Scheduling Landing Aircraft with Multiple Objectives under Continuous Descent Operation

Pengli Zhao, Junfeng Zhang, Songwei Liu, Dong Sui and Rong Hu
College of Civil Aviation, Nanjing University of Aeronautics and Astronautics, Nanjing, China, 211106

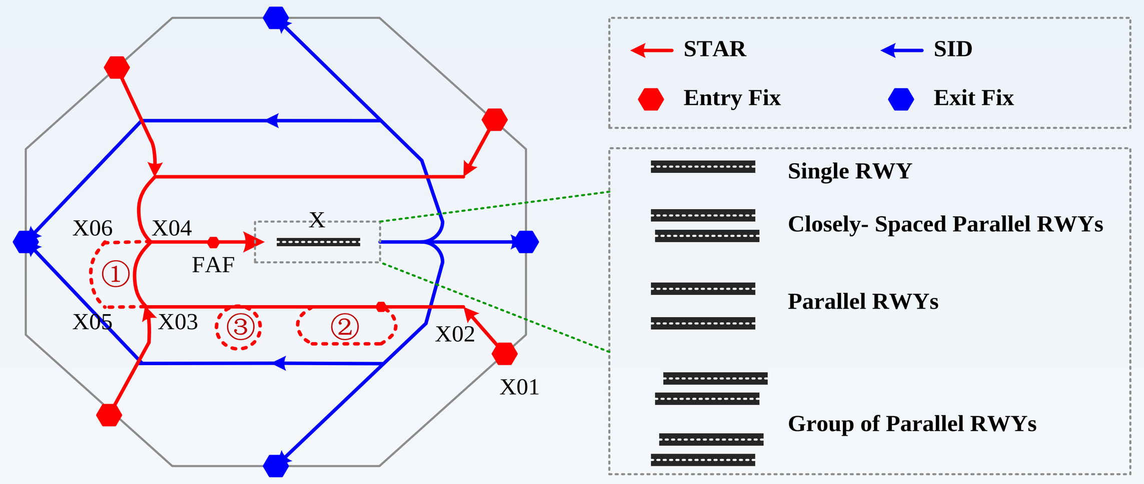
◆ Introduction

A new kind of multi-objective ALP model under 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).



In an ideal situation, this aircraft could conduct a Continuous Descent Operation (CDO), an environment-friendly arrival operation.

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}	$t_j^{ELT} = t_j^{AET} + \bar{D}_j$
Latest Landing Time	t_j^{LLT}	$t_j^{LLT} = t_j^{AET} + \bar{D}_j + M$
Actual Landing Time	t_j^{ALT}	Actual landing time of the aircraft j
Dwell Time	D_j	Fly time of aircraft j within TMA
Nominal Dwell Time	$\bar{D}_j$	Aircraft j follow the STAR and conduct CDO
Planned Entry Time	t_j^{PET}	$t_j^{PET} = t_j^{PLT} - \bar{D}_j$
Actual Entry Time	t_j^{AET}	$t_j^{AET} = t_j^{ELT} - \bar{D}_j$
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}	$L_j^{Total} = \max(t_j^{ALT} - t_j^{PLT}, 0)$

◆ Objection Selection

◆ **Capacity:**

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

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

◆ **Cost:**

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

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

◆ **Efficiency:**

- The TMA Lateness should be reduced.

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

◆ **Environment :**

- The extra fly time than CDO should be reduced.

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

Model Development

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

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

Feathers of the algorithm:

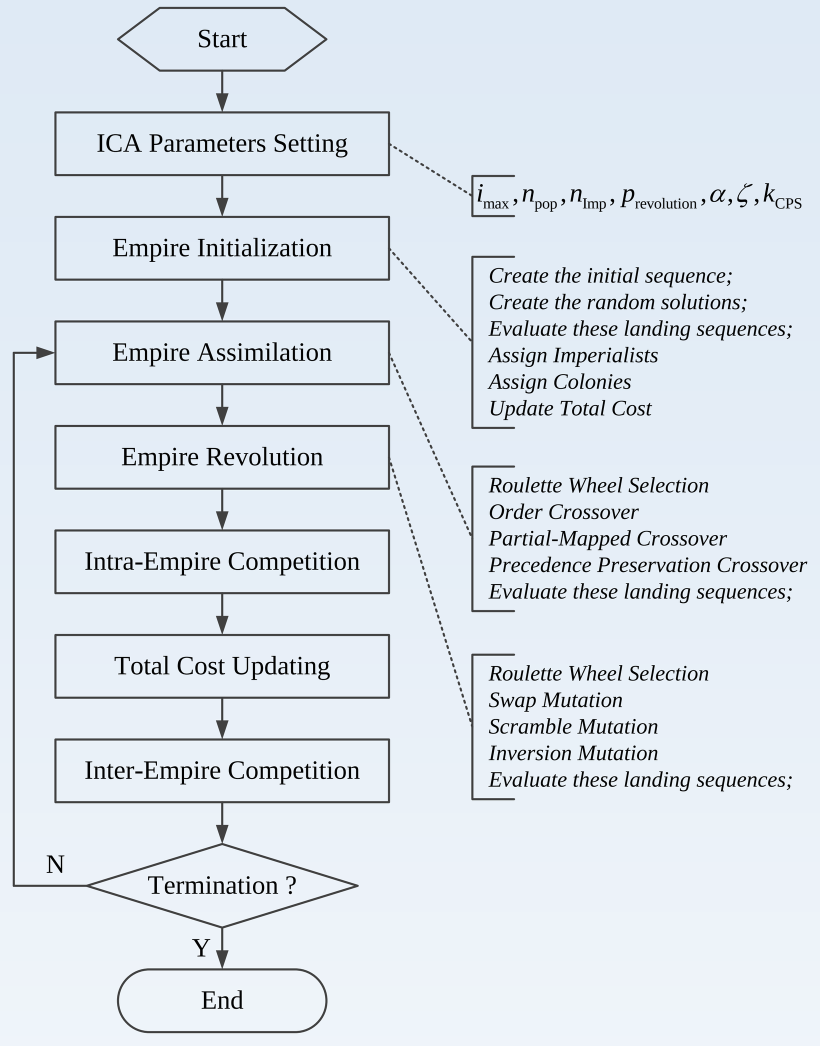
•the sequence of the flight will be got at first and the STA will be calculated

