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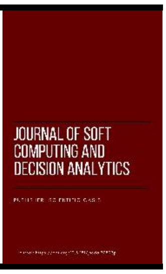

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# The Impact of Cruise Controllability on the Decision Making of Schedule Construction

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**ABSTRACT**

Nowadays, challenged by diverse uncertainties and disruptions (e.g., bad weather), as well as the strict environmental regulations imposed by authorities (e.g., on carbon emissions), airlines are struggling. How to improve their operational efficiency in such a volatile and adverse market becomes a top agenda of airlines. Among various operations, crew scheduling is fundamentally important as staffing cost is a big part of the total operational expenses. It is known that in crew scheduling, "robust crew pairing" is crucial to make the produced pairings less vulnerable in real operations. Existing studies generally construct robustness assuming that the aircraft cruise speed is fixed. However, prior studies have found that flight times exhibit significant variations due to reasons like cruise speed adjustment, and aircraft can control cruise speed for purposes like reducing delays. For crew, cruise speed controllability is also useful in hedging disruptions. For example, one flight can speed up to meet its on-time arrival even if it departs late due to crew disruptions. However, the impacts of cruise speed controllability on crew pairing robustness and the related environmental costs are under-explored. We thus propose this preliminary study to explore the possibility to use cruise speed controllability to enhance schedule robustness for crews.

## 1. Introduction

### *1.1 Background & Motivation*

In airline crew scheduling, the crew pairing problem (CPP) is to derive sufficient pairings (i.e., a sequence of flights to be served by the same crew which starts from and ends at the home base) to cover all flights while minimizing costs [1-5]. However, flight delays are common due to the great uncertainties in the air transportation industry (like bad weather). For example, it is reported that over 1.3 million flights encountered delayed arrivals in 2019 for major U.S. airlines. Therefore, robust crew pairing problems become crucial, where the possible disruptions in operations are considered during pairing construction, enabling the generated pairings to perform better in operations [6-11]. Traditional robustness enhancement approaches generally consider fixed aircraft cruise speed. However, from the industrial dataset, we interestingly found that the cruise speed of a flight varies

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on different operation days. Besides, prior studies reveal that flight times demonstrate significant variability due to reasons like speed control during the cruise stage [12]. For crew, cruise speed controllability is also useful in hedging disruptions. For example, one flight can speed up to meet its on-time arrival even if it departs late due to crew disruptions. However, the industry has not taken full advantage of cruise speed controllability in crew pairing robustness enhancement. Meanwhile, modern airlines have to operate under strict environmental regulations (e.g., on carbon emissions). Therefore, the higher fuel burn and gas emissions brought by higher cruise speeds not only incur high costs, but also impair airlines' image regarding environmental responsibility which may incur a heavy penalty/expense.

In the existing CPP literature, pairings are modelled in a team or an individual basis [13]. In American and European airlines, the team modelling approach is commonly used. Different from the single-qualified cockpit crew, multi-class cabin crew is generally cross-qualified to serve several types of aircraft with heterogeneous manpower requirements (e.g., A320 and A330 require different numbers of cabin crew members for each class) [4, so that some Asian airlines schedule each cabin crew member individually. However, the individual modelling approach is more complicated as the cabin crew members assigned to a flight may come from different preceding (upstream) flights, and they may serve different subsequent (downstream) flights after the current operations. For both team and individual pairings, cruise speed control can be used to enhance robustness. However, due to the higher flight connection diversity, the impact of cruise speed controllability on robustness enhancement is expected to be much larger when the individual modelling approach is applied. We thus plan to use the individual modelling approach to demonstrate our idea in this study (when cabin crew is considered).

Motivated by the preliminary findings, this study aims to propose a novel robust individual cabin crew pairing approach with cruise speed controllability and environmental considerations. In our proposed robustness concept, a flight can maintain its on-time arrival even if it encounters a delayed departure due to crew disturbances. We thus define robustness as the enhanced buffer facilitated by cruise speed controllability within flight connections. This idea is important but new to the literature.

### *1.2 Literature Review*

#### *1.2.1 Airline crew pairing problems*

The CPP is the first stage of the airline crew scheduling problem [4], with two modelling approaches applied in the literature: the team approach and the individual approach [14]. The team approach is commonly used in western airlines for problem traceability and team spirits development [15-22]. In recent years, using the team approach, some studies even explore the integrated airline crew scheduling problems by simultaneously considering the CPP and the second-stage crew rostering/assignment problem [18], while some research focuses on the integration of the CPP with other airline scheduling problems like fleet assignment and aircraft routing [2] [21]. Despite the wide application of the team approach, recent practice reveals that many Asian airlines are scheduling the multi-class cross-qualified cabin crew individually due to the higher flexibility in handling various types of aircraft.

