A Multi-Criteria Decision-Making Scheme for Multi-Aircraft Conflict Resolution [⋆]

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Abstract: Multi-Aircraft Conflict Resolution (MACR) is a Multi-Criteria Decision-Making (MCDM) problem, which involves multiple stakeholders (airline, air traffic controller, and aircraft) with competing and incommensurable objectives. This paper proposes a two-step MCDM scheme to the solution of MACR. In the first step, a second order cone program is adopted to generate a set of candidate resolution strategies with different minimum separations between trajectories. Each candidate strategy is then evaluated via three criteria modeling the interests of the stakeholders. In the second step, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) approach is used to determine the best strategy that realizes an adequate tradeoff among the competing interests while coping with their incommensurability. Some numerical results are presented to show the efficacy of the proposed scheme. Interestingly, the minimum separations associated with the best resolution strategies according to either the interest of the airline or that of the aircraft both differ from the one adopted in the current air traffic control operation.

Keywords: Multi-Aircraft Conflict Resolution, Multi-Criteria Decision-Making, Aerospace, Multi-agent systems.

1. INTRODUCTION

In order to meet the rapid growth of air traffic demand, enhanced technologies, such as satellite based navigation, Automatic Dependent Surveillance-Broadcast (ADS-B), digital communications, System Wide Information Management (SWIM), are widely deployed in the Air Traffic Control (ATC) system operation. This enables Collaborative Decision Making (CDM) of multiple stakeholders, including airline, air traffic controller, and aircraft, during the flight (see Prevot et al. (2003), Prevot et al. (2005), and Sipe and Moore (2009)).However, stakeholders have different decision objectives: airlines are interested in the economic benefits, hence, their aim is to reduce the flight cost by selecting the shortest trajectory from origin to destination; air traffic controllers are in charge of ensuring flight safety by maintaining aircraft at some safe distance; and pilots onboard of the aircraft care more about flight maneuverability in terms of flexibility available for handling safely emergency situations. Thus, ATC is a decision-making process that involved different, not directly comparable objectives, and it is hence necessary to develop solutions that realize a good tradeoff among them.

Multi-Aircraft Conflict Resolution (MACR) is one of the core ATC tasks (Kuchar and Yang (2000), Chaloulos et al. (2010)). As soon as a conflict, i.e., a violation of the prescribed minimum separation between aircraft, is detected, aircraft trajectories have to be modified using horizontal re-routing maneuvers, vertical ascending or descending maneuvers, or speed change strategies. These trajectory redesign process inevitably induces some deviation from the original trajectories, thus typically resulting in increased flight distance and fuel consumption, and flight delay. The minimum cost strategy is the best choice from the airlines perspective, whereas air traffic controllers look for a strategy that does not create any secondary conflicts and thus avoids the *domino effect*. As for the pilots onboard of the aircraft, they favor those resolution strategies that preserve some degree of flexibility so as to be able to handle the occurrence of unpredicted stochastic events during the flight. MACR is hence a Multi-Criteria Decision-Making (MCDM) problem with multiple stakeholders involved. In recent decades, many contributions on MACR have appeared in the literature (see the surveys Kuchar and Yang (2000), Chaloulos et al. (2010)). Approaches can be classified into three categories depending on the adopted stakeholder perspective:

(1) Pioneering works in MACR aim at minimizing the resolution strategy cost and hence are developed from the perspective of airlines. Specifically, the cost is defined as

the deviation of the modified trajectories from the original ones, in terms of, e.g., extra travel distance, and heading and altitude changes. Pallottino et al. (2002) addresses MACR by reformulating the problem as a Mixed Integer Linear Program (MILP) with conflict-free conditions described via linear constraints and using heading or velocity changes. Non-linear extensions of Pallottino et al. (2002) are proposed in Alonso-Ayuso et al. (2012) and Cafieri and Durand (2014). In Hu et al. (2002) an optimization based approach is pursued leading to a Second Order Cone Program (SOCP) where conflict-free conditions are approximated through convex constraints and the energy of the trajectory is minimized thus favoring straight line resolution trajectories traveled at constant speed. Recently, Rey et al. (2014) studies the fairness issue among airlines and designs fuel-equivalent resolution strategies obtained through velocity changes. Alonso-Ayuso et al. (2015) investigates different costs obtained via heading, altitude, and velocity changes.

