Dynamic runway configurations and flexible arrival / departure tradeoffs in metroplex airports

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Abstract—Runway system is central to airport capacity. Its inefficient utilization has been identified as a major source of airport congestions. This paper analyzes the patterns of demand-capacity imbalance and design a series of flexible strategies for air traffic demand management (ATDM), and then optimize runway configurations in metroplex (i.e. multi-airport system) airports, under a set of tradeoff settings for arrival and departure priorities. An optimization model with 4 imbalance cases, 11 tradeoff scenarios and 2 configuration strategies, are proposed to minimize the flight holding cost and the number of adjusted flights. The proposed evolutionary algorithm can obtain close-to optimal results with a very low computational cost. A case study of the Shanghai metroplex airports shows that, compared with the traditional static strategy, the proposed dynamic strategy can significantly reduce the number of adjusted flights. The proposed framework in this paper can be applied on pre-tactical (i.e. one-day planning) as well as tactical (i.e. 2-h rolling horizon) levels, to keep the balance between high demand and limited capacity through flexible ATDM options.

Keywords—air transport, metroplex, runway configuration, tradeoff, optimization, evolutionary algorithm

I. INTRODUCTION

The imbalance between demand and capacity has become a major concern in global air transport system, due to increasing traffic and insufficient capacity [1]. The resulting congestions and delays experienced at high-density traffic airports, incur significant costs to the relevant air transport stakeholders such as air navigation service providers, airport operators and airlines [2-3]. At major hub airports around the world, the runway system has been identified as a critical resource bottleneck in airport operations. Actually, the runway system is central to airport capacity and its configuration has significant influence on the demand-capacity balance (DCB) and the system-wide efficiency of air traffic operations in airports. Especially for a metroplex where a grouping of airports are in close geographic proximity with each other, the runway configuration of one airport has some effect on other airports simultaneously used for landing and takeoff.

Runway configuration, also known as the mode of runway operations, refers to the combination of runways that are active at any particular time in an airport system [4-5]. In choosing the runway configuration, air traffic controllers generally consider factors such as weather (wind and visibility), runway layout, runway availability, traffic volume, environmental

considerations such as noise abatement procedures, and the coordination of flows with neighboring airports. The current research focuses on the strategic configuration [6] and tactical configuration [7], taking into account the needs for decision-making and operation during different phases of airport activities. The runway configuration models are generally formulated based on the runway configuration capacity envelope (RCCE) which limit arrival and departure capacities. The RCCE is a piecewise linear curve representing the tradeoff between arrival movements and departure movements which can be served during a period of time (e.g., 15 minutes, 30 minutes or 1 hour) [8]. Given the weather, traffic demand and current runway configuration, some probabilistic and optimized models are proposed to predict the configuration of runway resources [9-10]. By adding uncertainty during airport operations to arrival demand in all planning time periods, the robust optimization theory is applied to minimize the average delay cost [11]. Besides the above influencing factors so far, others are also considered to analyze the flight delays during runway configuration. For example, reducing the number of runways is recognized as the primary factor in causing congestions and delays, with the secondary factors being reduced approach precision and high workload arising from uncommon runway configuration [12].

However, research to date ignores the impact of ATDM strategies on runway configurations in metroplex systems and mainly focuses on the runway configuration in a single airport system with a single-objective optimization. Hence, this paper is aimed at optimizing the selection of runway configurations in metroplex airports using flexible tradeoffs of the priorities between arrivals and departures. We analyze different categories of air traffic demand management (ATDM) options and their impact on runway capacity management, with the goal of runway configuration by integrating ATDM with capacity management. An optimization model is formulated for runway configuration in metroplex system under multiple objectives including flight holding cost (economic view) and number of adjusted flights (punctuality view). The designed evolutionary algorithm can obtain close-to optimal results with a very low computational cost. The model proposed in this paper allows the pattern analysis of demand and capacity balance (DCB), and optimization of the combination of runway configurations under different ATDM options for metroplex airports. The goal is to improve the effectiveness of runway configuration management and the flexible of arrival / departure tradeoffs in metroplex airports.