Research gap: Although the individual approach can better capture the distinctive operating characteristics of cabin crew (i.e., multiple classes, cross qualification, heterogeneous manpower requirements, crew substitution), little research studies the individual approach due to the higher problem complexity. Moreover, the benefit of cruise speed control on robustness enhancement is expected to be much higher if the individual approach is applied due to the higher flight connection diversity. Therefore, in this study, we will apply the individual modelling approach to characterize the robustness enhancement facilitated by cruise speed controllability for cabin crew pairings. Besides, if this study successfully gets funded, we will also study the application of the team modelling approach for cruise speed robustness enhancement. This study will provide a new research direction for the CPP.

### *1.2.2 Robust airline crew pairing problems*

In the robust CPP literature, increasing flight connection time (i.e. buffer) is a useful strategy to enhance robustness [23] [24]. For example, buffer time determined by the expected flight arrival delay of the previous flight is used to enhance pairing robustness in [23]. Some studies incorporate recovery strategies (like crew swaps) into pairings so that the disrupted schedule in real operations can recover naturally at a small cost [25] [26]. Additionally, propagated delay minimization for the flight network is also applied for the robust CPP [27] [28]. Besides, some studies explore the integrated robust airline scheduling problems, like the integrated aircraft routing and crew scheduling [11], and integrated fleet assignment and crew scheduling. However, it is noted that the existing works usually consider fixed cruise speed, while robust scheduling is generally based on the team modelling approach [12].

Research gap: In the existing robust CPP literature, cruise speed control has not yet been applied as a robustness instrument. In this study, we propose to utilize cruise speed controllability which can shorten cruise times to enhance the robustness of individual pairings. A new robust pairing modelling approach will be developed, providing a new research direction for the robust CPP.

### *1.2.3. Airline scheduling problems with cruise speed considerations*

Cruise speed controllability has been applied for airline recovery operations like aircraft rescheduling and passenger recovery [29-31]. For example, when a flight delay occurs, aircraft acceleration of subsequent flights is used to gradually reduce the delay of each downstream flight in the same aircraft route, and finally brings the disrupted flights back to the schedule in real operations [29]. Besides, speed adjustment is also integrated into scheduling problems like fleet assignment and aircraft routing [32-35]. For instance, cruise speed is controlled to ensure desirable passenger connection probabilities during fleet assignment and aircraft scheduling in [35]. However, aircraft acceleration is not free as it causes serious concerns due to the increased fuel burn and gas emissions. Therefore, in this study, we will analyze the benefits and the environmental costs brought by speed adjustment.

Research gap: Although the importance of cruise speed controllability for improving airline operations has been realized, how it would impact crew pairing robustness has not been revealed. Our work provides a new pairing robustness enhancement scheme using cruise speed controllability to add extra buffer in flight connections. Besides, we will develop a new optimization methodology which considers the trade-off between robustness and environmental costs.

## **2. Methodology**

### *2.1 Problem Description*

In this study, we will demonstrate our idea of enhancing pairing robustness by cruise speed controllability for multi-class cabin crew using the individual modelling approach (i.e., model each crew member individually). We briefly introduce it here. The cabin crew (for brevity, the word “cabin” will be omitted hereafter) is classified into $|R|$ classes. A set of flights ($f \in F$) with heterogeneous manpower requirements is to be covered. $b_{f,t}^{r}$ is the number of Class r ($r \in R$) crew members required by Flight f (decided by the aircraft type $t$ $(t \in T)$ used). The non-negative decision variable $x_{j_r}$ $(j_r \in J_r)$ represents whether Individual Pairing (for brevity, the word "Individual" will be omitted hereafter) $j_r$ of Class r crew is selected (and by how many times) or not. The binary flight coverage coefficient $a_{f j_r}$ represents whether Flight f is covered by Pairing $j_r$. Due to finite availability, airlines sometimes encounter manpower shortage. Crew members from other classes are then assigned to substitute the originally required ones (crew substitution). Variable $s_f^r$ records the number of times of Class $r$ crew being substituted on Flight $f$, creating a unit penalty cost $\mu$ to avoid unnecessary substitutions. In case when crew substitution fails to satisfy all manpower demands, the non-negative variable $x_{j_r^e}$ $(j_r^e \in J_r^e)$ is introduced with a large penalty $M$ to ensure solution feasibility (e.g., using additional manpower like reserve crew). We use $P$ to denote all potential pairings $(P = J_r \cup J_r^e$, for all $r \in R)$. The basic costs for Pairings $j_r$ and $j_r^e$ are represented by $c_{j_r}$ and $c_{j_r^e}$, respectively, which are determined by the pairing minimum duty guaranteed cost, waiting cost, rest cost and fixed cost. Note that $c_p$ $(p \in P) \ll \mu \ll M$. A feasible pairing should satisfy diverse regulations. For example, the connection time between two flight legs is termed as *sit*. As regulated, a feasible *sit* shall range from *MinS* to *MaxS* to ensure that those two flight legs can be operated by the same crew. A delayed flight arrival might leave insufficient *sit* for the on-time departure of the next flight to be served by the same crew (see Figure 1).

