A Composite Dispatching Rule-based Method for Multi-Objective Aircraft Landing Problem

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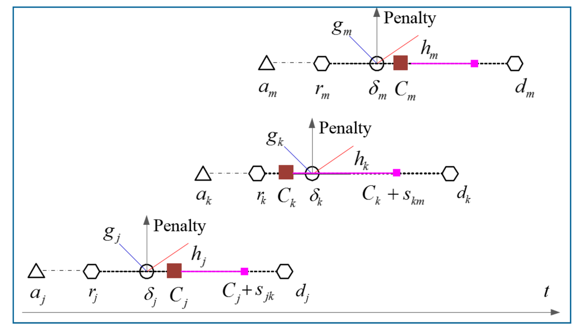
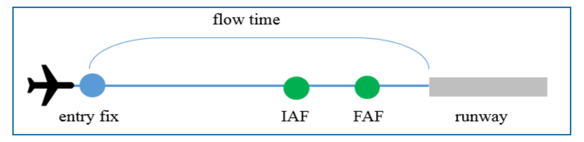
INTRODUCTION

A new Composite Dispatching Rule (CDR), inspired by the machine scheduling field, and the corresponding algorithm are proposed to tackle the multi-objective ALP.

Notation/ Variables	Single Machine Scheduling	Aircraft Landing Problem
J	a set of jobs	a set of landing aircraft
a_j	Appear time	Entry time
r_j	Release date	Earliest landing time
d_j	Deadline	Latest landing time
δ_j	Due date	Target landing time
s_{jk}	Set-up time	Wake Vortex separation
C_j	Completion time	Scheduled landing time
p_j	Processing time	Runway occupied time
g_j	Earliness weight	Incurred cost for early landing
h_j	Tardiness weight	Incurred cost for late landing
$F_j = C_j - a_j$	Flow time of job	Dwell time in the terminal area
$E_j = \max(\delta_j - C_j, 0)$	Earliness of job	Earliness of aircraft
$T_j = \max(C_j - \delta_j, 0)$	Tardiness of job	Tardiness of aircraft
$q_{kj} = \{0,1\}$	Sequence	Landing sequence



☝ The relationship between aircrafts



☝ The dwell time is defined as the flight time of an arrival aircraft from entering the terminal area at entry fix to landing on the runway.

OBJECTIVE SELECTION

- The **total dwell time** could be treated as a criterion for measuring air traffic controllers' workload.
- The **maximum dwell time** makes sure no flight will be kept in the air for too long, whose purpose is to ensure the equity among flights or airlines.
- **Minimizing total delay** could meet the Airlines' and passengers' requirements.
- **Total delays, total dwell time**, and **maximum dwell time** are chosen as the multiple objectives of ALP in this paper.

MULTI-OBJECTIVE MODEL

There are no objectives dominant in multi-objective ALP, We chose a **simultaneous strategy** for producing the formulation of multi-objective ALP.

$$\min \quad \alpha \sum_{j=1}^{n} F_j + (1-\alpha) \sum_{j=1}^{n} T_j \qquad (1)$$

$$\begin{aligned} s.t. \quad & F_j \le F_{max} && \forall j \in J && (2)\\ & r_j \le C_j \le d_j && \forall j \in J && (3)\\ & q_{k,j} + q_{j,k} = 1 && \forall k,j \in J; k > j && (4)\\ & C_j \ge C_k + q_{kj} s_{kj} - q_{jk}(d_k - r_j) && \forall k,j \in J; K \ne j && (5)\\ & E_j \ge \delta_j - C_j && \forall j \in J && (6)\\ & 0 \le E_j \le \delta_j - r_j && \forall j \in J && (7)\\ & T_j \ge C_j - \delta_j && \forall j \in J && (8)\\ & 0 \le T_j \le d_j - \delta_j && \forall j \in J && (9)\\ & C_j = \delta_j - E_j + T_j && \forall j \in J && (10)\\ & F_j = \delta_j - a_j && \forall j \in J && (11) \end{aligned}$$