II. METHODOLOGY

A. Air Traffic Demand Management Options

Whenever the air traffic demand exceeds the capacity, some measures of flight adjustment should be taken to ensure they can match each other well inside the RCCE. We divide all the mismatch points into 4 categories: *arrival outside and departure inside* (AODI), *arrival inside and departure outside* (AIDO), *arrival inside and departure inside* (AIDI) and *arrival outside and departure outside* (AODO). The ATDM options include 3 categories: *adjusting arrivals and not adjusting departures* (YAND), *not adjusting arrivals and adjusting departures* (NAYD) and *adjusting both arrivals and departures* (YAYD). Figure 1 illustrates the ATDM options under 4 cases of imbalance between demand and capacity.

Figure 1. ATDM options under different imbalance cases

1) Case a: AODI

Case a corresponds to the points R1 and R2 in Figure 1 and means that the RCCE does not have sufficient capacity to accommodate the number of arrivals (i.e. the arrival demand exceeds the *saturated arrival capacity* - SAC), but has sufficient capacity for the departures (i.e. the departure demand does not exceed the *saturated departure capacity* - SDC). Based on the *restricted departure capacity* (RDC), Case a can be divided into two subcases Case a-1 and Case a-2, of which the ATDM options are YAND and YAYD respectively. The flight adjustment function to calculate the arrival and departure queue (i.e. the adjusted number of aircraft) for Case a is

$$Adj (Case a) = \begin{cases} R_1 \rightarrow R_1' & , Case a-1 \\ R_2 \rightarrow R_2' R_2'' & , Case a-2 \end{cases} \quad (1)$$

2) Case b: AIDO

Case b corresponds to the points R3 and R4 in Figure 1 and means that the RCCE does not have sufficient capacity to accommodate the number of departures, but has sufficient capacity for the arrivals. In other words, all the points in the area of Case b reveal the fact that the departure demand exceed the SDC and the arrival demand does not exceed the SAC.

Based on the *restricted arrival capacity* (RAC), Case b can be divided into two subcases Case b-1 and Case b-2, of which the ATDM options are NAYD and YAYD respectively. The flight adjustment function to calculate the arrival and departure queue for Case b is

$$Adj (Case b) = \begin{cases} R_3 \rightarrow R_3' & , Case b-1 \\ R_4 \rightarrow R_4' R_4'' & , Case b-2 \end{cases} \quad (2)$$

3) Case c: AIDI

Case c corresponds to the point R5 in Figure 1 and means that the RCCE has sufficient capacity to accommodate the number of arrivals and departures separately, but does not have sufficient capacity for the sum of the number of arrivals and departures. In other words, all the points in the area of Case c reveal the fact that the arrival demand does not exceed the SAC, and the departure demand does not exceed the SDC. However, the sum of the arrival and departure demand exceeds the range of the RCCE. Case c has no subcases, of which the ATDM options are YAND, NAYD and YAYD respectively. The flight adjustment function to calculate the arrival and departure queue for Case c is

$$Adj (Case c) = R_5 \rightarrow R_5' R_5'' \quad (3)$$

4) Case d: AODO

Case d corresponds to the point R6 in Figure 1 and means that the RCCE does not have sufficient capacity to accommodate the number of arrivals or departures. That is to say, all the points in the area of Case d reveal the fact that the arrival demand exceeds the SAC, and the departure demand exceeds the SDC. Case d has no subcases, of which the ATDM option is YAYD. The flight adjustment function to calculate the arrival and departure queue for Case d is

$$Adj (Case d) = R_6 \rightarrow R_6' R_4'' / R_4'' R_5'' / R_5'' R_2'' / R_2'' R_6'' \quad (4)$$

According to Figure 1 and the expressions (1)~(4), Table 1 illustrates the selection strategy of ATDM options under the imbalance cases of AODI, AIDO, AIDI and AODO.

