminal 5 in John F. Kennedy Airport (USA)	2008	Jet Blue	Newly built terminal focusing on old TWA terminal
Budget Terminal in Zhengzhou Airport (China)	2008	Spring Airlines, Shenzen Airlines	Renovated temporary international hall
Bordeux Illico in Bordeaux Airport (France)	2010	BMIbaby, Flybe, EasyJet, Jet2, RyanAir, Norwegian Air Shuttle	Newly built terminal

Source: Graham (2008) and CAPA (2009)

LCTs are opened in airports with an intention to obtain traffic volume from LCC segments. Figure 1 shows numbers of passengers of four LCTs. The LCT in KLIA and LCT in JFK have attracted more than 10 million passengers in 2008 and 2009.

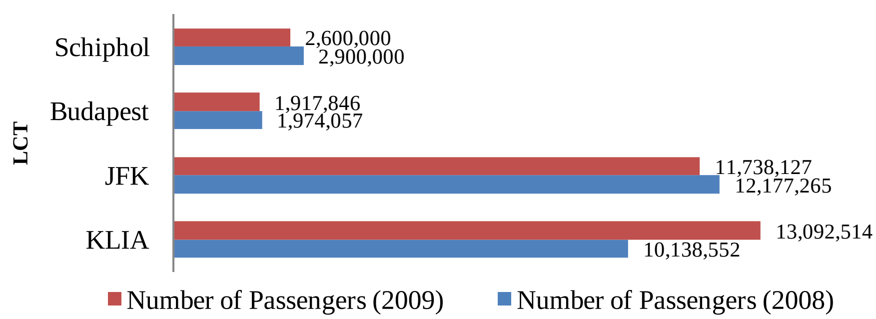

Figure 1: Number of Passengers in LCTs (Source: Respective Airports)

LCT in KLIA is mainly used by AirAsia, the leading LCC in Asia. LCT in KLIA is proved to be beneficial for AirAsia. It has contributed to AirAsia's cost reduction and output expansion (Zhang et al., 2008). LCT in JFK is dedicated for JetBlue Airways. The number of passengers for LCTs in Schiphol and Budapest is currently around one fifth of passengers in LCTs in KLIA and JFK. This is clearly influenced by the capacity of the LCT itself. The construction area for LCT in KLIA and JFK is 35,290 m^2 and 58,000 m^2 respectively. On the other hand, the construction area for LCT in Schiphol is 6,150 m^2, while it is 7,990 m^2 for LCT in Budapest. The trend of traffic is slightly decreasing from 2008 to 2009 for LCT in Europe and America, while traffic in LCT in KLIA keeps increasing.

(2) Low Cost Airport

In addition to LCT development, the transition from secondary airport to Low Cost Airport (LCA) also arose as the effect of increasing growth of LCCs industry. A secondary is defined as an under-utilized and reliever airport that complements the main or primary airport of a city (Sabar, 2009)[5)]. This trend happened mostly in Europe, North America, and Australia. In North America, there is little urgency to develop separate terminal for LCCs since most of the airlines are happy to share facilities and the cost of operation at US airports is only 4-6% of their total cost (CAPA, 2009). Therefore, LCCs in North America mainly rely on secondary airports that are slowly shifted into LCAs. Table 2 shows the list of existing LCAs.