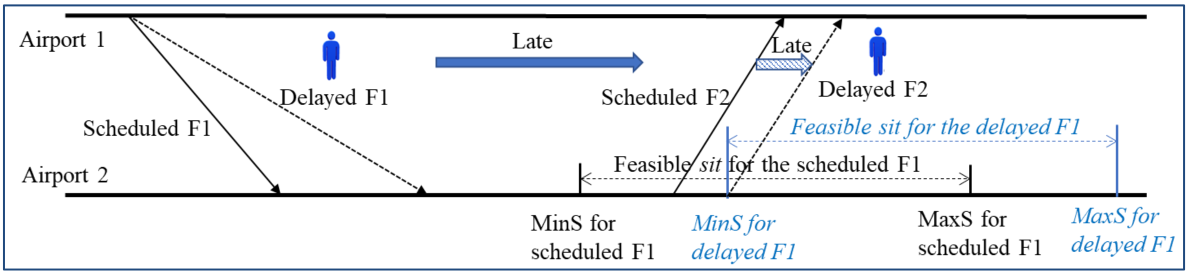

**Fig. 1.** Delay of the next (downstream) flight due to the delayed arrival of the previous (upstream) flight operated by the same crew

Buffer time is often used as a robustness strategy to absorb upstream disruptions. Traditionally, the buffer time between Flight $f$ and its preceding Flight $f^-$ is $\varphi_f^{f^-} = de^s(f) - MinS - ar^s(f^-)$, where $de^s(f)$ and $ar^s(f^-)$ are the scheduled departure of Flight $f$ and the scheduled arrival of Flight $f^-$, respectively. That is, the longest arrival delay of Flight $f^-$ that will not affect Flight $f$ is $\varphi_f^{f^-}$ (Figure 2(a)). If the arrival delay of Flight $f^-$ exceeds $\varphi_f^{f^-}$, Flight $f$ is then disrupted (Figure 2(b)).