Table 1 ATDM option selection strategy under different imbalance cases

ATDM options	Case a		Case b		Case c	Case d
	Case a-1	Case a-2	Case b-1	Case b-2		
YAND	√	√	×	×	√	×
NAYD	×	×	√	√	√	×
YAYD	×	√	×	√	√	√

In order to quantify the modeling of ATDM options, we propose two parameters $p_a, p_d \in [0,1]$ to define the priority of arrival and departure movements. And $p_a + p_d = 1$. For example, $p_a = 1, p_d = 0$ means that the arrival movements have an absolute priority on punctuality. In other words, departure aircraft are adjusted to keep the DCB. Table 2 presents the priority and scenario under the ATDM options.

Table 2 Priority and scenario settings under the ATDM options

ATDM options	Priority settings	Tradeoff scenarios
YAND	$p_a = 0, p_d = 1$	(0,1)
NAYD	$p_a = 1, p_d = 0$	(1,0)
YAYD	$0 < p_a, p_d < 1$	(0.1,0.9)~(0.9,0.1)

Based on the above 4 imbalance cases in RCCE, we design 11 tradeoff scenarios of ATDM with different arrival / departure priority settings, which includes:

- (1) 1 strategy of prior arrival adjustment: {(0,1)};
- (2) 1 strategy of prior departure adjustment: {(1,0)};
- (3) 9 strategies of the arrival and departure tradeoffs: {(0.1,0.9), (0.2,0.8), (0.3,0.7), (0.4,0.6), (0.5,0.5), (0.6,0.4), (0.7,0.3), (0.8,0.2), (0.9,0.1)}.

B. Model Formulation

Consider a set of airports A in a metroplex system, we focus on formulating a multi-objective optimization model for the dynamic runway configuration problem. Let S be the set of intervals in the planning horizon, indexed by t . Each airport i ($i \in A$) has an available runway configuration set denoted as M_i , depending on the factors including wind, visibility, runway status. Let $M_{it} \subseteq M_i$ be the set of available runway configurations in the interval t ($t \in S$) at airport i ($i \in A$), indexed by k . Let Φ be the set of ATDM cases proposed in Table 1, indexed by l . Note that $l=1, \dots, 6$ corresponds to *Case a-1*, *Case a-2*, *Case b-1*, *Case b-2*, *Case c*, *Case d*. The notations of the model are shown in Table 3.

Table 3 Notations of the model

Variables

- ξ_{itk} is 1 if configuration k is used in interval t at airport i , and 0 otherwise.
- τ_{itl} is 1 if case l is the imbalance No. of DCB in interval t at airport i , and 0 otherwise.
- σ_{itk} is 1 if configuration k used in interval t at airport i will be switched to a new configuration at the end of interval t , and 0 otherwise.
- ϕ_{it} (ϕ_{it}) is the number of served arrivals (departures) in interval t at airport i
- p_{it} (q_{it}) is the number of extra / adjusted arrivals (departures) at the end of interval t at airport i

Parameters

- p_a (p_d) is the weight coefficient of priority for arrival (departure) movements

- a_{it} (d_{it}) is the number of scheduled arrivals (departures) in interval t at airport i
- χ_{it} (η_{it}) is the airborne (ground) holding cost for arrivals (departures) at the end of interval t at airport i
- Λ_{itk} is the set of linear segments defining the RCCE for configuration k in interval t at airport i
- α_{itkj} (β_{itkj}) is the coefficient for arrivals (departures) of segment j for configuration k in interval t at airport i
- γ_{itkj} is the constant of segment j for configuration k in interval t at airport i
- Z_{itkj} is a large constant associated with segment j for configuration k in interval t at airport i
- C_t is the maximum acceptance rate of metroplex system in interval t
- ω_i is the capacity loss coefficient during configuration transition at airport i

