Scheduling Landing Aircraft with Multiple Objectives under Continuous Descent Operation

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♦ Introduction

A new kind of multi-objective ALP model under Continuous Descent Operation(CDO) is proposed.
•The performance indicators for the ALP is analyzed and deducted. only **two objectives** remain while modeling ALP.
•The Imperialist Competitive Algorithm for multi-objective (MOICA) was purposed to solve the multi-objective ALP.
•The results demonstrate the efficiency of our proposed approach for solving ALP, which could simultaneously token the **Capacity, Cost**, **Efficiency**, **Environment**, and **Equity** into consideration.

♦ Promblem Defination

Arrival aircraft generally enter the TMA through an **entry fix** to a **runway** via a Standard Terminal Arrival Route (**STAR**).

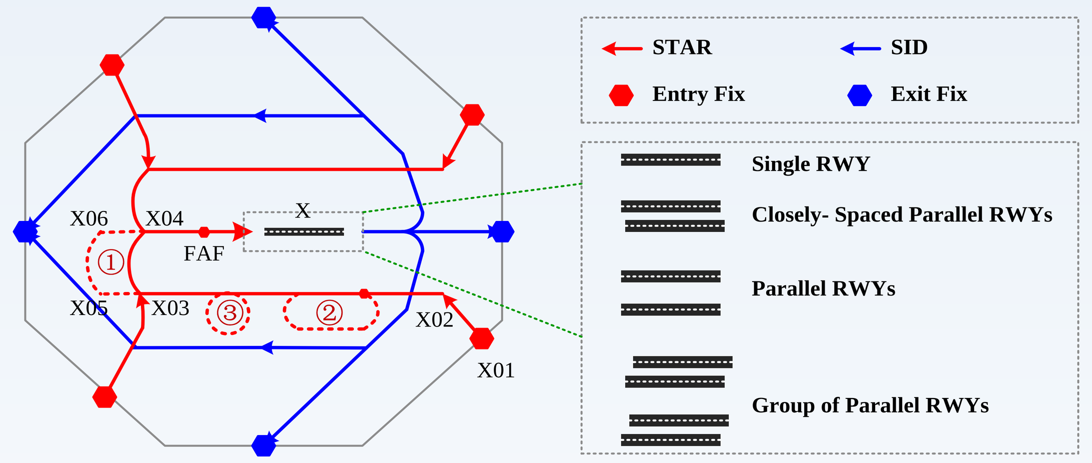

Fig.1 Schematic Diagram of TMA Operation

Benefits when conducting Continuous Descent Operation(CDO)

- Less level flight at low altitude means faster speed.
- Idle thrust mode means save excessive fuel consumptions;
- Reducing air pollutant emissions and mitigate noise pollutions.

Tabel.1 Defination of the variables

Name	Notion	Description
Planned Landing Time	t_j^{PLT}	Published and updated on the timetable
Scheduled Landing Time	t_j^{SLT}	Optimized landing time obtained by algorithm
Earliest Landing Time	t_j^{ELT}	$t_j^{ELT}=t_j^{AET}+\overline{D}_j$
Latest Landing Time	t_j^{LLT}	$t_j^{LLT}=t_j^{AET}+\overline{D}_j+M$
Actual Time of Arrival	t_j^{ATA}	Actual time of arrival of the aircraft j
Dwell Time	D_j	Fly time of aircraft j within TMA
Nominal Dwell Time	$\overline{D}_j$	Aircraft j follow the STAR and conduct CDO
Planned Entry Time	t_j^{PET}	$t_j^{PET}=t_j^{PLT}-\overline{D}_j$
Actual Entry Time	t_j^{AET}	$t_j^{AET}=t_j^{ELT}-\overline{D}_j$
Entry Lateness	L_j^{Entry}	$L_j^{Entry}=\max(t_j^{AET}-t_j^{PET},0)$
TMA Lateness	L_j^{TMA}	$L_j^{TMA}=t_j^{ALT}-t_j^{ELT}$
Total Lateness	L_j^{Total}	$L_j^{Total}=\max(t_j^{ALT}-t_j^{PLT},0)$