(2) The air traffic controllers perspective is taken in Krozel et al. (2001). One of the decision criteria is stability of the multi-aircraft system, which relates to the domino effect. The smaller is the domino effect, the higher are the guarantees of flight safety. The taskload for the air traffic controller defined as the number of flight maneuvers to implement the resolution strategy is investigated in Vela et al. (2010) and Vela et al. (2009). MACR is solved via integer programming implementing velocity changes so as to minimize the taskload.

(3) The trajectory with the maximum flexibility is generated as resolution maneuver for the benefit of the aircraft pilot in Idris et al. (2011), Idris et al. (2007), and Idris et al. (2009). Maneuverability of the aircraft in the velocity space is used as a measure of flexibility. More specifically, the aircraft is supposed to fly along some fixed path with the velocity as only degree of freedom, and the set of velocities such that the aircraft will not encounter other aircraft along its path is defined as reachable velocity set: the larger the reachable velocity set, the larger is the flexibility of the trajectory since the aircraft has a larger maneuverability during the flight.

To the purpose of comprehensively accounting for the different objectives of the stakeholders, a Multi-Criteria Decision-Making (MCDM) scheme for MACR is proposed in this paper. The decision problem is far from trivial since it involves multiple competing and incommensurable objectives. In order to solve this challenge, the proposed scheme is composed of two steps: In the first step, we adopt a SOCP model (Hu et al. (2002), Yang et al. (2017)) to generate a set of candidate conflict resolution strategies with different separations between conflicting aircraft. Each candidate resolution strategy is evaluated in terms of three criteria, i.e., cost, stability as defined in Krozel et al. (2001), and flexibility as measured in Idris et al. (2007), according to the perspective of airlines, air traffic controllers, and aircraft, respectively. In the second step, we resort to a MCDM approach to determine the tradeoff among the competing interests of the multiple stakeholders. Specifically, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Hwang and Yoon (1981)) is adopted to overcome the issue of incommensurability of different attributes. Some numerical results are presented

to show the efficacy of the proposed scheme. Specifically, the conflict resolution strategies associated with a set of separations are investigated for various symmetric conflicting scenarios with a different number of aircraft. Results of this study reveal that the separation corresponding to the best strategy differs from the one currently adopted in the ATC operation if either the perspective of airlines or that of aircraft is highlighted.

The rest of the paper is organized as follows. Section 2 introduces the proposed MCDM scheme for MACR. Section 3 describes the numerical results. Finally, some conclusions are drawn in Section 4.

2. MULTI-CRITERIA DECISION-MAKING SCHEME

In this section we present the proposed MCDM scheme for MACR, which rests on the design of a set of candidate resolution strategies, their assessment based on different criteria, and the application of the TOPSIS for selecting the tradeoff solution.

2.1 Design of the candidate resolution strategies

Consider a multi-aircraft encounter involving n aircraft that fly at constant altitude from some starting waypoints a_i, $i = 1, \ldots, n$, to some destination waypoints b_i, $i = 1, \ldots, n$, along straight line trajectories during the time horizon $[t_s, t_d]$. In order to guarantee a desired minimum separation, say d_k, between trajectories, we introduce the intermediate waypoints $c_{i,k}$, $i = 1, \ldots, n$, at time $t_c \in [t_s, t_d]$ and consider resolution trajectories composed of two consecutive straight line legs from a_i to $c_{i,k}$ and from $c_{i,k}$ to b_i, each leg traveled at constant velocity. The intermediate waypoints $c_{i,k}$, $i = 1, \ldots, n$ can be determined by solving the following SOCP (see Hu et al. (2002), Yang et al. (2017) for details):