In this paper, we formulate a multi-objective runway i configuration model to minimize the flight holding cost (economic view) and number of adjusted flights (punctuality view) in metroplex airports, subject to a variety of constraints. For example, the constraints of exclusive configuration selection, identification of demand management case, configuration transition, RCCE feasible space, traffic flow conservation, maximum acceptance rate are considered. The problem can then be formulated as follows:

$$\min \sum_{i \in A} \sum_{t \in S} \sum_{k \in M_{it}} \sum_{l \in \Phi} \xi_{itk} \tau_{itl} (\chi_{it} p_{it} + \eta_{it} q_{it}) \quad (5)$$

$$\min \sum_{i \in A} \sum_{t \in S} \sum_{k \in M_{it}} \sum_{l \in \Phi} \xi_{itk} \tau_{itl} (p_{it} + q_{it}) \quad (6)$$

subject to

$$\sum_{k \in M_{it}} \xi_{itk} = 1, \forall i \in A, \forall t \in S \quad (7)$$

$$\sum_{l \in \Phi} \tau_{itl} = 1, \forall i \in A, \forall t \in S \quad (8)$$

$$\sigma_{itk} = \begin{cases} \xi_{itk} \xi_{i,t-1,k'}, & k \neq k' \\ 0, & k = k' \end{cases}, \forall i \in A, \forall t \in S \quad (9)$$

$$\alpha_{itkj} \phi_{it} + \beta_{itkj} \phi_{it} \leq \gamma_{itkj} (1 - \sigma_{itk} \omega_i) + Z_{itkj} (1 - \xi_{itk}), \quad \forall i \in A, \forall t \in S, \forall k \in M_{it}, \forall j \in \Lambda_{itk} \quad (10)$$

$$\phi_{it} + p_{it} = a_{it} + p_{i,t-1}, i \in A, \forall t \in S \quad (11)$$

$$\phi_{it} + q_{it} = d_{it} + q_{i,t-1}, \forall i \in A, \forall t \in S \quad (12)$$

$$\sum_{i \in A} (\phi_{it} + \phi_{it}) \leq C_t, \forall t \in S \quad (13)$$

In this formulation, the first objective function (5) is related to the system flight delay that minimizes the total holding cost of all the adjusted arrival and departure flights beyond the RCCE under certain options of ATDM. The second objective function (6) is related to the flight punctuality that minimizes the total number of all the adjusted arrival and departure flights beyond the RCCE under certain options of ATDM. Constraint (7) ensure that only one exclusive runway configuration is selected in any airport i and any interval t . Constraint (8) is similar to (7) and ensure that only one ATDM case is identified in any airport i and any interval t . Constraint (9) ensure that the capacity loss during any two different runway configurations used in two successive intervals must hold. Constraint (10) ensure that any feasible point corresponding to the combination of arrivals and departures must fall into the RCCE. Constraints (11) and (12) ensure that the conservation of air traffic flow between interval t and $t-1$ must hold. In other words, the sum of the number of served and remaining or extra arrivals (departures) in interval t must equal the sum of the number of scheduled arrivals (departures) and number of remaining arrivals (departures) in interval $t-1$. Constraint (13) ensure that the number of served arrivals and departures should not be larger than the maximum acceptance rate.

C. Evolutionary Algorithm

Considering the multiple optimization objectives in our model, we design an evolutionary algorithm, to address the runway configuration problem in metroplex systems, based on the non-dominated sorting genetic algorithm with the strategy of elitist selection [13]. The iteration procedure of the proposed evolutionary algorithm is shown in Figure 2.

Figure 2. Iteration procedure of the evolutionary algorithm

Our evolutionary algorithm use techniques inspired by evolutionary biology such as inheritance, mutation, natural selection, and recombination to find the approximate optimal solutions. The steps of the proposed evolutionary algorithm are presented below.

Step 1: Set the generation number of runway configuration $g = 0$. Generate randomly the initial parent population P_g to represent the configuration number of all the intervals at each airport in the metroplex system in the planning horizon, and calculate the domination parameter n_p of each chromosome, which is defined as the number of solutions that dominate the solution p on the two objectives of holding cost and number of adjusted flights.

Step 2: By applying the genetic operators of binary tournament selection, crossover and mutation to the initial runway configuration parent population P_g , we get the initial runway configuration offspring population Q_g , whose size is the same as that of the initial runway configuration parent population P_g ($|Q_g| = |P_g|$). Then the number of chromosomes in generation g , defined as I_g , equals the sum of the individuals in the initial runway configuration parent and offspring population, $I_g = |Q_g| + |P_g|$.