♦ Objectives Selection

♦ **Capacity:**

- The total additional flight time in TMA should be reduced.
- The last aircraft should be scheduled as earlier as possible.

$$\min\sum(D_j-\overline{D}_j)\rightarrow\min\sum(t_j^{SLT}-t_j^{ELT})\rightarrow\boxed{\min\sum(t_j^{SLT})}\ \Big|\ \boxed{\min\max t_j^{SLT}}$$

♦ **Cost:**

- The time cost could be viewed as the controller workload
- The fuel cost can be viewd as extra fly time than CDO.

$$\min\sum(D_j)\rightarrow\boxed{\min\sum(t_j^{SLT})}\ \Big|\ \min\sum(D_j-\overline{D}_j)\rightarrow\boxed{\min\sum(t_j^{SLT})}$$

♦ **Efficiency:**

- The TMA Lateness should be reduced.

$$\min\sum L_j^{TMA}\rightarrow\min\sum(D_j-\overline{D}_j)\rightarrow\boxed{\min\sum(t_j^{SLT})}$$

♦ **Environment :**

- The extra fly time than CDO should be reduced.

$$\min\sum(D_j-\overline{D}_j)\rightarrow\boxed{\min\sum(t_j^{SLT})}$$

♦ Model Development

$$
\begin{array}{llr}
min & max\ t_j^{SLT} & (1)\\
min & \sum(t_j^{SLT}) & (2)\\
min & max(D_j-\overline{D}_j) & (3)\\
s.t. & t_j^{ELT}=t_j^{AET}+\overline{D}_j \quad \forall j\in J & (4)\\
 & t_j^{SLT}=t_j^{AET}+D_j \quad \forall j\in J & (5)\\
 & t_j^{LLT}=t_j^{AET}+\overline{D}_j+M \quad \forall j\in J & (6)\\
 & t_j^{ELT}\le t_j^{SLT}\le t_j^{LLT} \quad \forall j\in J & (7)\\
 & q_{kj}\in\{0,1\} \quad \forall k,j\in J;k\neq j & (8)\\
 & q_{kj}+q_{jk}=1 \quad \forall k,j\in J;k\neq j & (9)\\
 & t_j^{SLT}\ge t_k^{SLT}+q_{kj}s_{kj}-q_{jk}(t_k^{LLT}-t_j^{ELT}) \quad \forall k,j\in J;k\neq j & (10)\\
 & L_j^{TMA}=t_j^{SLT}-t_j^{ELT} \quad \forall j\in J & (11)
\end{array}
$$

In the purposed model.The **Equation 1** concerns the **Capacity** KPI, the **Equation 2** concerns the **Cost / Efficiency / Environment** KPIs, and **Equation 3** concerns the **Equity** KPI.

♦ Algorithm

♦ **Features:**
•The dispatching rules (ERD,EDD) are used to initialize the country.
•The sequence of the flight will be got at first and then STA will be calculated.
•CPS principle is adopted to guarantee the effectiveness of the neighborhood solution.

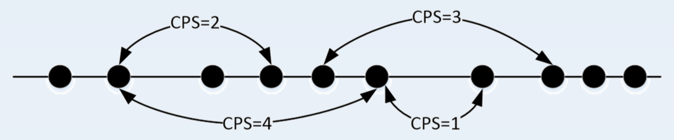

Fig.2 Constrained Position Shifting

•The $\overline{D}$ constraint ensures to get feasible solution.