Table 2: List of LCAs worldwide

Low Cost Airport	LCCs Operating	Origin prior to development
Conventry - West Midlands Airport (UK)	Thomsonfly, Wizz Air	Secondary airport
Robin Hood Doncaster Airport (UK)	Ryanair, Flybe, EasyJet, Thomsonfly, Wizz Air	Converted military airport
Glasgow Prestwick Airport (UK)	Ryanair, Flybe, Wizz Air	Secondary airport
Stanted Airport (UK)	Ryanair, EasyJet, Germanwings	Secondary airport
Parma Airport (Italy)	Ryanair	Secondary airport
Uppsala Airport (Sweden)	Ryanair, EasyJet, Wizz Air	Converted military airport
Pittsburgh Airport (USA)	Jet Blue, Southwest	Regional hub airport
Dallas Love Field (USA)	Southwest	Regional hub airport
Hamilton Ontario Airport (Canada)	Westjet	Regional airport
Macau Airport (China)	Viva Macau, AirAsia, Jetstar, Tiger Airways	Regional airport
Ibaraki Airport (Japan)	Skymark	Secondary airport
Avalon Airport (Australia)	Jetstar, Tiger Airways, AirAsia X	Regional airport
Newcastle Airport (Australia)	Jetstar, Tiger Airways	Regional airport
Gold Coast Airport (Australia)	AirAsia X, Jetstar, Tiger Airways, Virgin Blue	Regional airport

According to the record of LCT and LCA developments worldwide, the implementation of low cost facilities in airport can be categorized into two concepts based on the trigger factor: (1) airport-driven, or (2) airline-driven. Airline-driven execution can occur if there is one main LCC operated in the airport. Dedicated terminal in KLIA was specially requested by AirAsia, while budget terminal in Changi is prepared for Tiger Airways' base. Terminal 5 in John. F. Kennedy (JFK) Airport is managed directly by Jet Blue Airways. The implementation of LCA in North America is also generally triggered by the dominated LCC, for example Southwest who dominates traffic in Dallas Love Airport and also Westjet who underpins domestic operation in Hamilton Ontario Airport. Both of the airports slowly shifted their business model to suit LCC operation. For Ibaraki Airport case, the Skymark plays a big role in shifting Ibaraki as the Tokyo's secondary airport into LCA.

The initiative of low-cost facilities development is came from the airport side (airport-driven) when the airport manager see the opportunity of growing LCCs industry and the airport tends to attract as many LCCs as possible. This concept can be seen from the new Bordeaux Illico terminal in Bordeaux Airport who successfully attracts around 6 LCCs to fly to/from the new-built terminal.

3. Suitable Configuration for Low Cost Terminal

In this study, suitable configuration for LCT will be examined. Parameters considered are passenger walking distance and construction area. These two parameters are chosen because they highly affect time and cost performance in LCT, for both aircraft and airport. Passenger walking distance affects time needed by passengers to embark to aircraft, thus tends to increase turnaround time of the aircraft and also affect passenger disutility. Moreover, LCT is an additional facility that is built after the airport started operation and the available area is limited. Therefore it is important to choose the configuration that minimizes construction area.

There are 4 terminal configurations discussed: (1) linear; (2) single pier, (3) T-shaped pier, and (4) Y-shaped pier. They are simple configurations that are suitable for LCT. Satellite and transporter configurations require highly-cost automatic passenger mover (APM) that is not preferable for LCT. The average walking distance is calculated as total walking distance required to travel from end point of waiting area to each gates (from the most distant and the closest gate) divided by the number of gates. In LCC business process, transferring passenger is treated in similar way with arriving and departing passengers since most LCCs serve point-to-point flights. To make connection with LCC, two separate tickets are needed and they will be counted as separate contracts. The connection point will be treated as final destination and the transfer passengers need to check in again as if they depart from that airport. As a result, transfer passengers cannot directly travel from one gate to another.

The construction area and average passenger walking distance can be calculated using the formulas provided in Table 2 and Table 3. The distance between gates is assumed similar. This assumption is reasonable since most LCCs are using one type of aircraft, thus the space needed for gates and aircraft stand is similar. Formulas provided are applicable for even number of gates (symmetrical configuration). In Y-shaped pier configuration, the angles between arms are assumed to be 120^{o}. The formulas can be changed easily to suit the gate configuration problem in the real world, for instance, the unequal length of the arm piers.