Step 3: Combine the initial runway configuration parent population P_g and the initial runway configuration offspring population Q_g to form a completed generation $R_g = P_g \cup Q_g$, and assign the non-domination rank of each chromosome based on Pareto non-dominated sorting. Then a number of Pareto frontiers $\{F_s | s = 1, 2, 3, \dots\}$ are created by comparing the rank of each pair of two chromosomes, and all the individuals in the same rank have no relationship of domination on the objectives of holding cost and number of adjusted flights.

Step 4: Calculate the crowding distance of the chromosomes in all the Pareto frontiers, and use the comparison operator to analyze the relationship among different chromosomes in the same Pareto frontier F_s . The chromosomes in the same F_s have the same domination parameter. To keep the diversity of the runway configuration population, we choose the best $|P_g|$ individuals to form the next parent population P_{g+1} . The rule for selecting the optimal runway configuration solutions is firstly based on the non-domination rank and then decided by the crowding distance.

Step 5: Similar to Step 2, the new runway configuration parent population P_{g+1} is used for the new process of binary tournament selection, crossover, and mutation to create a new runway configuration offspring population Q_{g+1} with the same size $|Q_{g+1}| = |P_{g+1}|$. Different from the traditional evolutionary algorithm, we use the method of non-dominated sorting and crowding distance to create high quality individuals in the new generation of runway configuration by selecting the best individuals of size $|P_{g+1}|$, and then use the best P_{g+1} to get a same-sized Q_{g+1} .

Step 6: Analyze whether the current evolutionary process satisfies the pre-set termination condition (for example, the maximum evolution generation) for the problem of runway configuration. If yes, then algorithm ends and outputs Pareto optimal solutions, generating a group of runway configuration solutions. Otherwise, set $g = g + 1$ and proceed to Step 3 for the next iteration.

Note that all the variables τ_{itl} , σ_{itk} , ϕ_{it} , ϕ_{it} , p_{it} , q_{it} can be calculated based on the values of ξ_{itk} . We then use the binary variable ξ_{itk} to generate the gene, in the form of

Figure 3. Rules for the design of each chromosome in the solution space

According to the optimization objectives expressed in (5) ~ (6), the fitness functions of our algorithm are designed in the form of maximum optimizing represented as follows.

$$f_1 = \left\{ \sum_{i \in A} \sum_{t \in S} \sum_{k \in M_{it}} \sum_{l \in \Phi} \xi_{itk} \tau_{itl} (\chi_{it} p_{it} + \eta_{it} q_{it}) + \varepsilon \right\}^{-1} \quad (14)$$

$$f_2 = N - \sum_{i \in A} \sum_{t \in S} \sum_{k \in M_{it}} \sum_{l \in \Phi} \xi_{itk} \tau_{itl} (p_{it} + q_{it}) \quad (15)$$

where $\varepsilon \in (0,1)$ denotes any real number, N denotes total number of arrivals and departures in the planning horizon at the metroplex system.

Let the gene codes on the same position in the old two chromosomes are x and y , we conduct the crossover operation between any two chromosomes, then the gene codes in the new chromosomes can be represented as follows.

$$x' = \text{int} \{ \mu x + (1 - \mu) y \} \quad (16)$$

$$y' = \text{int} \{ \nu y + (1 - \nu) x \} \quad (17)$$

Where int denotes round down function, μ and ν denote random numbers, and $\mu, \nu \in [0,1]$.