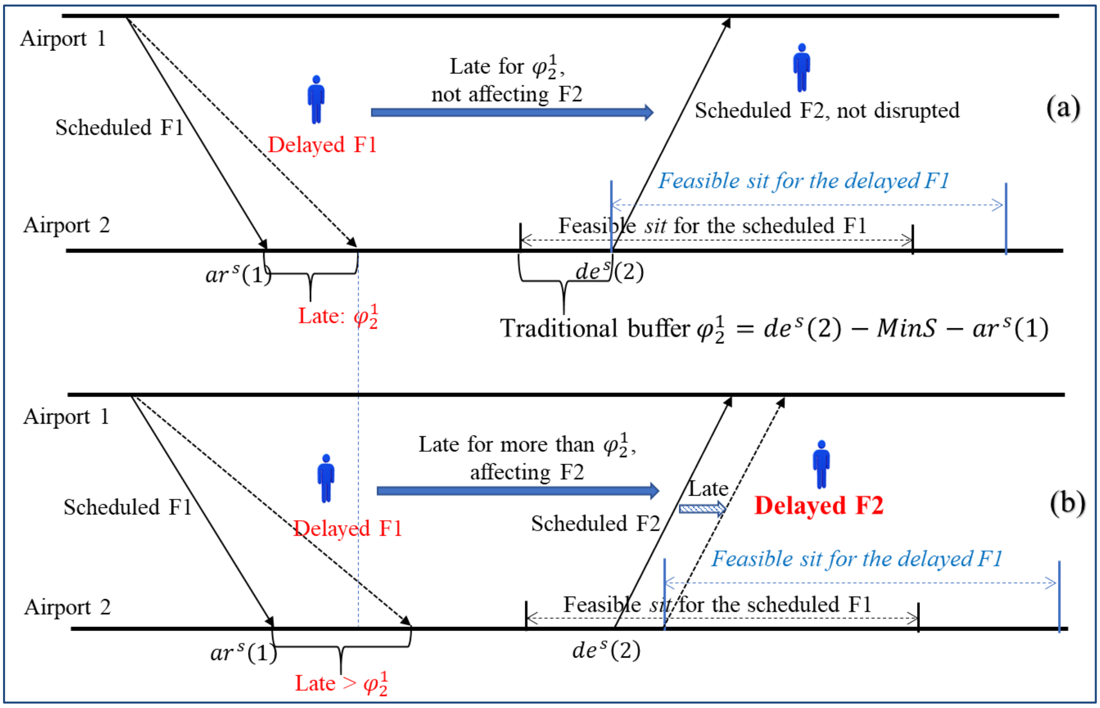

**Fig. 2.** The effects of traditional buffer time

### *2.2 A New Robustness Enhancement Tactic by Cruise Speed Controllability*

In this study, we aim to enhance crew pairing robustness through aircraft acceleration during the cruise stage of downstream flights. The logic is to shorten the cruise time of the subsequent flight by flying faster to ensure its on-time arrival even if it departs late due to crew disruptions of previous flights, so that flights can better withstand upstream disruptions in operations, which is different from the traditional buffer approach. Actually, flights contain several stages like takeoff, climb, cruise, and descent. However, except the cruise stage, there is little room to control the others as they are generally dictated by air traffic control [29]. Therefore, we focus on the cruise stage and assume that all the other stages are operated as scheduled. We preliminarily model the robustness improved by cruise stage acceleration as the reduction in cruise time which can serve as an extra buffer within flight connections. For Flight $f$ operated by aircraft type $t$, if we denote the cruise distance and scheduled cruise speed by $d_f^t$ and $v_f^{t,s}$, respectively, the planned cruise time is $d_f^t/v_f^{t,s}$. Traditionally, cruise speed is assumed to be fixed. In this study, we plan to model cruise speed as a decision variable $v_f^t$ which can be accelerated. The cruise time reduction of Flight $f$ by speeding up to $v_f^t$ (i.e., $\Delta_f^t(v_f^t) = d_f^t/v_f^{t,s} - d_f^t/v_f^t$) is the extended buffer time between Flights $f$ and $f^-$, as depicted in Figure 3. There is generally an upper limit for cruise speed for each flight operated by each type of aircraft due to factors like air traffic conditions. Therefore, cruise time reduction is bounded. We will carry out data analytics (e.g., statistics) to identify the highest cruise speed that aircraft type $t$ can achieve for Flight $f$, which is denoted as $v_f^{t,m}$. Therefore, we have $v_f^t \in \left[v_f^{t,s}, v_f^{t,m}\right]$. The maximum possible cruise time reduction for Flight $f$ is thus $\Delta_f^{t,m} = d_f^t/v_f^{t,s} - d_f^t/v_f^{t,m}$. Accordingly, we can preliminarily model the overall robustness level of Pairing $p$ ($\beta_p$) enhanced by cruise stage acceleration as in Eq. (1). $A_p$ represents the set of flight connections contained in Pairing $p$. Note that the enhanced buffer within flight connections is determined by the traditional buffer and the cruise-acceleration extended buffer. Using the individual modelling approach, we can characterize the different flight connections contained in each individual pairing, thus precisely formulating the specific robustness levels.

$$\beta_p = \sum_{(f^-,f)\in A_p}\left(\varphi_f^{f^-} + \Delta_f^t(v_f^t)\right),\ \Delta_f^t(v_f^t) \in \left[0, \Delta_f^{t,m}\right],\ p \in P,\ P = J_r \cup J_r^e\ (\text{for all } r \in R),\ t \in T. \tag{1}$$

Note that we will further study the robustness enhancement setting in which the preceding (upstream) flight can accelerate to arrive earlier to leave more time for the downstream flight to handle potential disruptions during flight connections.