Table 3: Construction area

Terminal configuration	Construction Area
Linear	Ndw
1 Pier	$\frac{N}{2}dw$
T-shaped Pier	$w\left\{\frac{1}{2}dN + 3y\right\}$
Y-shaped pier	$w\left\{\frac{1}{2}dN + 3y + \frac{1}{4}\sqrt{3}w\right\}$

Table 4: Total and average walking distance

Terminal configuration	Average	Condition
Linear	$\frac{2w + d}{2}$	Number of entrance points $= \frac{N}{2}$
1 Pier	$\frac{\sum_{i=0}^{n=\left(\frac{N}{2}-1\right)} 2(\frac{1}{2}d + di + \frac{1}{2}w)}{N}$	Pier has even number of gates
T-shaped Pier	$\frac{\sum_{i=0}^{n=\left(\frac{N_1}{2}-1\right)} 2(\frac{1}{2}d + di + \frac{1}{2}w) + \sum_{i=0}^{n=\left(\frac{N_2}{4}-1\right)} 4\left\{\left(d\frac{N_1}{2} + 2y + \frac{1}{2}w\right) + \left(\frac{1}{2}d + di + \frac{1}{2}w\right)\right\}}{N_1 + N_2}$	Piers in arm position have the equal length and number of gates $N = N_1 + N_2$ N_1 = number of gate in main concourse. N_2 = number of gate in arm piers
Y-shaped pier	$\frac{\sum_{i=1}^{n=\left(\frac{N_1}{2}-1\right)} 2(\frac{1}{2}d + di + \frac{1}{2}w) + \sum_{i=0}^{n=\left(\frac{N_2}{4}-1\right)} 4\left\{\left(d\frac{N_1}{2} + 2y + \frac{1}{3}\sqrt{3}w\right) + \left(\frac{1}{2}d + di + \frac{1}{2}w\right)\right\}}{N_1 + N_2}$	

Where: N = number of gates in the terminal (i = 1, …, N), d = distance between gates, w = width of the piers, y = clearance between main concourse and arm piers on the inner side.

4. Model Development

In this study, mathematical model is developed to solve the problem of terminal site and terminal configuration determination for LCT more systematically. The concept of the optimization model can also be implemented for location and configuration of other types of terminal. The main idea is to find the best terminal site and configuration for LCT that minimize the distance travelled by passengers and aircrafts according to the number of aircraft gates desired. The mathematical model has two objectives. Objective (1) minimizes average passenger walking distance from waiting point to aircraft gates. Objective (2) minimizes average aircraft taxiing distance required from runways to apron area and vice versa.

With the above discussion in mind, the following notation and model formulation are presented below. Consider an airport in a network that has a potential growth of LCCs and the decision maker wants to build a new terminal to serve LCCs. It is required to find the location and configuration such that the total distance travelled by passengers and aircraft is minimized.

$i = 1, 2, \ldots, l$	index for alternative sites for the new terminal
$j = 1, 2, \ldots, m$	index for terminal configurations
$k = 1, 2, \ldots, n$	index for runway points for departing and arriving aircrafts
x_{ij}	number of aircraft gates that can be accommodated in new terminal site i with configuration j
$f(x_{ij})$	passenger walking distance as a function of the number of aircraft gates x_{ij} in terminal site i with configuration j
d_{ik}	taxi-out distance required to travel by aircraft from terminal site i to runway point k
d_{ki}	taxi-in distance required to travel by aircraft from runway point k to terminal site i
A_{ij}	capacity available for aircraft gates in terminal site i with configuration type j; each terminal site has different area thus has different capacity for accommodating aircraft gates
z_{ij}	equals to 1 if new terminal opens in site i with configuration j, 0 otherwise

Model Formulation

$$\text{Min } DW = \sum_i \sum_j z_{ij} f(x_{ij}) \qquad (1)$$

$$\text{Min } DT = \frac{1}{n} \sum_i z_{ij} \sum_k (d_{ik} + d_{ki}) \qquad (2)$$

