RGC Ref. No.:
UGC/FDS14/E04/19
(please insert ref. above)

RESEARCH GRANTS COUNCIL
COMPETITIVE RESEARCH FUNDING SCHEMES FOR THE LOCAL SELF-FINANCING DEGREE SECTOR

FACULTY DEVELOPMENT SCHEME (FDS)

Completion Report

(for completed projects only)

Submission Deadlines:
1. *Auditor's report with unspent balance, if any: within **six** months of the approved project completion date.*
2. *Completion report: within **12** months of the approved project completion date.*

Part A: The Project and Investigator(s)

1. Project Title

Impacts of Dependent Flight Delay on Cabin Crew Pairing Reliability in Airlines

2. Investigator(s) and Academic Department(s) / Unit(s) Involved

Research Team	Name / Post	Unit / Department / Institution
Principal Investigator	Dr. MA Hoi-Lam / Associate Professor	Supply Chain and Information Management / The Hang Seng University of Hong Kong
Co-Investigator	Prof. CHOI Tsan-Ming, Jason / Chair Professor	Operations and Supply Chain Management/ University of Liverpool Management School
Co-Investigator	Dr. CHUNG Sai-Ho, Nick / Associate Professor	Industrial and Systems Engineering / The Hong Kong Polytechnic University

3. Project Duration

	Original	Revised	Date of RGC / Institution Approval *(must be quoted)*
Project Start Date	1st January 2020	-	
Project Completion Date	31st December 2022	31st December 2023	Approved by RGC on 24 May 2023
Duration *(in month)*	36	48	

Deadline for Submission of Completion Report	31st December 2023	31st December 2024	

4.3 Please attach photo(s) of acknowledgement of RGC-funded facilities / equipment.

Part B: The Final Report

5. Project Objectives

5.1 Objectives as per original application

1. To develop a new machine learning algorithm to estimate the reducing flying time;
2. To develop a new dependent flight delay model for Cabin-CP;
3. To develop a new CG based methodology to solve the new Cabin-CP problem with the estimated reducing flying time and dependent flight delay model;
4. To verify the proposed CG based methodology and analyze the impacts of dependent flight delay on Cabin-CP reliability.

5.2 Revised objectives

Date of approval from the RGC: N/A

Reasons for the change: ____________________

1.

2.

3. ....

5.3 Realisation of the objectives

(Maximum 1 page; please state how and to what extent the project objectives have been achieved; give reasons for under-achievements and outline attempts to overcome problems, if any)

To achieve ***Objective 1***, we obtained a set of real data from our partner, regarding 19,117 international passenger and cargo flights operated among eight sectors covering different geographical regions. The flights were performed from April 2015 to March 2017 by 107 wide-body aircraft distributed as Airbus A330-300 (31 aircrafts) and Boeing 747-400 (9 aircrafts)/747-800 (14 aircrafts)/777-300 (53 aircrafts). The data consisted of detailed information on operational parameters related to 1) carrier with aircraft performance and operations, 2) date/time of departure and arrival per sector with crew allocation, 3) weather and atmospheric conditions, 4) sector and aircraft local and global conditions, and 5) fuel requirements at different tanks and consumption levels. Among the collected data, instead of putting all operational parameters into algorithms, we worked in a more novel way by extracting the relevant operational parameters contributing to fuel consumption and thus we related the fuel consumption deviation with flying time deviation for each flight legs. Accordingly, we proposed a new self-organizing constructive neural network by improving an original cascade correlation learning algorithm and its variants. The key idea is to analytically determine connection weights on both sides of the network rather than iterative tuning with modified cascade architecture. We proposed to analytically determine connection weight by the orthogonal linear transformation of input units, whereas weights of hidden units to output units by the ordinary least squares method. The proposed algorithm is named cascade principal component least squares neural network.

To achieve ***Objective 2***, we built a novel robust crew pairing model which is resistant against potential flight delays based on the flight departure-arrival interdependency as well as the departure-dependent flight flying time variability. We model the expected arrival and departure times of consecutive flights based on the identified flight flying time structure. To ensure the problem was tractable, regarding the flight (departure-dependent) flying time variability, we only considered its impact on the expected arrival time of the immediate subsequent flight, without the propagated impact on the other latter flights in the pairing. We modelled the flight flying time by a normal distribution with a mean and a standard deviation which depended on the actual departure time of the flight. By assuming that the aircraft were always available for each flight to exclude the impact of aircraft disruptions, we proposed two novel robust crew pairing models to enhance the robustness of flights in the constructed pairings against departure delays.

To achieve ***Objective 3***, we constructed a mathematical model for the robust crew pairing problem. The crew pairing problem was generally modelled as a set-covering or set-partitioning problem. The objective was to determine a set of legal pairings with the minimum total costs, while the constraint(s) were to ensure that each flight was covered by (at least) one pairing. We modelled a bi-criteria model which integrates the minimization of basic operating costs and the minimization of robustness-related costs. Basic operating costs for crews were fixed component and other costs, e.g., rest, waiting, deadhead. Robustness-related costs were used to encourage the occurrence of deviation-affected-free flights in the pairings generated, and discourage the occurrence of deviation-affected flights in the pairings generated. We built a column-generation based solution algorithm to solve the proposed robust crew pairing models. The restricted master problem (RMP) was the linear relaxation of the CPP with a limited number of feasible pairings, while the sub-problem was usually formulated as a resource-constrained shortest path problem to identify promising pairings from the whole solution pool.