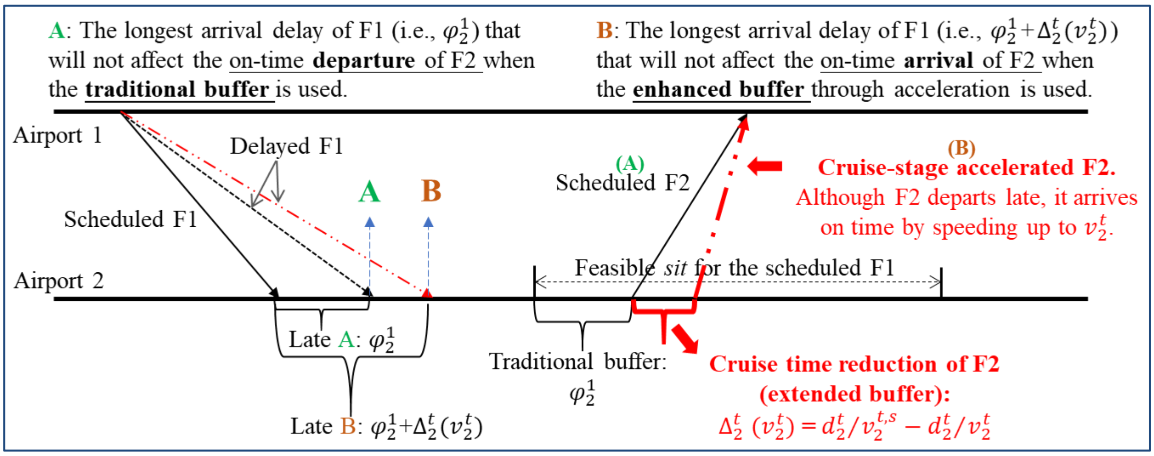

**Fig. 3.** Extended buffer facilitated by cruise stage acceleration of the downstream flight

### *2.3 Solution Evaluation Mechanism*

Although aircraft acceleration is beneficial to enhance robustness, it will yield higher environmental costs with higher fuel consumption. Thus, in this study, we plan to propose a new solution evaluation mechanism involving robustness and environmental costs. We preliminarily apply the cruise stage fuel burn formulation developed by the Base of Aircraft Data (BADA) study of EUROCONTROL [29][30][31][34][36]: $\tau(v_f^t)$=$d_f^t \cdot ({\delta_1^t v_f^t}^2 + \delta_2^t v_f^t + \delta_3^t/{v_f^t}^2 + \delta_4^t/{v_f^t}^3)$, where $\tau(v_f^t)$ is the fuel burn (kg) for Flight $f$ operated by aircraft type $t$ at cruise speed $v_f^t$ for cruise distance $d_f^t$. Coefficients $\delta_i^t$ are determined by aircraft specific drag and fuel consumption coefficients, aircraft properties (e.g., mass of aircraft), air density, etc. We will refer to BADA user manual for the required parameters. If the unit price of fuel is $p_u$, the overall environmental cost of all flights (cruise stage) is $E_F = \sum_{f\in F} p_u\, \tau(v_f^t)$. Now, we study how to develop a new solution evaluation mechanism. We preliminarily propose to maximize the weighted overall robustness ($\phi = \sum_{p\in P} \beta_p x_p$) and minimize the weighted environmental cost $E_F$ in Eq. (2). Weightings are $w_i$. Note that as the units of $\phi$ and $E_F$ are different, normalization is needed (denoted by $\widehat{\ }$).

$$\text{Min: } w_1(-\widehat{\phi}) + w_2\widehat{E_F}. \tag{2}$$

Note that as airlines nowadays have to operate under strict environmental regulations (e.g., on emissions), we thus further enhance the mechanism to ensure that the gas emission will not exceed an upper limit ($C_{max}$) imposed by airlines or authorities. Gas emission is shown to be proportional to the weight of fuel consumed, as represented by $\varepsilon(v_f^t) = k\tau(v_f^t)$, where $k$ is the gas emission coefficient. Therefore, the emission constraint can be modelled as $\sum_{f\in F} \varepsilon(v_f^t) \leq C_{max}$.

## 3. The Optimization Model and Solution Algorithm

### *3.1 The Model*

We preliminarily consider a single-home-base problem. For multi-class cabin crew, we plan to build the flight network for each class for the generation of individual pairings, in order to better model the robustness enhanced by cruise speed control as well as the distinctive operating characteristics (see Figure 4). We plan to formulate the novel robust individual cabin crew pairing model with cruise speed controllability and environmental considerations as in (4) to (10). Objective (3) is to strike a balance between the overall robustness level enhanced by aircraft cruise acceleration and the environmental cost. The environmental cost $E_F$ is related to the cruise speed of each flight ($v_f^t$). The overall robustness level $\Phi$ equals $\sum_{r\in R}\sum_{j_r\in J_r}\beta_{j_r}x_{j_r}+\sum_{r\in R}\sum_{j_r^e\in J_r^e}\beta_{j_r^e}x_{j_r^e}$, where $\beta_{j_r}$ and $\beta_{j_r^e}$ are the robustness levels facilitated by cruise speed control of Pairing $j_r$ and Pairing $j_r^e$, respectively, as determined by Eq. (1). Therefore, during the individual pairing construction for each crew class ($r \in R$) and type ($j_r$ or $j_r^e$), the cruise speed of each flight ($v_f^t$) will be considered. Besides, Constraint (9) limits the total gas emissions decided by aircraft cruise speeds, while Constraint (10) sets a range for the cruise speed adjustment for each flight operated by a certain aircraft type ($v_f^t \in \left[v_f^{t,s}, v_f^{t,m}\right]$). Constraint (4) is to satisfy the flight heterogeneous manpower requirements with crew substitution, while Constraint (5) ensures that each class is assigned with at least one member from the originally required class on each flight. Constraint (6) records the number of times that Class $r$ crew is substituted on Flight $f$, while Constraint (7) requires that the summation of the pairing durations ($\sigma_{j_r}$) of all Class $r$ pairings selected will not exceed an upper limit for the base ($\Omega_r$) to satisfy the manpower availability restriction. Constraint (8) is to control that the total pairing basic cost does not increase too much (i.e., $q\%$) compared with the optimal basic cost obtained when the cruise-speed-enhanced robustness and environmental concerns are not considered (i.e., $C_A$).