$$\underset{\{c_{i,k}\}_{i=1}^n}{\text{minimize}} \sum_{i=1}^n \|c_{i,k} - \bar{c}_i\|^2 \tag{1}$$

subject to:

$$c_{i,k} - c_{j,k} \in P_{ij}^+(d_k), \tag{2}$$

$$\|c_{i,k} - a_i\| \le \bar{v}(t_c - t_s), \quad \|c_{i,k} - b_i\| \le \bar{v}(t_d - t_c), \tag{3}$$

$$\|c_{i,k} - p_{i,1}\| \le r_i, \quad \|c_{i,k} - p_{i,2}\| \le r_i, \tag{4}$$

$$1 \le i < j \le n, \, i = 1, \cdots, n.$$

By minimizing the quadratic cost function in (1) where $\bar{c}_i = \frac{(t_d - t_c)a_i + (t_c - t_s)b_i}{t_d - t_s}$, $i = 1, \ldots, n$, is the intermediate waypoint position that would make the two-legs aligned on the same straight line, one actually minimizes the energy of the multi-aircraft joint maneuver. The linear constraint (2) serves the purpose of guaranteeing a minimum separation distance larger or equal to d_k for the aircraft pair (i, j), being $P_{ij}^+(d_k)$ a polytopic approximation of the admissible (conflict-free) region for $c_{i,k} - c_{j,k}$. Constraints on the velocities $v_{i,1} = \frac{\|c_i - a_i\|}{t_c - t_s}$ and $v_{i,2} = \frac{\|b_i - c_i\|}{t_d - t_c}$ for the first and second legs of each aircraft i are given by (3), $\bar{v}$ being the maximum admissible velocity. As it is easily seen in Fig. 1 (right plot), $v_{i,1}$ and $v_{i,2}$ satisfy by construction the condition $v_{i,1}(t_c - t_s) + v_{i,2}(t_d - t_c) \ge v_i(t_d - t_s)$, where $v_i = \frac{\|b_i - a_i\|}{t_d - t_s}$. This provides also a lower bound
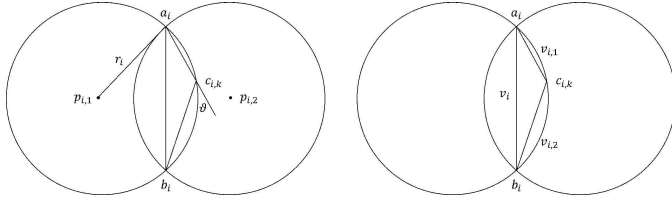
Fig. 1. Geometric construction of: turning angle constraints (left); minimum velocity constraints (right).

on the velocities. For instance, if $t_c = \frac{1}{2}(t_d - t_s)$, then $v_{i,2} \geq 2v_i - v_{i,1} \geq 2v_i - \bar{v}$, and, similarly, we have that $v_{i,1} \geq 2v_i - \bar{v}$.

Constraints (4) are introduced to avoid a sharp turn between the two legs and are derived based on the geometric construction shown in Fig. 1 (left plot), where ϑ denotes the (maximum) turning angle and waypoints a_i and b_i are interpreted as the intersections of two virtual circles with radius $r_i = \frac{\|b_i - a_i\|}{2\sin(\vartheta)}$ centered at

$$p_{i,1} = \frac{a_i + b_i}{2} + \frac{\cot(\vartheta)}{2} \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} (b_i - a_i)$$

$$p_{i,2} = \frac{a_i + b_i}{2} - \frac{\cot(\vartheta)}{2} \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} (b_i - a_i).$$

A set of candidate conflict resolution strategies expressed through the intermediate waypoints $\{c_{i,k}\}_{i=1}^n$, $k = 1, \ldots, m$, associated with the of minimum separations d_k, $k = 1, \ldots, m$, is computed by solving the corresponding SOCP via standard convex optimization tools, such as, CVX (Grant and Boyd (2013)).