To achieve ***Objective 4***, we conducted various numerical experiments to examine the robustness of the proposed two novel robust crew pairing models, in terms of various aspects, e.g., basic operating cost, total deviation-buffer time, total deviation-delay time, no. of deviation-affected-free flights, no. of total deviation-affected flights, etc. In addition, we examined how the variation in flying time (flying speed) could affect the robustness and its related cost effect, i.e., fuel consumption cost.

5.4 Summary of objectives addressed to date

Objectives *(as per 5.1/5.2 above)*	**Addressed** *(please tick)*	**Percentage Achieved** *(please estimate)*
1. To develop a new machine learning algorithm to estimate the reducing flying time	✓	100%
2. To develop a new dependent flight delay model for Cabin-CP	✓	100%
3. To develop a new CG based methodology to solve the new Cabin-CP problem with the estimated reducing flying time and dependent flight delay model	✓	100%
4. To verify the proposed CG based methodology and analyze the impacts of dependent flight delay on Cabin-CP reliability	✓	100%

6. Research Outcome

6.1 Major findings and research outcome
(Maximum 1 page; please make reference to Part C where necessary)

Finding 1: Relationship of Flying Speed and Fuel Consumption (***Part C: Annexes I, III, V***)
From the analysis of extracting each operational parameter and fuel consumption, we found that flight time and distance travel were directly related to fuel consumption. It was intuitive that the more the aircraft was airborne, the more the fuel would consume. Flight duration and covered distance significantly contributed to aircraft operational expenses. When fuel was expensive, the operating cost would be lower, which meant a slower speed of the aircraft. Operating an aircraft at low-speed resulted in a higher climb rate due to excessive engine thrust and, simultaneously, it was recommended to fly at a higher altitude to lower fuel consumption. Similarly, when fuel was cheap, the operating cost would be higher, and a faster aircraft would operate to be less airborne to reduce the amount of operational cost at the cost of more consumed fuel. Thus, it can conclude that the operating cost affects shortening or lengthening the airborne phase by changing the aircraft speed, depending on fuel prices and operational expenses to cut overall expenses.

Finding 2: Flight Delay Prediction Horizon (***Part C: Annex III and V***)
We analyzed the highly noisy, unbalanced, dispersed, and skewed historical high dimensional data provided by the industrial partner to examine the performance of our proposed forecasting models. The result showed that for a 4-h forecast horizon, the constructive neural network machine learning algorithm with the Synthetic Minority Over Sampling Technique-Tomek Links sampling technique was able to achieve better average balanced recall accuracy of 65.5%, 61.5%, 59% for classifying delay status and predicting delay duration at thresholds of 60min and 30min, respectively. Similarly, for minority labels, the model achieved better results of 32.44% and 35.14% compared to the parallel model of 26.43% and 21.02% for thresholds of 60min and 30min, respectively.

Finding 3: Influencing Factors of Flight Delay (***Part C: Annexes II, III and V***)
We also analyzed the importance of different influencing factors on flight delay. We applied the mutual information (bits) evaluation method to determine the most influencing factor that highly contributing. We found that the top five influencing factors that contributed to flight delays were distance travelled, aircraft registration, ramp weight, cruise initial altitude, and aircraft type. Other influencing factors in priority were alternative airport, altitude (final), arrival airport, departure airport, departure schedule (hour), runway direction, aircraft speed, arrival schedule (hour), and wind speed.

Finding 4: Impacts of Dependent Flight Delay on Cabin Crew Pairing (***Part C: Annexes I, IV and V***)
We examined the impacts of considering departure delay with the variation of flying speed on arrival delay in cabin crew pairing. By analyzing the two proposed strategies (encouraging deviation-affected-free flights and discouraging deviation-affected flights), we found that the increment in the total operating cost was about 9% to about 14%. However, we obtained a remarkable increase in buffering time between flights, implying a more robust crew pairing was achieved. In addition, we found that maximizing pairing robustness could also help enhance energy efficiency slightly. This might be explained as follows. As improving solution robustness may adjust flight connections and affect flight durations strategically, the fuel consumption can thus be influenced.

6.2 Potential for further development of the research and the proposed course of action *(Maximum half a page)*

In this project, we examined the relationship between departure delay and arrival delay with the consideration of flying speed variation. In addition, our focus was limited to cabin crew pairing. In future development, it is believed that the studies can be more comprehensive by integrating crew pairing with aircraft routing. Moreover, as the reduction of carbon emissions has also gained much attention in aviation, more research work can be done in this aspect.