$$
\begin{array}{llll}
\text{Min} & w_1(-\widehat{\Phi})+w_2\widehat{E_F} & & (3)\\
\text{s.t.} & \sum_{r\in R}\sum_{j_r\in J_r}a_{fj_r}x_{j_r}+\sum_{r\in R}\sum_{j_r^e\in J_r^e}a_{fj_r^e}x_{j_r^e}\geq\sum_{r\in R}b_{f,t}^r, & f\in F, t\in T, & (4)\\
 & \sum_{j_r\in J_r}a_{fj_r}x_{j_r}+\sum_{j_r^e\in J_r^e}a_{fj_r^e}x_{j_r^e}\geq 1, & f\in F, r\in R, & (5)\\
 & \sum_{j_r\in J_r}a_{fj_r}x_{j_r}+\sum_{j_r^e\in J_r^e}a_{fj_r^e}x_{j_r^e}+s_f^r\geq b_{f,t}^r, & f\in F, r\in R, t\in T, & (6)\\
 & \sum_{j_r\in J_r}\sigma_{j_r}x_{j_r}\leq\Omega_r, & r\in R, & (7)\\
 & \sum_{r\in R}\sum_{j_r\in J_r}c_{j_r}x_{j_r}+\sum_{r\in R}\sum_{f\in F}\mu s_f^r+\sum_{r\in R}\sum_{j_r^e\in J_r^e}(c_{j_r^e}+M)x_{j_r^e}\leq(1+q\%)C_A, & & (8)\\
 & \sum_{f\in F}\varepsilon(v_f^t)\leq C_{max}, & t\in T, & (9)\\
 & v_f^{t,s}\leq v_f^t\leq v_f^{t,m}, & f\in F, t\in T. & (10)
\end{array}
$$

Note that we will further study a multi-home-base problem and other forms of manpower availability constraints like the maximum number of pairings allowed in an operation day [37].

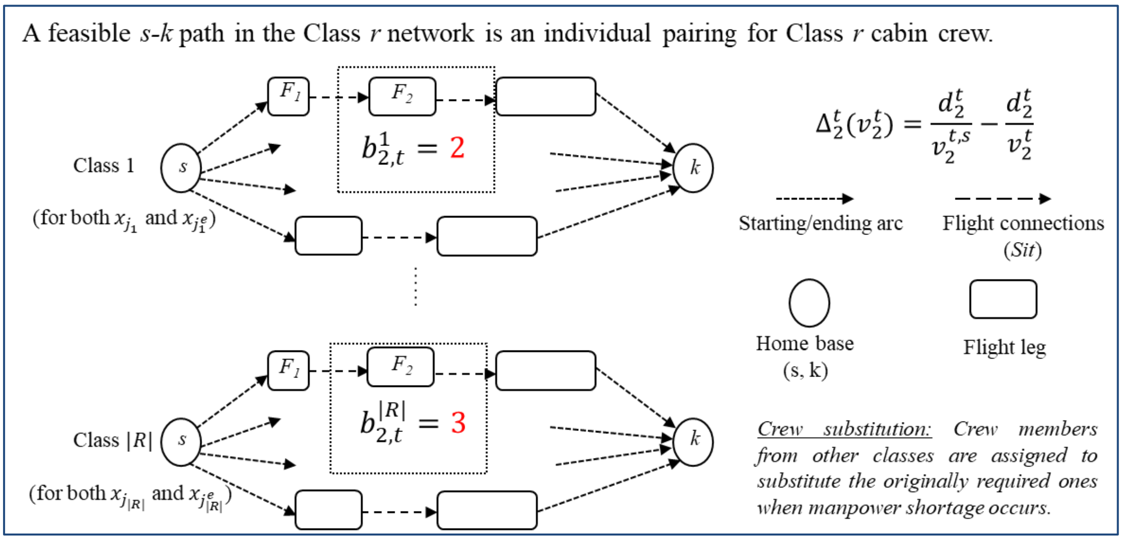

**Fig. 4.** Flight networks for multi-class cabin crew

### *3.2 The Solution Algorithm*

The crew pairing problem is well-known as NP-hard. In this study, we will propose a new CG based solution methodology with new methodological acceleration techniques. Due to the large scale (e.g., millions or even billions of possible pairings), we preliminarily apply the CG approach to solve the problem proposed. We tentatively plan to consider the cruise speed decisions in the restricted master problem (RMP) with a limited number of individual pairings. For the sub-problem of CG, new potential individual pairings with negative reduced costs will be identified. Note that the cruise speed decisions may also be studied in the sub-problem. We will further study the efficacy of considering cruise speeds in the RMP and in the sub-problem. When the sub-problem fails to identify a better pairing, the CG ends. The branch-and-price technique will then be applied to obtain integer solutions. The CG sub-problem usually occupies most computational time. We thus plan to propose two methodological acceleration techniques as follows.

The sub-problem can be transformed to solve a resource-constrained shortest path problem (RCSPP) in the flight network for each crew class and type. The resources can be working rules and regulations. Note that in addition to the traditional considerations like the pairing basic cost and resource consumption, the cruise speed enhanced robustness $(\varphi_f^{f^-} + \Delta_f^t(v_f^t))$ should also be integrated into the process of path extension in the RCSPP. Accordingly, a new path dominance rule based on the cruise speed enhanced robustness levels can be constructed to reduce computational efforts thus accelerating the RCSPP. Besides, even if several promising individual pairings can be added to the restricted master problem simultaneously in each iteration, the sub-problems of CG still waste plenty of time on those networks with little potential, which limits its application. Therefore, in this study, we will study problem features and develop a new network-selection technique which can provide useful instructions regarding when certain crew class (es) and type (s) have the highest potential to generate promising new pairings, in order to avoid useless searching and thus accelerate the CG.