2.2 Decision criteria of the stakeholders

In this section, decision criteria modeling the objectives and interests of the different stakeholders (airline, air traffic controller, and pilot) are introduced.

Cost criterion From the airline perspective, a measure of the quality of a candidate resolution strategy should account for fuel consumption, time to reach the destination, and other economical costs. An adequate criterion in our setting where a candidate resolution strategy is described by the intermediate waypoints $\{c_{i,k}\}_{i=1}^n$ is then given by the cost function in (1), i.e.,

$$C_k = \sum_{i=1}^n \|c_{i,k} - \bar{c}_i\|^2, \quad k = 1, \ldots, m. \quad (5)$$

This is in fact the sum of the squared deviations of the two-leg resolution trajectories of all the n aircraft from the straight line trajectories connecting their starting waypoints to their destination waypoints. The cost (5) then is related to the increased traveled distance and thus to the additional fuel consumption. Flight delays are instead not modeled in our setting since the travel time from origin to destination is kept constant when designing the resolution trajectories.

Stability criterion The main concern of an air traffic controller is safety. Here, motivated by the concept of domino effect in (Krozel et al. (2001)), we define as air traffic controller criterion for assessing the performance of a candidate strategy k its stability S_k, which is evaluated

in terms of the ratio between the number of conflict alerts after and before that strategy is implemented. More precisely,

$$S_k = \frac{A_k}{A_0} - 1, k = 1, \ldots, m, \quad (6)$$

where A_0 is the number of conflict alerts when the aircraft fly along their original trajectories and A_k is the corresponding number of conflict alerts after the implementation of the k-th candidate resolution strategy. In our setting, the original aircraft trajectories are the straight lines connecting starting to destination waypoints, the candidate resolution strategies are the two-leg trajectories defined by the intermediate waypoints $\{c_{i,k}\}_{i=1}^n$, $k = 1, \ldots, m$. The standard separation $d_s = 9.25\,km\,(5\,nmi)$ is adopted to check for conflicts every Δ time instants within the time horizon $[t_s, t_d]$. Thus, the air traffic controller aims at minimizing the stability measure in (6) to clear all conflicts, since in fact the minimum $S_k = -1$ is achieved when $A_k = 0$, i.e., all conflicts are resolved.

Flexibility criterion Suppose that the trajectory is fixed based on the considered k-the candidate strategy as defined by $\{c_{i,k}\}_{i=1}^n$. At each time t_h, $h = 1, \ldots, n_\Delta$, sampled from $[t_s, t_d]$ at regular time intervals of length Δ, one can let the velocity v_i of aircraft i vary and determine the ranges for v_i such that no conflict occurs with any other aircraft $j \neq i$ at that time t_h. Fig. 2 shows the velocity space of aircraft i at time $t_h \in [t_s, t_d]$. Velocity obstacles are represented by the shadowed parts. If aircraft i flies with a velocity v_i belonging to a velocity obstacle (see the dotted line in Fig. 2), then, there will be some conflict in the future. We can then determine all the intervals $[\underline{v}_i^{(s)}(t_h), \overline{v}_i^{(s)}(t_h)]$, $s = 1, \ldots, n_{ih}$, for v_i such that v_i is outside the velocity obstacles (solid line in Fig. 2) and define as flexibility of aircraft i the sum of the lengths of such intervals for all sampled times t_h in $[t_s, t_d]$:

$$F_{ik} = \sum_{h=1}^{n_\Delta} \sum_{s=1}^{n_{ih}} [\overline{v}_i^{(s)}(t_h) - \underline{v}_i^{(s)}(t_h)].$$

F_{ik} describe the flexibility of aircraft i associated with the candidate strategy k and is the criterion that a pilot would maximize in order to improve the maneuverability of the aircraft within the joint resolution maneuver k. Details on the computation of the velocity intervals $[\underline{v}_i^{(s)}(t_h), \overline{v}_i^{(s)}(t_h)]$, $s = 1, \ldots, n_{ih}$, are omitted and the reader is referred to Fang et al. (2015).

