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AIRPORT TERMINALS - OPTIMUM CONFIGURATIONS AND GATE POSITION REQUIREMENT

BY

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "Airport Terminals - Optimum Configurations and Gate Position Requirement", submitted by J. M. S. J. Bandara in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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Abstract

Passenger walking distance is a major consideration in determining the geometry of an airport terminal configuration. The number of aircraft gate positions and the expected passenger mix are the significant elements to be considered in planning new terminal buildings.

Two different methods: 1) level of service method, 2) minimum cost method, are reported to determine the gate position requirement. The level of service method is used to calculate the number of gate positions that are required to provide a given level of reliability. The randomness of the relevant parameters; aircraft arrival rate at the gate positions, gate occupancy time and the aircraft separation time at gates, is taken into account in the analysis. The gate requirement at Calgary International Airport is analyzed for common and preferential gate use policies. In the minimum cost method, an optimum number of gate positions that will minimize the sum of the cost of gates and the cost of delay to aircraft is obtained. An approximate procedure to determine the deterministic delay to aircraft, based on the information regarding the peaking of the aircraft arrival rate and the number of peaks per day is presented. Closed-form solutions are obtained for the cases of one peak and several identical non- overlapping peaks respectively. The optimum number of gates required for the Calgary International Airport, based on a common gate use policy, is reported.

Given the size of a terminal in terms of the number of aircraft gates, an analytical expression is obtained for the mean passenger walking distance based on: the fraction of arriving, departing and transferring (hub and non-hub) passengers;

gate spacing; spacing requirement for aircraft maneuvering; and the terminal block dimensions. Commonly used configurations of pier, satellite and pier-satellite terminals are considered for the analysis. It is assumed that all aircraft parking positions are capable of handling any type of aircraft and arriving, departing and non-hub transferring passengers are equally distributed among all the gate positions. Two groups of hub transfers are defined to accommodate different levels of hub and spoke operations.

A continuum approximation is used to model passenger walking within the piers or the satellites. Walking distance between the piers or the satellites are modeled using discrete methods. The optimum geometry in terms of the number of piers or satellites and their sizes, is obtained by minimizing the mean walking distance for all the passengers. When there is no closed-form solution for the optimum number of piers or satellites, lower and upper bounds of the optimum number of piers or satellites is obtained so that the optimum geometry can be obtained using numerical methods. The optimum number of piers or satellites is proportional to the square root of the total number of gates for some of the configurations.

The probability distribution of the walking distance of a passenger is generated by simulation. Given an acceptable maximum walking distance, several statistical parameters that are suitable to choose the best configuration from among several optimum geometries are suggested. A numerical example to illustrate the selection of the best terminal geometry for the LaGuardia main terminal, Atlanta Hartsfield terminal and for a hypothetical terminal is presented. Examples to illustrate the effect of people mover systems on walking distance and the use of the suggested technique for a terminal expansion situation are also given.

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Notation

a_T - The clearance requirement for aircraft parking at the intersection of two satellite arms in T-shaped satellites.

a_Y - The clearance requirement for aircraft parking at the intersection of two satellite arms in Y-shaped satellites.

a' - $4(A_M - \bar{A})/T_0^2$.

a'' - $2(A_M - \bar{A})/T_0$.

A - Arrival rate of aircraft.

$\bar{A}$ - Mean arrival rate.

A_E - Area between the arrival rate curve and the service rate curve.

A_M - Maximum aircraft arrival rate during a peak period.

A_{MP} - Maximum aircraft arrival rate at any particular time.

A_P - Peak hour aircraft arrivals.

$\bar{A}_P$ - Expected value of peak hour aircraft arrivals.

$A(t)$ - Aircraft arrival rate at time t.

b_p - Combined mean walk for arriving and departing passengers within the terminal block in pier terminals.

b_S - Combined mean walk for arriving and departing passengers within the terminal block in satellite terminals.

b_t - Number of schedule flights at time t.

B_{OC} - Shortest distance between the intersection point of the extended connector centerlines and the perimeter of the largest satellite in a semi-centralized circular satellite.

B_{OR} - Shortest distance between the intersection point of the extended connector centerlines and the perimeter of the largest satellite in a semi-centralized rectangular satellite.

B_{OT} - Shortest distance between the intersection point of the extended connector centerlines and the perimeter of the largest satellite in a semi- centralized T-shaped satellite.

B_C - Shortest distance between the intersection point of the extended connector centerlines and the perimeter of a centralized circular satellite.

B_{R1} - Shortest distance between the intersection point of the extended connector centerlines and the perimeter of a centralized type I rectangular satellite.

B_{R2} - Shortest distance between the intersection point of the extended connector centerlines and the perimeter of a centralized type II rectangular satellite.

B_T - Shortest distance between the intersection point of the extended connector centerlines and the perimeter of a centralized T-shaped satellite.

B_Y - Shortest distance between the intersection point of the extended connector centerlines and the perimeter of a centralized Y-shaped satellite.

B_{YP} - Shortest distance between the intersection point of the extended connector centerlines and the perimeter of a centralized Y-shaped pier- satellite.

B_{TP} - Shortest distance between the intersection point of the extended connector centerlines and the perimeter of a centralized T-shaped pier-satellite.

B_M - Minimum clearance requirement between the terminal block and a satellite.

c - Marginal capital, maintenance and operating cost of a gate position per day.

C - Design hour volume for aircraft arrivals and departures.

C_g - Gate capacity.

C_{op} - Annual operating cost.

C_t - Wing tip clearance.

C_T - Total delay and capital cost.

CCS - Centralized circular satellite.

CRP - Centralized radial pier.

CRS - Centralized rectangular satellite.