## 4. Conclusions

In this preliminary study, we explore the possibility to use cruise speed controllability to enhance schedule robustness for crews. Specifically, we have discussed the impact of flight duration variability of upstream flights on downstream flights, based on which we develop a new robustness enhancement tactic by controlling cruise speed. Besides, we also take sustainability issues into account, e.g., by considering the fuel consumption and carbon emission in the optimization objective. Moreover, we preliminarily propose to build a solution approach based on branch and price. Note that as cruise speed is generally controlled during the operational stage to hedge against departure delays or to reduce arrival traffic jam, how this measurement could be applied during tactic scheduling is still a question. We thus propose that to validate the effect of cruise speed control to enhance tactic schedule robustness as a promising future research direction.

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### Conflicts of Interest

The authors declare no conflicts of interest.

## References

[1] Barnhart, C., & Cohn, A. (2004). Airline schedule planning: Accomplishments and opportunities. Manufacturing & service operations management, 6(1), 3-22. https://doi.org/10.1287/msom.1030.0018

[2] Cacchiani, V., & Salazar-González, J. J. (2017). Optimal solutions to a real-world integrated airline scheduling problem. Transportation Science, 51(1), 250-268. https://doi.org/10.1287/trsc.2015.0655

[3] Deveci, M., & Demirel, N. C. (2018). Evolutionary algorithms for solving the airline crew pairing problem. Computers & Industrial Engineering, 115, 389-406. https://doi.org/10.1016/j.cie.2017.11.022

[4] Haouari, M., Mansour, F. Z., & Sherali, H. D. (2019). A new compact formulation for the daily crew pairing problem. Transportation Science, 53(3), 811-828. https://doi.org/10.1287/trsc.2018.0860

[5] Wen, X., Chung, S. H., Ji, P., & Sheu, J. B. (2022). Individual scheduling approach for multi-class airline cabin crew with manpower requirement heterogeneity. Transportation Research Part E: Logistics and Transportation Review, 163, 102763. https://doi.org/10.1016/j.tre.2022.102763

[6] Antunes, D., Vaze, V., & Antunes, A. P. (2019). A Robust Pairing Model for Airline Crew Scheduling. Transportation Science, 53(6), 1751-1771. https://doi.org/10.1287/trsc.2019.0897

[7] Deveci, M., & Demirel, N. Ç. (2018). A survey of the literature on airline crew scheduling. Engineering Applications of Artificial Intelligence, 74, 54-69. https://doi.org/10.1016/j.engappai.2018.05.008

[8] Gao, C., Johnson, E., & Smith, B. (2009). Integrated airline fleet and crew robust planning. Transportation Science, 43(1), 2-16. https://doi.org/10.1287/trsc.1080.0257

[9] Tekiner, H., Birbil, Ş. İ., & Bülbül, K. (2009). Robust crew pairing for managing extra flights. Computers & Operations Research, 36(6), 2031-2048. https://doi.org/10.1016/j.cor.2008.07.005

[10] Wei, K., & Vaze, V. (2018). Modeling crew itineraries and delays in the national air transportation system. Transportation Science, 52(5), 1276-1296. https://doi.org/10.1287/trsc.2018.0834

[11] Weide, O., Ryan, D., & Ehrgott, M. (2010). An iterative approach to robust and integrated aircraft routing and crew scheduling. Computers & Operations Research, 37(5), 833-844. https://doi.org/10.1016/j.cor.2009.03.024

[12] Wen, X., Ma, H. L., Chung, S. H., & Khan, W. A. (2020). Robust airline crew scheduling with flight flying time variability. Transportation Research Part E: Logistics and Transportation Review, 144, 102132. https://doi.org/10.1016/j.tre.2020.102132

[13] Wen, X., Sun, X., Sun, Y., & Yue, X. (2021). Airline crew scheduling: Models and algorithms. Transportation Research Part E: Logistics and Transportation Review, 149, 102304. https://doi.org/10.1016/j.tre.2021.102304

[14] Yan, S., Tung, T. T., & Tu, Y. P. (2002). Optimal construction of airline individual crew pairings. Computers & Operations Research, 29(4), 341-363. https://doi.org/10.1016/S0305-0548(00)00070-8

[15] AhmadBeygi, S., Cohn, A., & Weir, M. (2009). An integer programming approach to generating airline crew pairings. Computers & Operations Research, 36(4), 1284-1298. https://doi.org/10.1016/j.cor.2008.02.001

[16] Erdoğan, G., Haouari, M., Matoglu, M. Ö., & Özener, O. Ö. (2015). Solving a large-scale crew pairing problem. Journal of The Operational Research Society, 66(10), 1742-1754. https://doi.org/10.1057/jors.2015.2

[17] Quesnel, F., Desaulniers, G., & Soumis, F. (2019a). A branch-and-price heuristic for the crew pairing problem with language constraints. European Journal of Operational Research. https://doi.org/10.1016/j.ejor.2019.11.043