•the D constrain ensure to feasible solution

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

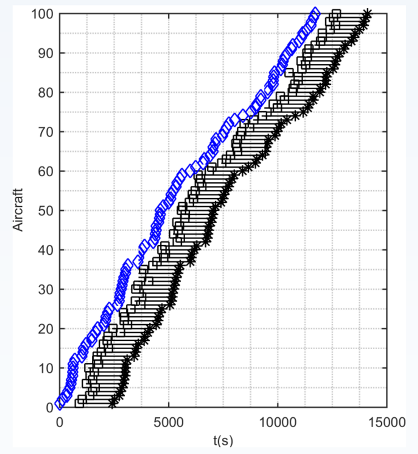
•The dispatching rules (ERD,EDD) are used to initialize the country.

•CPS principle is adopted to guarantee the effectiveness of the neighborhood solution. The CPS allows the new position of the flight will not be far away from the former position.



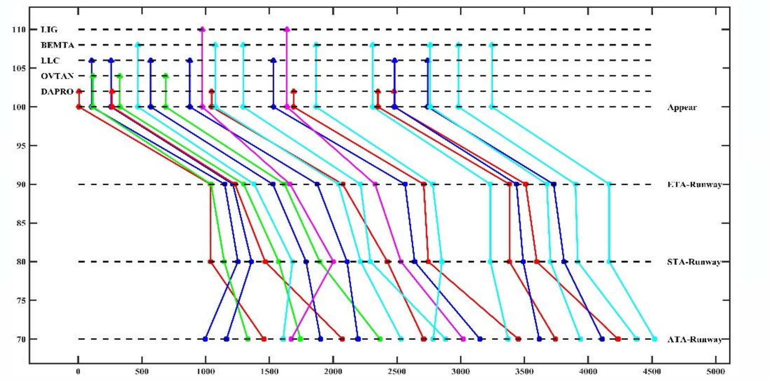
▲The flowchar of the MOICA

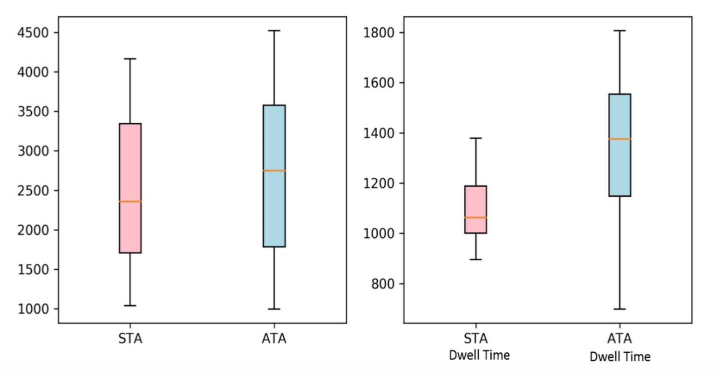
◆ OR data & Real-case Simulation



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

▲ A benchmark instance taken from the OR library.The optimization results are shown in the table.





▲ Left is the comparison between Appear Time, ETA, STA, and ATA; Right is the Optimization performance between the Scheduled Landing Time and the Actual landing Time.

◆ Discussion

◆ **From benchmark**

a) $\min \sum (D_j - \bar{D}_j)$ 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) Left shows that after the optimization, half of the STA calculated are smaller than the actual landing time(ATA).

b) 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

- After analyzing the performance indicators and clarifying the relation and distinction,only two objectives are remained to construct the model.
- Imperialist Competitive Algorithm for Multi-objective (MOICA) was purposed.The benchmark instances and the real case instances were used to validate the proposed model and algorithm.
- 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.

◆ Acknowledgements

This work was supported by the National Natural Science Foundation of China (71401072) and Foundation of Graduate Innovation Center in NUAA (kfjj20180708).