7. Layman's Summary

(Describe in layman's language the nature, significance and value of the research project, in no more than 200 words)

Reliable crew pairing is critical in airline operations. Since disruption recovery is costly and would seriously jeopardize normal scheduled flight operations, it has received much attention. In this project, to enhance the robustness of crew pairing generated, we analyze the relationship between departure delay and arrival delay, combining with the consideration of flying speed variation to generate crew pairing. From the results of our experiments conducted, we demonstrated that airline crew scheduling should carefully consider the impact of flight flying time variability on the generated crew pairings, in addition to the basic operating costs (e.g., rest cost/deadhead cost). As flight flying time variability led by the fluctuating cruise speed has become a common disruption for the daily operations of the air transportation industry, failing to integrate the consideration of flight flying time variability may produce fragile pairings that are easily disrupted in real practice. In addition, by enhancing the robustness of crew pairing, it is found that energy efficiency can also be enhanced. Moreover, through a set of real flight data from an international airline in Hong Kong, this project review and identify various influencing factors causing flight delay. This project provides theoretical and practical contributions to the aviation industry.

Part C: Research Output

8. Peer-Reviewed Journal Publication(s) Arising Directly From This Research Project

(Please attach a copy of the publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.)

The Latest Status of Publications				Author(s) *(denote the correspond-ing author with an asterisk*)*	Title and Journal / Book *(with the volume, pages and other necessary publishing details specified)*	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this Report *(Yes or No)*	Acknowledged the Support of RGC *(Yes or No)*	Accessible from the Institutional Repository *(Yes or No)*
Year of Publication	**Year of Acceptance** *(For paper accepted but not yet published)*	**Under Review**	**Under Preparation** *(optional)*						
2020				Xin Wen, **Hoi Lam Ma, Sai Ho Chung**, Waqar Ahmed Khan	**Robust airline crew scheduling with flight flying time variability.** *Transportation Research Part E*, 141, 102132.	**2023**	Yes (Annex I)	Yes	Yes https://researchdb.hsu.edu.hk/view/publication/202000214
2021				Waqar Ahmed Khan, **Hoi Lam Ma**, Liam Xu Ouyang, Daniel Mo	**Prediction of aircraft trajectory and the associated fuel consumption using covariance bidirectional extreme learning machines.** *Transportation Research Part E*, 145, 102189.	**2023**	Yes (Annex II)	Yes	Yes https://researchdb.hsu.edu.hk/view/publication/202000215
2021				Waqar Ahmed Khan, **Sai Ho Chung**, **Hoi Lam Ma**, Xin Wen	**Hierarchical integrated machine learning model for predicting flight departure delays and duration in series.** Transportation	**2023**	Yes (Annex III)	Yes	Yes https://researchdb.hsu.edu.hk/view/publication/202100245

					Research Part C, 129, 103225.				
2023				Xin Wen, **Sai Ho Chung**, **Hoi Lam Ma,** Waqar Ahmed Khan	**Airline crew scheduling with sustainability enhancement by data analytics under circular economy.** Annals of Operations Research 342, 959–985. https://doi.org/10.1007/s10479-023-05312-7	**2023**	Yes (Annex IV)	**Yes**	Yes https://researchdb.hsu.edu.hk/view/publication/202300236
	2024			**Hoi Lam Ma***, Ye Wang, Weichen Wang	Book Chapter: **Cascading delay risk of airline workforce deployments** Encyclopedia in Operations Management	**No**	Yes (Annex V)	**Yes**	No

9. Recognized International Conference(s) In Which Paper(s) Related To This Research Project Was / Were Delivered

(Please attach a copy of each conference abstract)

Month / Year / Place	**Title**	**Conference Name**	**Submitted to RGC** *(indicate the year ending of the relevant progress report)*	**Attached to this Report** *(Yes or No)*	**Acknowledged the Support of RGC** *(Yes or No)*	**Accessible from the Institutional Repository** *(Yes or No)*
August/ 2023/ Luxembourg	Crew pairing problems with Consideration of Crew Preferences in Low-Cost Carriers	ISER International Conference on Science, Technology, Engineering and Management (ISCTEM-2023)	No	Yes (Annex VI)	Yes	No

10. Whether Research Experience And New Knowledge Has Been Transferred / Has Contributed To Teaching And Learning

(Please elaborate)

This project provides a significant contribution to our teaching materials. The findings regarding the relationship between departure delay and arrival delay, influencing factors on flight delay, the flying speed with fuel consumption, etc. have been created as teaching materials for teaching.

11. Student(s) Trained

(Please attach a copy of the title page of the thesis)

Name	**Degree Registered for**	**Date of Registration**	**Date of Thesis Submission / Graduation**
NA			

12. Other Impact

(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, teaching enhancement, etc.)

13. Statistics on Research Outputs

	Peer-reviewed Journal Publications	**Conference Papers**	**Scholarly Books, Monographs and Chapters**	**Patents Awarded**	**Other Research Outputs (please specify)**	
No. of outputs	4	1	1	0	Type	No.

arising directly from this research project						

14. Public Access Of Completion Report

(Please specify the information, if any, that cannot be provided for public access and give the reasons.)

Information that Cannot Be Provided for Public Access	**Reasons**
NA	