One can then define as flexibility of the k-th candidate strategy the following quantity

$$F_k = \min_{i=1,2,\ldots,n} F_{ik}, \quad (7)$$

which accounts for all aircraft involved.

2.3 TOPSIS-based multi-criteria decision-making

In order to obtain the best strategy according to the multiple criteria $\{C_k, S_k, F_k\}$ defined in equations (5), (6), and (7) and evaluated on the candidate resolution strategies indexed by $k \in \{1, \ldots, m\}$, we first normalize all criteria setting $\hat{C}_k = C_k / \|C_k\|$, $\hat{S}_k = S_k / \|S_k\|$ and $\hat{F}_k = F_k / \|F_k\|$. We then define the *positive ideal strategy* P as the strategy with the best performance from the
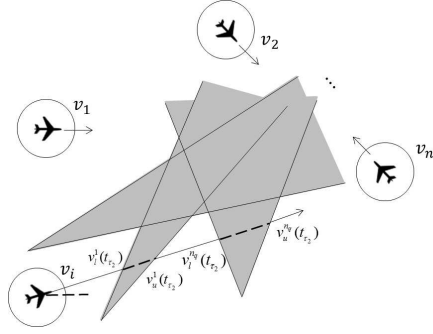
Fig. 2. Velocity space of aircraft i with the other aircraft viewed as intruders.

perspective of all stakeholders, i.e., with minimal values for the (normalized) cost and stability criteria and maximal value for the (normalized) flexibility criterion $P = [\hat{C}_{min}, \hat{S}_{min}, \hat{F}_{max}]$, where $\hat{C}_{min} = \min\{\hat{C}_k, \ k = 1, \ldots, m\}$, $\hat{S}_{min} = \min\{\hat{S}_k, \ k = 1, \ldots, m\}$, and $\hat{F}_{max} = \max\{\hat{F}_k, \ k = 1, \ldots, m\}$. Similarly, we shall define the *negative ideal strategy* N as the strategy with the worst performance $N = [\hat{C}_{max}, \hat{S}_{max}, \hat{F}_{min}]$.

The relative distance between the k-th candidate strategy and the negative ideal strategy N can be defined as

$$R_k = \frac{r_{k,N}}{r_{k,N} + r_{k,P}}$$

where $r_{k,N} = \|[\hat{C}_k, \hat{S}_k, \hat{F}_k] - N\|$ and $r_{k,P} = \|[\hat{C}_k, \hat{S}_k, \hat{F}_k] - P\|$ are the distances between the k-th candidate strategies and the ideal strategies P and N and are computed as the Euclidean distance between the corresponding performance vectors. Based on the values of R_k ranging from 0 to 1, the candidate strategies can be compared and ranked. If the candidate strategy k has $R_k = 1$, then $r_{k,P} = 0$ and this strategy has the same performance of the ideal positive strategy. While if $R_k = 0$, then, $r_{k,N} = 0$ and strategy k is identified as the worst candidate strategy.

A weighted version of R_k can be defined to give a different relevance to the three criteria. Let $W = diag([w_1, w_2, w_3])$ be a diagonal matrix with weights $w_j > 0$, $j = 1, 2, 3$. Then, we can define the weighted relative distance of strategy k from N as

$$R_k^W = \frac{r_{k,N}^W}{r_{k,N}^W + r_{k,P}^W} \tag{8}$$

where $r_{k,N}^W$ and $r_{k,P}^W$ are the Euclidian distances between the weighted performance vector $[\hat{C}_k, \hat{S}_k, \hat{F}_k]W$ of strategy k and the weighted N and P vectors NW and PW.