CDR METHODS

- CDR is a **ranking expression** that combines a number of basic dispatching rules. Each basic rule in the CDR has its own scaling parameter that is chosen to properly scale the contribution of the basic rule to the total ranking expression**.**
- **ERD** rule and **FLT** rule are choosen to construct the CDR for multi-objective ALP.

$$F_{ERD}(t,j) = exp(-max(r_j - t, 0)/K_1) \qquad (12)$$

$$F_{FLT}(t,j) = exp((max(r_j, t + s_{ij}) - a_j - K_2)/K_3) \qquad (13)$$

$$I^i_{CDR}(t,j) = exp\left[-\frac{max(r_j - t, 0)}{K_1}\right] * exp\left[-\frac{max(r_j, t + s_{ij}) - a_j - K_2}{K_3}\right] \qquad (14)$$

ALGORITHMS

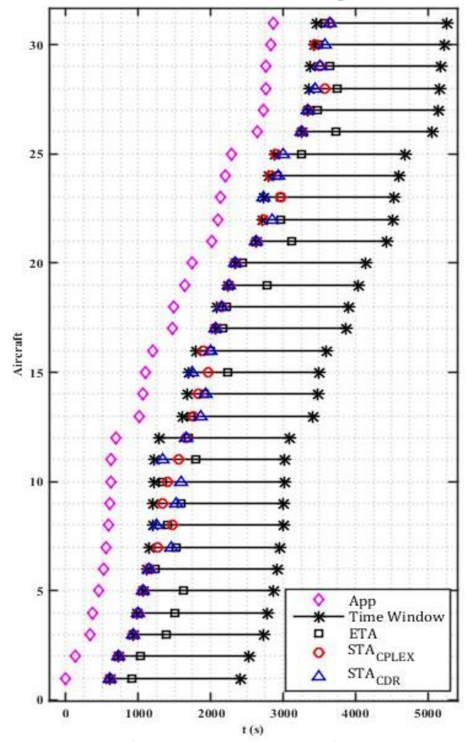
- In this study, a **two-step** optimization strategy is used to tackle the multi-objective ALP.

Set the initial value $t = 0; C_j = 0; J = \{1,2,\dots,n\}; \forall j \in J$
For $\forall j \in J$*, get the index using Eq.(14)* $I^i_{CDR}(t,j)$*, set* $s_{ij} = 0$
Put $j = \{j \in J \mid \max\{I^i_{CDR}(t,j)\}\}$ *on the first place.*
Set $C_i = \delta_i$*,* $t = C_i$
remove j from Set J
While $J \ne \Phi$ *do*
  Get the index using Eq.(14) $I^i_{CDR}(t,j)$*,* $\forall j \in J$
  Select $j = \{j \in J \mid \max\{I^i_{CDR}(t,j)\}\}$ *to be the next.*
    Update $C_j = \max(r_j, C_i + s_{ij})$
    update $t = C_i$
    remove j from Set J
End While
CPLEX is adopted to get the result

- Firstly, a sequence is obtained by using the CDR method. Then, the remaining aircraft will be assigned one by one based on the Eq.(14).
- Secondly, take the sequence into the formulation of multi-objective ALP, in which Eq.(5) should be changed since qk,j has been determined.
- Finally, CPLEX is adopted to solve the multi-objective ALP.

EXPERIMENTS AND RESULTS

In this experiment, a set of benchmark instances from the **OR Library** is used.