Subject to:

$$x_{ij} \leq A_{ij} \quad \forall\, i, j \qquad (3)$$

$$\sum_i \sum_j z_{ij} = 1 \qquad (4)$$

$$z_i, z_j \in (0,1) \quad \forall\, i, j \qquad (5)$$

Both objective functions use (0,1) multipliers z_{ij}. The role of z_{ij} is to assure the choice of one site and one configuration for the new terminal. The model is built based on the assumption that the decision maker has decided how many airport gates will be built in the new terminal. The value of x_{ij} will be set according to the decision. In objective (1), walking distance $f(x_{ij})$ is calculated based on the determined x_{ij} by using average passenger walking distance equations provided in Section 3 (Table 5). Objective (2) aims to minimize average total taxi-out and taxi-in distance from n available runways in airport. Constraint (3) guarantees that the number of aircraft gates desired in new terminal site i with configuration j does not exceed the capacity of the new terminal site, A_{ij}. Constraint (4) and (5) guarantees that only one new site with one configuration should be chosen as a solution.

The weighted sum of the objective method can be applied to solve bi-objective optimization of terminal location and configuration problem. The basic idea of weighted sum method is to combine both objective functions in one single functional form. It entails selecting scalar weights (w_i) and minimizing the following composite objective function: $\sum_{i=1}^{k} w_i F_i$. If all the weights are positive, then minimizing U function provides a sufficient condition for Pareto optimality, which means the minimum of U is always Pareto optimal (Zadeh, 1963)[6)].

The paired comparison method is chosen to set the weights because it provides systematic means to rate objective functions by comparing them. One function is treated as a reference function. Weight w_i represents the tradeoff between F_i and the reference function at the solution point to the weighted sum problem (Marler & Arora, 2009)[7)]. Considering the solution to the weighted sum problem is always Pareto optimal, the slope of the Pareto optimal curve is determined as $\frac{d\,F_2}{d\,F_1} = -\frac{w_1}{w_2}$. The left side can be approximated as $\frac{\Delta\,F_2}{\Delta\,F_1}$.With knowledge of the objectives and careful selection of the weights, the final solution may reflect the intended preferences that are incorporated in the weight.

In terminal location and configuration problem, F_1 refers to walking distance (DW) function and F_2 refers to taxiing distance (DT) function. In order to obtain the weights (w_1 and w_2), passenger value of time per unit distance will be compared to aircraft value of time per unit distance according to US FAA (2007)[8)]. Since LCC passengers dominated by leisure/nonbusiness passenger, we use personal passenger value of time ($23.30), instead of business ($45.00) or general passenger value of time ($37.20). The information about average passenger walking speed and average aircraft taxiing speed are also available, therefore, we can obtain passenger time value and aircraft time value per unit distance.

Table 5: Passenger and aircraft time value

Passenger time value (personal trip)	$23.30/ hour
Aircraft variable cost	$362.00 / hour
Average passenger walking speed	4.32 km/hour
Average aircraft taxiing speed	30 km/hour
Passenger time value	$0.00539/ meter
Aircraft time value	$0.01207 /meter

5. Conclusion

This study has presented a method to determine location and configuration of LCT in an airport by considering aircraft taxiing distance and passenger walking distance. LCCs, as the main clients of LCT, care about passenger walking distance and aircraft taxiing distance because it affects their operational time and cost. Small savings in time may appear insignificant, but when cumulated over a day they can have a major impact. Besides, the development of LCT is generally held after airport started the operation, therefore it is important to choose the efficient location and configuration when the available land is limited. However, the concept of the optimization model presented in this study can be implemented for other types of terminal.

The solution of location and configuration problem is found by solving the linear integer programming model. The weighted sum method is used to combine the two objective functions into single objective function. The weight of each objective function is determined using pair comparison method. Although such model presented involves considerable simplification of the real world, it yields results that can be helpful in making some judgments regarding the solution to the problem.

This paper also gives insight about LCT & LCA industry worldwide and can be categorized as a pioneer in this topic area. Despite the merits, the proposed model points a number of directions for future work. The model can be expanded to include other elements such as construction cost. Future works can pay closer attention in defining passenger and aircraft time value. The model can be tested using more realistic data for the expanded area.

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