[18] Quesnel, F., Desaulniers, G., & Soumis, F. (2019b). Improving air crew rostering by considering crew preferences in the crew pairing problem. Transportation Science. https://doi.org/10.1287/trsc.2019.0913

[19] Saddoune, M., Desaulniers, G., & Soumis, F. (2013). Aircrew pairings with possible repetitions of the same flight number. Computers & Operations Research, 40(3), 805-814. https://doi.org/10.1016/j.cor.2010.11.003

[20] Salazar-González, J. J. (2014). Approaches to solve the fleet-assignment, aircraft-routing, crew-pairing and crew-rostering problems of a regional carrier. Omega, 43, 71-82. https://doi.org/10.1016/j.omega.2013.06.006

[21] Shao, S., Sherali, H. D., & Haouari, M. (2017). A novel model and decomposition approach for the integrated airline fleet assignment, aircraft routing, and crew pairing problem. Transportation Science, 51(1), 233-249. https://doi.org/10.1287/trsc.2015.0623

[22] Yan, S., & Tu, Y. P. (2002). A network model for airline cabin crew scheduling. European Journal of Operational Research, 140(3), 531-540. https://doi.org/10.1016/S0377-2217(01)00215-6

[23] Chung, S. H., Ma, H. L., & Chan, H. K. (2017). Cascading delay risk of airline workforce deployments with crew pairing and schedule optimization. Risk Analysis, 37(8), 1443-1458. https://doi.org/10.1111/risa.12746

[24] Yen, J. W., & Birge, J. R. (2006). A stochastic programming approach to the airline crew scheduling problem. Transportation Science, 40(1), 3-14. https://doi.org/10.1287/trsc.1050.0138

[25] Muter, İ., Birbil, Ş. İ., Bülbül, K., Şahin, G., Yenigün, H., Taş, D., & Tüzün, D. (2013). Solving a robust airline crew pairing problem with column generation. Computers & Operations Research, 40(3), 815-830. https://doi.org/10.1016/j.cor.2010.11.005

[26] Shebalov, S., & Klabjan, D. (2006). Robust airline crew pairing: Move-up crews. Transportation Science, 40(3), 300-312. https://doi.org/10.1287/trsc.1050.0131

[27] Dunbar, M., Froyland, G., & Wu, C. L. (2012). Robust airline schedule planning: Minimizing propagated delay in an integrated routing and crewing framework. Transportation Science, 46(2), 204-216. https://doi.org/10.1287/trsc.1110.0395

[28] Sun, X., Chung, S. H., Choi, T. M., Sheu, J. B., & Ma, H. L. (2020). Combating lead-time uncertainty in global supply chain's shipment-assignment: Is it wise to be risk-averse? Transportation Research Part B: Methodological, 138, 406-434. https://doi.org/10.1016/j.trb.2020.05.015

[29] Aktürk, M. S., Atamtürk, A., & Gürel, S. (2014). Aircraft rescheduling with cruise speed control. Operations Research, 62(4), 829-845. https://doi.org/10.1287/opre.2014.1279

[30] Arıkan, U., Gürel, S., & Aktürk, M. S. (2016). Integrated aircraft and passenger recovery with cruise time controllability. Annals of Operations Research, 236(2), 295-317. https://doi.org/10.1007/s10479-013-1424-2

[31] Arıkan, U., Gürel, S., & Aktürk, M. S. (2017). Flight network-based approach for integrated airline recovery with cruise speed control. Transportation Science, 51(4), 1259-1287. https://doi.org/10.1287/trsc.2016.0716

[32] Duran, A. S., Gürel, S., & Aktürk, M. S. (2015). Robust airline scheduling with controllable cruise times and chance constraints. IIE Transactions, 47(1), 64-83. https://doi.org/10.1080/0740817X.2014.916457

[33] Gürkan, H., Gürel, S., & Aktürk, M. S. (2016). An integrated approach for airline scheduling, aircraft fleeting and routing with cruise speed control. Transportation Research Part C: Emerging Technologies, 68, 38-57. https://doi.org/10.1016/j.trc.2016.03.002

[34] Şafak, Ö., Çavuş, Ö., & Selim Aktürk, M. (2018). Multi-stage airline scheduling problem with stochastic passenger demand and non-cruise times. Transportation Research Part B: Methodological, 114, 39-67. https://doi.org/10.1016/j.trb.2018.05.012

[35] Şafak, Ö., Gürel, S., & Aktürk, M. S. (2017). Integrated aircraft-path assignment and robust schedule design with cruise speed control. Computers & Operations Research, 84, 127-145. https://doi.org/10.1016/j.cor.2017.03.005

[36] EUROCONTROL. (2009). Base of aircraft data (BADA) aircraft performance modelling report.

[37] Dunbar, M., Froyland, G., & Wu, C. L. (2014). An integrated scenario-based approach for robust aircraft routing, crew pairing and re-timing. Computers & Operations Research, 45, 68-86. https://doi.org/10.1016/j.cor.2013.12.003