CSP - Centralized standard satellite.

CTS - Centralized T-shaped satellites

$CTPS$ - Centralized T-shaped pier-satellite.

$CYPS$ - Centralized Y-shaped pier-satellite.

D_S - Maximum distance from the intersection point of the extended connector centerlines to the perimeter of the terminal block.

D_T - Total delay to aircraft per hour.

E - $T_0(A_M - \bar{A})/A_E$.

F - Cumulative density function of Type I extreme value distribution.

g_α - Gate requirement for $\alpha\%$ reliability.

G - Number of gate positions.

G_L - Lower bound of the gate position requirement.

k - Average cost of delay to airline and passengers per aircraft per hour.

K_0 - $1 + P$.

K_1 - $1 + P - 4PQ/3$.

K_{1r} - $1 + P - 4PQr/3$.

K_{1ra} - $1 + P - 4PQr_a/3$.

K_2 - $1 + P - 2PQ$.

K_{2ra} - $1 + P - 2PQr_a$.

K_{2ro} - $1 + P - 2PQr_O$.

K_{3r} - $2PQ(1 - r)$.

K_4 - $2P(1 - Q)$.

K_{4r} - $2P(1 - Qr)$.

K_{5ra} - $1 + P - 2PQr_a/3$.

L - Total length of the piers.

l_m - Length of the main arm of the largest satellite.

l_{max} - Perimeter length of the largest rectangular satellite.

l_s - Length of a secondary arm of the largest satellite.

L_a - Length requirement for aircraft parking.

L_T - Total linear gate frontage.

L_1 - Linear gate frontage for the i^{th} satellite.

m - Number of taxi lanes.

m_i - Percentage of type i aircraft in fleet mix.

n - Number of piers or satellites.

n_i - Number of peaks with the arrival rate greater than the service rate at the i^{th} step.

N^E - Optimum number of piers for a semi-centralized pier satellite with equal length piers.

N^L - Lower bound of the optimum number of piers or satellites.

N^U - Upper bound of the optimum number of piers or satellites.

N^* - Optimum number of piers or satellites.

$N(t)$ - Total number of aircraft occupying gate positions.

O - Intersection point of the extended connector centerlines.

$p(t)$ - The probability that a flight is present at a gate position.

P - Fraction of transfers with respect the total number of passengers.

P' - Fraction of transfers with respect to the total enplanements.

P_E - The percentage of passengers that walk more than the specified maximum distance.

Q - Fraction of hub transfers.

$Q(t)$ - Aircraft queue at time t.

r - Fraction of hub transfers that are known to depart from the arrival pier or satellite only.

r_a - $r + (1 - r)/n$.

r_o - $(n - 1)(1 - r)/n$.

R - Inscribed radius of the pier base.

R_S - Radius of a circular satellite.

S - Spacing between two piers or centralized satellites.

S_C - Spacing between two semi- centralized circular satellites.

S_g - Spacing between two gate positions.

S_R - Spacing between two semi-centralized rectangular satellites.

S_T - Spacing between two semi-centralized T-shaped satellites.

S_{YP} - Spacing between two centralized Y-shaped pier- satellites.

S_{TP} - Spacing between two centralized T- shaped pier- satellites.

S_1 - Perpendicular clearance requirement at each pier base in radial pier terminals.

SCS - Semi-centralized circular satellite.

SPP - Semi-centralized parallel pier.

SRS - Semi-centralized rectangular satellite.

STS - Semi-centralized T-shaped satellite.

t - Time.

t_m - Time at which the aircraft arrival rate is a maximum.

t_S - Aircraft separation time.

$\bar{t}_S$ - Mean of the aircraft separation time.

T - Gate occupancy time.

$\bar{T}$ - Mean gate occupancy time.

T_0 - Time during which aircraft arrival rate exceed its mean value.

U - Gate utilization factor.

w_i - A portion of average walking distance in a centralized-standard pier terminal.

$\bar{W}$ - Mean walking distance for all passengers.

$\bar{W}_A$ - Mean walking distance for arriving and departing passengers.

W_E - Excess walking distance.

$\bar{W}_E$ - Excess mean walking distance.

$\bar{W}_H$ - Mean walking distance for hub transfers.

$\bar{W}_{H1}$ - Mean walking distance for hub transfers that are known to depart from the arrival pier or satellite.

$\bar{W}_{H2}$ - Mean walking distance for hub transfers that are equally likely to depart from any gate in the terminal.

W_{max} - Acceptable maximum walking distance.

$\bar{W}_N$ - Mean walking distance for non-hub transfers.

W_p - Width of a pier.

W_s - Width of a satellite arm

W_t - Taxi lane width.

$W_{.85}$ -Eighty fifth percentile of the cumulative walking distance distribution.

x - Length of a rectangular satellite.

x_i - length of the i^{th} pier or a secondary arm of the i^{th} satellite.

X - Entrance point from the terminal block to the concourse connecting the piers in a centralized-standard pier terminal.

y - Width of a rectangular satellite.

α - Half of the angle subtended at the center of a circular satellite by a aircraft parked at a gate position.

β - Angle of spread.

Δt_S - Error in the estimate of t_S.

ΔU - Error in the estimate of U.

θ - Half of the angle subtended by two piers or satellite connectors at the intersection point of their extended centerlines.

λ - $\mu - \bar{A}$.

μ - Aircraft service rate (aircraft per hour).

μ^* - Optimum service rate.

σ_A^2 - Variance of aircraft arrival rate.

σ_G^2 - Variance of gate position requirement.

$\sigma_{t_S}^2$ - Variance of aircraft separation time.

σ_T^2 - Variance of gate occupancy time.

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