3. NUMERICAL RESULTS AND DISCUSSION

The proposed scheme is applied to three scenarios of symmetric encounters involving $n = 3$, $n = 5$, and $n = 7$ aircraft, respectively. The starting waypoints and destination waypoints of the aircraft are evenly distributed on a circle centered at $(148.16, 148.16)$ with radius 141.7 km (see Fig. 3 where starting waypoints are marked with a circle). All aircraft fly at the same constant velocity measured in km/min, during the time horizon $[0, 20]$ min, with the time of arrival at the intermediate waypoints set to $t_c = 10$ min. The maximum velocity is set to 17 km/min and, as a consequence we get a lower velocity bound
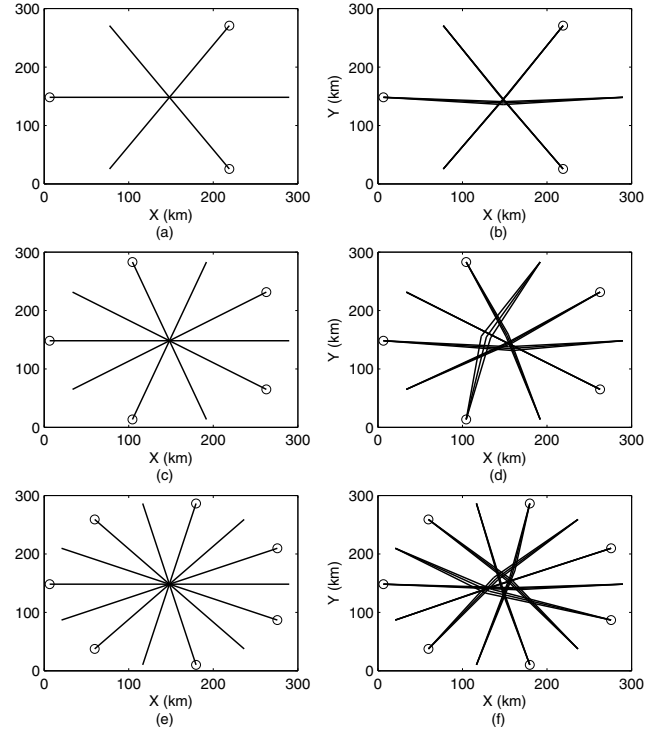

Fig. 3. Multi-aircraft encounters (left) and three candidate resolution strategies (right).

11.34 km/min. The safety distance for evaluating the stability and flexibility criterion is $d_s = 9.25$ km (which is equal to 5 nautical mile).

3.1 Candidate resolution strategies

For each scenario, 20 candidate resolution strategies $\{c_{i,k}\}_{i=1}^n$, $k = 1, \ldots, 20$, are generated corresponding to minimum aircraft separations $d_k = 7.25 + 0.25k$, $k = 1, \ldots, 20$. The strategies are then labeled by $k = 1, \ldots, 20$.

Fig. 3 represents the three scenarios of symmetric encounter in the left-hand-side plots (a), (c), and (e). The corresponding candidate strategies for the separations $d_1 = 7.5$ km, $d_{10} = 9.75$ km, and $d_{20} = 12.25$ km are depicted in the corresponding right-hand-side plots (b), (d), and (f).

3.2 Performance according to the stakeholders criteria

The performance of the 20 candidate strategies evaluated in terms of the cost, stability, and flexibility criteria is plotted in Fig. 4 for the three scenarios. Here, the flexibility of aircraft 1 is considered. The cost criterion is deteriorating (increasing) as a function of k while flexibility is improving (increasing). This is because the minimum separation d_k is growing with k and, in general, an aircraft that maintains a larger separation from the others needs to travel longer additional distances while gaining in terms of space of maneuverability. The airline pays more for the fuel cost while the pilot gains more freedom of adjusting the aircraft velocity. Not surprisingly, the stability criterion improves (decreases) as k grows and achieves and maintains its minimum value -1 when $k = 8$ since the minimum separation d_k satisfies $d_k \geq d_s = 9.25$ km for $k \geq 8$, and hence