III. RESULTS

We conduct a case study of runway configuration in the Shanghai metroplex, which is well known as the most complex

configuration number k , in each chromosome in the proposed evolutionary algorithm. The phenotype of each gene is randomly created in the set of M_{it} , $\forall i \in A, \forall t \in S$. For example, $\xi_{123} = 1$ means the runway configuration $3 \in M_{12}$ is used in interval $2 \in S$ at airport $1 \in A$. Obviously, the number of genes in each chromosome equals to $|A| \cdot |S|$, which is the product of the number of airports in the metroplex and the number of intervals in the planning horizon. Figure 3 illustrates the rules for the design of each chromosome in the solution space.

metroplex system in the world. Using the proposed mathematical model and evolutionary algorithm, we determine the optimal configuration in each interval in the planning horizon for the ZSPD and ZSSS airports. Runway configuration is planned from 10:00 to 20:00, 25 Jul 2013. The configuration change time is assumed to be 1 hour and there are 10 intervals in the planning horizon. The traffic volume in the Shanghai metroplex is 1225, the total number of ZSPD and ZSSS are 708 and 517 respectively, and the total number of arrival and departure aircraft are 634 and 591 respectively. The parameters of the proposed evolutionary algorithm are as follows. The size of runway configuration population in each generation is 100, the maximum evolution number of generation for the problem of runway configuration is 200, and the coding length of each chromosome is 20. The crossover and mutation probability are 0.9 and 0.15 respectively.

Without loss of generality, we firstly set the weight coefficients of arrival and departure priority as $p_a = 0.6$ and $p_d = 0.4$ for analysis. The results under other 10 settings in Table 2 is similar with the setting (0.6, 0.4). Figure 4 shows the changes of the holding cost and number of adjusted flights during the evolution. Figure 4(a) shows that the flight holding cost in the Shanghai metroplex during runway configuration decreases from 627,000 RMB yuan to 283,000 RMB yuan, and tends to optimal at generation No.57. Figure 4(b) and Figure 4(c) are the holding costs of flight in the ZSPD and ZSSS airports, respectively, with the optimal performance achieved at generations No.36 and No.11, respectively. Figure 4(d) shows that the number of adjusted flights in the Shanghai

metroplex decreases from 177 to 81 aircraft, and tends to optimal at generation No.57. In additional, Figure 4(e) and

Figure 4(f) are the number of adjusted flights in the ZSPD and ZSSS airports, respectively.

Figure 4. Changes of the holding cost and number of adjusted flights during the evolution

Figure 5 shows the distribution of the scheduled and remaining flights in the Shanghai metroplex, ZSPD and ZSSS airports. Figure 5(a) shows the number of adjusted arrivals and departures in the Shanghai metroplex which are 30 and 51 aircraft, respectively. Figure 5(b) shows that the number of adjusted arrivals in the ZSPD and ZSSS airports are 13 and 17 aircraft, respectively. The corresponding number of the

adjusted departures are 29 and 22 aircraft, respectively. Hence, the total number of adjusted flights in the ZSPD and ZSSS airports are 42 and 39 aircraft, respectively. There are 3 intervals (14:00-15:00, 17:00-18:00, 18:00-19:00) with 10 more adjusted flights, and the number of adjusted departures higher than the adjusted arrivals.

Figure 5. Distribution of remaining flights in each interval

In addition, under each tradeoff scenarios of runway configuration, we use two configuration strategies, static (single and fixed) configuration and dynamic (multiple and flexible) configuration, to validate the optimization effect of our method. Figure 6 shows the two optimization objectives for

the static and dynamic strategies. For the former, the flight holding cost and number of adjusted flights are 449, 000 RMB yuan and 131 aircraft (including 44 arrivals and 87 departures). For the dynamic configuration, the corresponding figures are 283, 000 RMB yuan and 81 aircraft (including 30 arrivals and

51 departures). Compared with the static configuration, the dynamic configuration has a significant effect with 37.0% and

38.2% reductions in the flight holding cost and number of adjusted flights, respectively.

Figure 6. Comparison of optimization objectives for different strategies

Note that the results in Figure 4 ~ Figure 6 are based on the priority setting $p_a = 0.6$ and $p_d = 0.4$. Therefore, the results under other 10 tradeoff settings for arrivals and departures priority $\{(0,1), (0.1,0.9), (0.2,0.8), (0.3,0.7), (0.4,0.6), (0.5,0.5), (0.7,0.3), (0.8,0.2), (0.9,0.1), (1,0)\}$ are presented in Figure 7.