$$t_j^{SLT}-t_j^{AET}\le const\ \overline{D}\ \forall j\in J$$

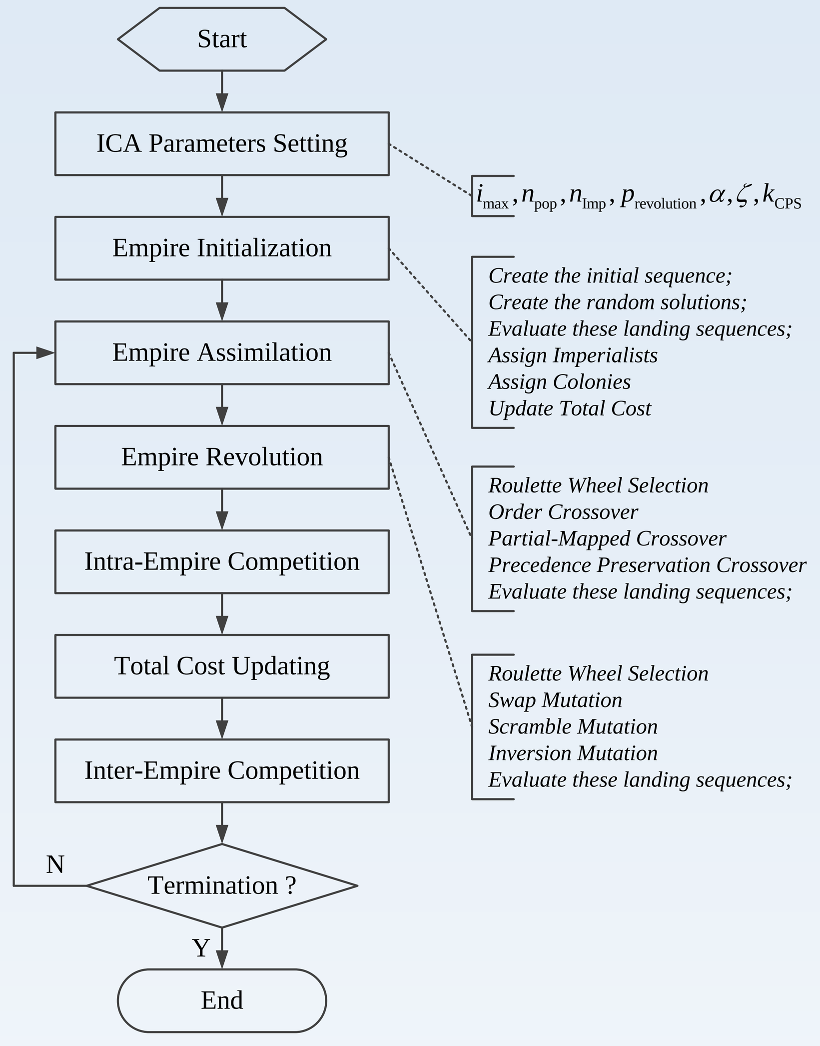

Fig.3 The flowchart of the MOICA

♦ OR data & Real-case Simulation

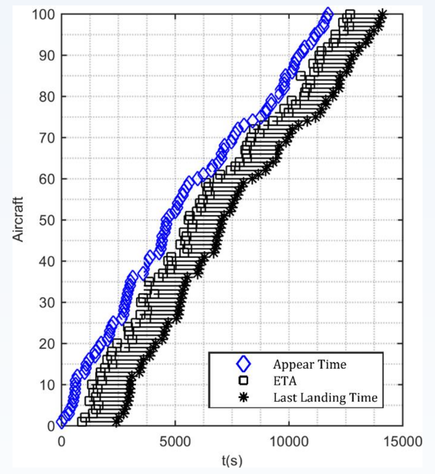

Fig.4 A instance taken from the OR library

Table.2 performance indicators by optimizing instance airland #9

Methods	Objectives	$\frac{1}{n}\sum(t_j^{SLT})$	$\max\sum(t_j^{SLT})$	$\frac{1}{n}\sum(D_j-\overline{D}_j)$	$\max\sum(D_j-\overline{D}_j)$
CPLEX	$\min\frac{1}{n}\sum(t_j^{SLT})$	6406.24 s	12723 s	1016.23 s	1662 s
	$\min\max\sum(t_j^{SLT})$	6441.80 s	12723 s	1051.79 s	1610 s
	$\min\frac{1}{n}\sum(D_j-\overline{D}_j)$	6406.24 s	12723 s	1016.23 s	1662 s
	$\min\max\sum(D_j-\overline{D}_j)$	6430.00 s	12726 s	1039.99 s	1306 s
ICA	$\min\frac{1}{n}\sum(t_j^{SLT})$ $s.t.\ D_j-\overline{D}_j<Const$	6416.29 s	12726 s	1026.28 s	1387 s

▲ Fig.4 shows the data set containing 100 aircrafts. The optimization results are shown in the table.2.