no secondary conflicts are generated, which is the best strategy from the perspective of air traffic controller. When all decision objectives (minimizing the cost and stability while maximizing the flexibility) of the airline, air traffic controller, and pilot stakeholder are considered, it is non-trivial to find the best strategy since they are competing and not directly comparable.
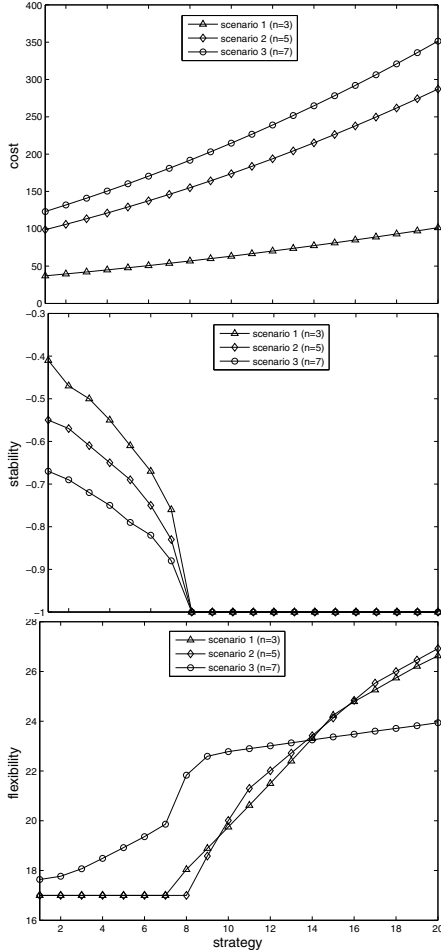

Fig. 4. Candidate strategies performance in the three scenarios in terms of cost, stability, and flexibility.

3.3 Results of multi-criteria decision-making

We start by determining the strategies that best compromise between each pair of the three performance criteria (cost, stability, and flexibility) through Pareto optimality analysis. In Fig. 5, we reported three plots, each one referring to a pair of criteria. In each plot, a candidate strategy k is represented by a point with coordinates given by the degradation of the performance with respect to that of the positive ideal strategy $P = [C_{min}, S_{min}, F_{max}]$ in terms of the considered criteria. Specifically, the curve in the leftmost plot in Fig. 5 is obtained by interpolating the points $\{(C_k - C_{min}, S_k - S_{mim})\}_{k=1}^{20}$, the one in the middle plot by interpolating $\{(S_k - S_{mim}, F_{max} - F_k)\}_{k=1}^{20}$, and the one in the rightmost plot by interpolating $\{(C_k - C_{mim}, F_{max} - F_k)\}_{k=1}^{20}$. By connecting all points from $k = 1$ to $k = 20$ we obtain a Pareto frontier. The ideal strategy should then have coordinated $(0, 0)$ in all three plots. The closest strategy to $(0, 0)$ is the one realizing
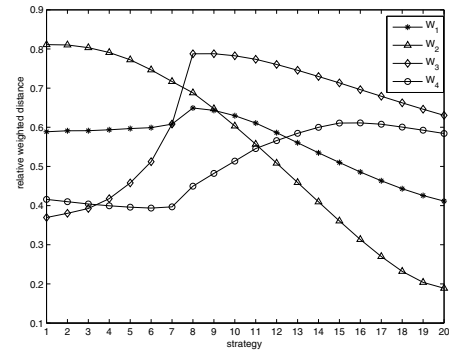

Fig. 6. TOPSIS results: relative weighted distance of the candidate strategies from the negative ideal strategy.

the best compromise between the two considered criteria. The best strategy based on the Pareto frontier of cost-stability in plot (a) of Fig. 5 is strategy $k = 8$ (marked as the filled circle) with minimum separation $d_8 = 9.25\ km$, because it is a non-dominated strategy (there is no other strategy that would improve on both criteria with respect to $k = 8$) and dominates the candidate strategies with $k \geq 9$. The cost of strategy $k = 8$ is just slightly worse (18.73%) than that of other non-dominated strategies, such as $k = 7$ (marked as filled square), but it achieves the best value in terms of stability criterion (distance 0 from the P strategy). In plot (b) of Fig. 5, strategy $k = 20$ (marked as the filled circle) dominates all other strategies and is the best one considering stability and flexibility. In plot (c) of Fig.5, strategy $k = 1$ (marked as the filled circle) is selected as the strategy that best compromises cost and flexibility. Clearly, considering all three criteria poses a challenge in the choice of the best strategy.