Figure 7. Comparison of results under 11 tradeoff settings

It can be easily seen that the adjustment of arrivals and departures depends on the weight coefficients of priority for arrivals and departures. Figure 7 shows that, the number of adjusted arrivals decreases and the number of adjusted departures increases, as the priority coefficients for arrivals increases. Similarly, the number of adjusted departures increases and the number of adjusted arrivals decreases, as the priority coefficients for departures decreases. In practice at the Shanghai metroplex system, a group of multiple and flexible priority settings can be dynamically set to get the expected results of flight adjustments.

IV. DISCUSSIONS

For any airport systems (metroplex, ZSPD or ZSSS), the number of adjusted flights for the static strategy is much larger than the dynamic strategy. Taking the static configuration strategy as the baseline, the proposed dynamic configuration strategy further reduces the number of adjusted flights in the Shanghai metroplex by 38.2%. In practice at the Shanghai metroplex system, airport congestion and flight delay will deteriorate if a single and fixed configuration is used for a long period of time. The advantages of using dynamic runway configuration is critical to the reduction of the impact of insufficient capacity on air traffic demand through efficient utilization of scarce runway resources in busy airports.

For any configuration strategies (static or dynamic), the number of adjusted flights in the Shanghai metroplex is the sum of those in the ZSPD and ZSSS airports. In particular, the number of adjusted flights in ZSPD is larger than that in ZSSS because the air traffic flow in ZSPD is denser than that in ZSSS. Taking the proposed dynamic configuration strategy as an example, the proportion of flight adjustment in ZSPD / ZSSS is 51.9% / 48.1%, and the proportion of flight adjustment for arrivals / departures in Shanghai metroplex are 37.0% / 63.0%. In practice, at the Shanghai metroplex, the number of scheduled flights in ZSPD and ZSSS can be further optimized at the strategic level of making flight schedules.

V. CONCLUSIONS

This paper has addressed the integrated management of runway resources in metroplex airports and provides a framework for characterization of ATDM options and optimization of runway configurations. This framework yields a set of flexible and dynamic options for ATDM for the selection of runway configurations. Our depiction of ATDM options are combinations of DCB process in 4 cases of

imbalance in the RCCE. Building on the ATDM options, static and dynamic configurations are modeled to optimize the multiple objectives of flight holding cost and number of adjusted flights, while enforcing a set of constraints. We design an efficient evolutionary algorithm to seek the Pareto optimal solutions of this computationally challenging problem.

The importance of this work in the context of runway configuration is underlined by the demonstrated cases with 10-hour air traffic flow in the Shanghai metroplex system. The computational results show that the proposed method can rapidly search for the Pareto optimal solutions in the decision space and has a significant effect in the process of population evolution, with a 54.9% reduction in flight holding cost and a 54.2% reduction in number of adjusted flights. There are some obvious consistencies on the convergence characteristics of the optimal performance between the two optimization objectives during the evolutionary process of our algorithm. Compared with the traditional static strategy as the baseline, our dynamic strategy can significantly reduce the number of adjusted flights in the Shanghai metroplex by 38.2%. Taking the proposed dynamic configuration strategy as an example, the proportion of flight adjustment in ZSPD / ZSSS are 51.9% / 48.1%, and the proportion of flight adjustment for arrivals / departures in Shanghai metroplex are 37.0% / 63.0%.

Our method can dynamically utilize the runway capacity through multiple ATDM options, to keep the balance between air traffic demand and runway capacity, and with further reductions in flight holding cost and number of adjusted flights than the traditional static configuration method. The significance of this paper is a new optimization model and efficient evolutionary algorithm of runway configuration in metroplex airports, which brings significant benefits to air traffic demand management and runway capacity utilization of metroplex airports. The findings are useful to air transport decision makers, such as air navigation service providers, airport operators and airlines, for enhancing the integrated operation performance of runway systems in metroplex airports on the pre-tactical (i.e. one-day planning) and tactical (i.e. 2-h rolling horizon) levels.

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