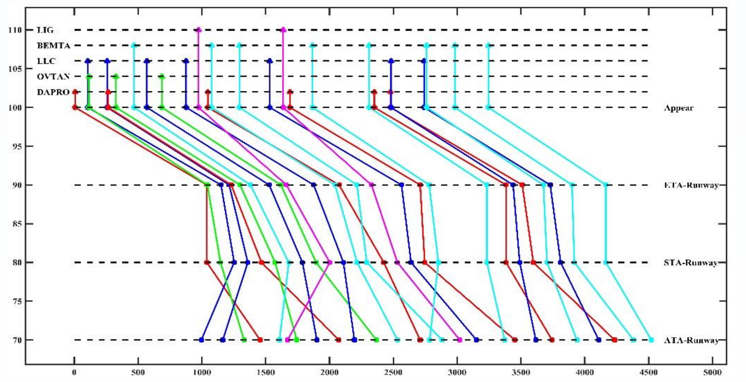

Fig.5 The comparison between Appear Time, ETA, STA, and ATA;

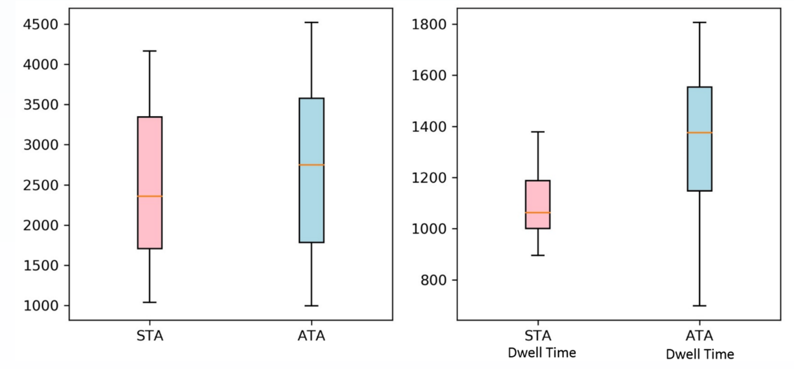

Fig.6 The optimization performance between the STA and ATA

▲ The STA optimized by purposed algorithm is compared with the ATA from real operation.

♦ Discussion

♦ **From benchmark case**

a) $\min\sum(D_j-\overline{D}_j)$ and $\min\sum(t_j^{SLT})$ could produce the same results;
b) $\min\sum(t_j^{SLT})$could obtain the minimum value of $\max t_j^{SLT}$ just as $\min\max t_j^{SLT}$.
c) The proposed ICA could balance all the performance indicators, that is to say, the proposed ICA could achieve the multi-objective scheduling for ALP.

♦ **From real case**

a) Fig.3 shows that after the optimization, half of the STAs calculated are smaller than the actual time of arrival (ATA).
b) In Fig.4, red line denotes the mean. Both the average and maximum STA are smaller than the average and maximum ATA. As well for the results between the average and maximum dwell time.

♦ Conclusion

- From the benchmark case.The result proved the analysis for the relation between performance indicators is correct. It also proved the proposed ICA could achieve the multi-objective scheduling for ALP.
- From the real case, the result demonstrated the efficiency of the proposed algorithm and effectiveness of the model, which could optimal different performing indicators simultaneously.
- How to solve the multi-objective problem in the multiple runways and how to improve the efficiency of the MOICA will be our target in the futher.

♦ Contact

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