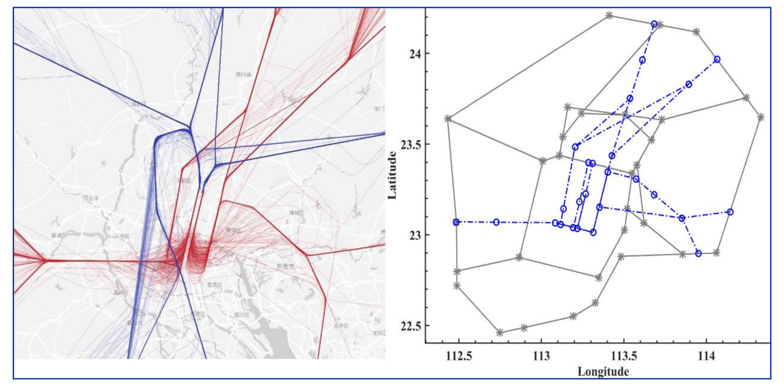
Instances	Items	$\sum T_j/n$	$\sum F_j/n$	$\max F_j$	Multi-objective
Airland #9	CPLEX	4.02	684.49	1,140.00	344.26
	CDR+ CPLEX	10.03	694.01	1,072.00	352.02
	Gap	6.01	9.52	-68.00	7.76
Airland #10	CPLEX	10.14	700.65	1,232.00	355.39
	CDR+ CPLEX	28.19	726.38	1,231.00	377.29
	Gap	18.05	25.73	-1.00	21.89
Airland #11	CPLEX	0.58	674.06	1,020.00	337.32
	CDR+ CPLEX	11.64	696.48	1,182.00	354.06
	Gap	11.06	22.42	162.00	16.74
Airland #12	CPLEX	3.60	674.85	1,231.00	339.23
	CDR+ CPLEX	11.41	686.68	1,220.00	349.05
	Gap	7.81	11.83	-11.00	9.82

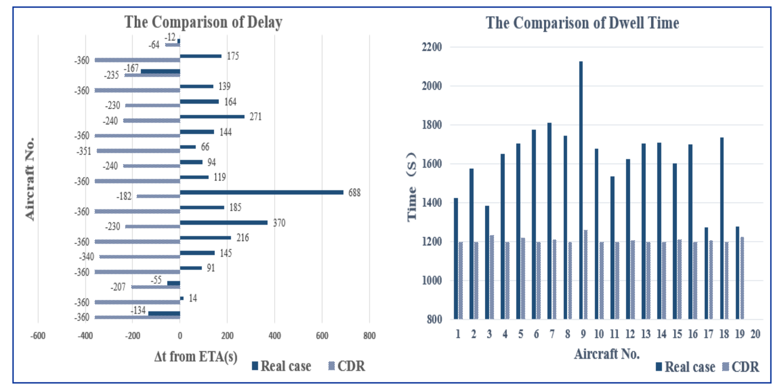
Items	Airland #9	Airland #10	Airland #11	Airland #12	Items
CPLEX	629.88	668.06	745.47	844.83	CPLEX
CDR+ CPLEX	13.18	8.08	9.78	10.50	CDR+ CPLEX

The airland#9 to airland#12 are choosen. The number of aircraft in airland#9 to airline#12 are 100, 150, 200, and 250. And Fmax of different instances are set to 1,200, 1,300, 1,300, and 1,300, respectively.

EXPERIMENTS AND RESULTS

- In this experiment, the real case is taken into account. A comparative analysis between the optimized landing time and the actual landing time is carried out.





- The radar tracks are analyzed to get the appearing time, the earliest/target/latest landing time, the aircraft wake vortex type, and the actual landing time. In addition, the maximum dwell time is set to be 1,800s
- The computational results illustrate the efficiency of our approach, which could simultaneously enhance the runway capacity, reduce the workloads of air traffic controllers and maximize the cost-effectiveness of airlines.

CONCLUSION

- The most prominent feature of this proposed method is that it could quickly obtain a near-optimal result for the multi-objective ALP.Because the CDR part could get a good starting sequence for the further optimization part.
- How to combine the CDR-based method and meta-heuristic algorithm to tackle the ALP is worthy of further in-depth study.

ACKNOWLEDGMENTS

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