We now apply the TOPSIS based multi-criteria decision-making approach with different weights on the criteria to define the best compromising strategy for all three of them and comparatively analyze the obtained results.

We consider the following four weighting matrices $W_1 = diag([1, 1, 1])$, $W_2 = diag([3, 1, 1])$, $W_3 = diag([1, 3, 1])$, $W_4 = diag([1, 1, 3])$, and for each for $j = 1, 2, 3, 4$ we evaluate the best compromising strategy $k_j^\star$ as the one maximizing the relative weighted distance $R_k^{W_j}$ defined in (8) and plotted in Fig. 6. It can be seen that the strategy $k = 8$ with the standard separation $d_8 = d_s = 9.25\ km$ is not the best one in all cases. For instance, if the cost criterion is given more weight by using W_2, then, $k_2^\star = 1$, which indicates that the strategy with the smallest predefined minimum separation ($d_1 = 7.5\ km$) is adequate to meet the requirements of stability and flexibility while reducing the cost as well. If stability is given more relevance by adopting W_3, then, $k_3^\star = 9$ is selected, where the minimum separation is set equal to $d_9 = 9.5\ km$. A larger separation than d_s is then chosen in this case. One possible reason is that a larger separation is able to provide more safe resolution space for the aircraft. If the individual aircraft flexibility is given more relevance, a much larger separation becomes necessary compared with the traditional separation d_s and indeed $k_4^\star = 16$ is the best compromising strategy, which corresponds to a minimum separation $d_{16} = 11.25\ km$.
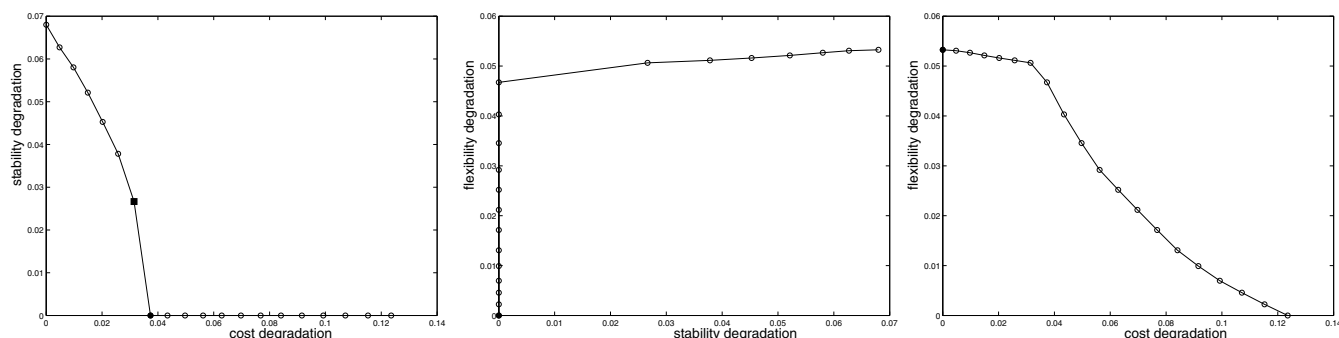
Fig. 5. Pareto frontier for stability-cost (left plot), flexibility-stability (middle plot), and flexibility-cost (right plot).

4. CONCLUSION

We proposed a multi-criteria decision-making scheme for multi-aircraft conflict resolution, which rests on the design of a set of candidate strategies and the selection of the best one based on an appropriate tradeoff among the competing interests of airlines, air traffic controllers, and aircraft. In future work, we shall investigate a mechanism for the prioritization of the stakeholders interests so as to obtain a more practical strategy, and account for uncertainties in decision-making to enhance the robustness of the scheme.

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