Analysis of Conflict Resolution Methods for Manned and Unmanned Aviation Using Fast-Time Simulations

9 th SESAR Innovation Days

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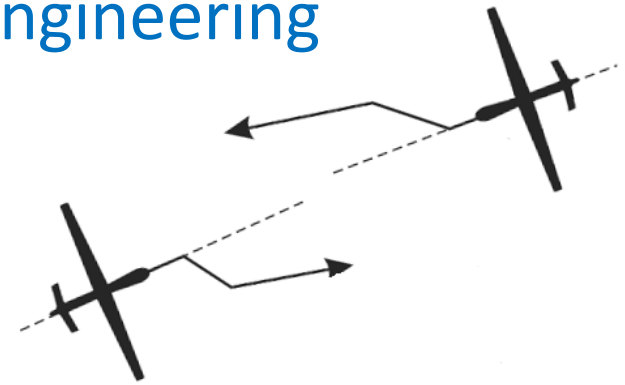


2 – 6 December 2019, Athens, Greece

Engage

founding members

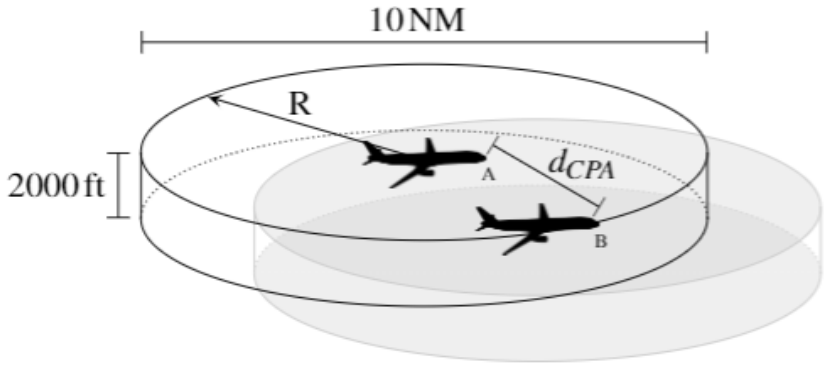
Review of CR Models

- Europe had 11 million manned flights in 2018 and may expect a constant increase until 2025 [1].
- Unmanned Aerial Vehicles (UAVs) must have Sense & Avoid capability to be allowed in the civil airspace [2].
- No direct comparison between researched CR models.
- No standardized simulation tool, scenarios → results are not comparable.

[1] EUROCONTROL, Performance Review Report An Assessment of Air Traffic Management in Europe during the Calendar Year 2018, 2018.
[2] FAA, "FAA Modernization and Reform Act of 2012, Conference Report," FAA, Tech. Rep., 2012.

Minimum Separation

- Manned Aviation: most CD&R studies use ICAO's [1] definition of 5NM horizontal separation and 1000ft vertical separation.



- Unmanned Aviation: no pre-defined standard separation distance; although 50 m is a value commonly used in research [2].

[1] I. C. A. Organization, Doc 4444: Procedures for air navigation. Air Traffic Management, sixteenth ed., 2016
[2] D. Alejo, R. Conde, J. Cobano, and A. Ollero, “Multi-UAV collision avoidance with separation assurance under uncertainties” in 2009 IEEE International Conference on Mechatronics. IEEE, 2009

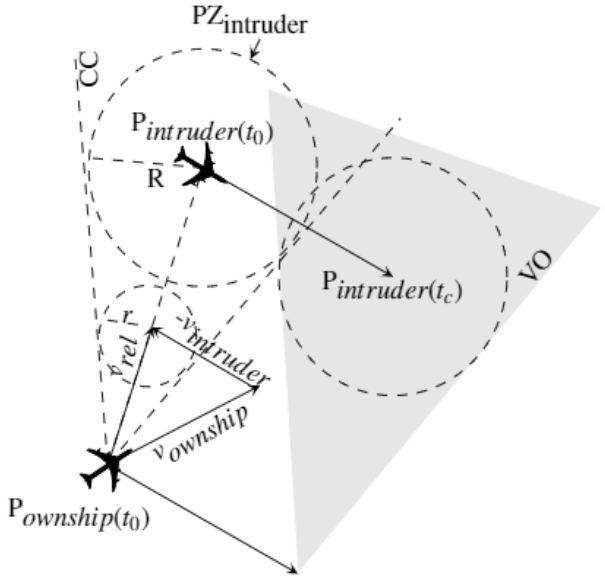
Conflict Resolution Models (2-D)

- Velocity Obstacles Theory:
  1. MVP
  2. SSD
3. Coordinated Resolution
4. Centralized Cost Solution

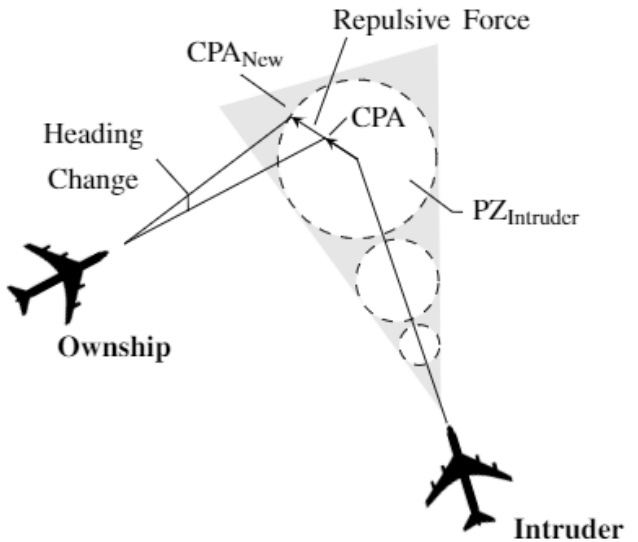
Planning	Tactical			
Control	Decentralized			Centralized
Coordination	Implicit		Explicit	**Cost**
Conflict Resolution	Pairwise	Global	**Coord**	
	MVP	**SSD**		

Conflict Resolution Models

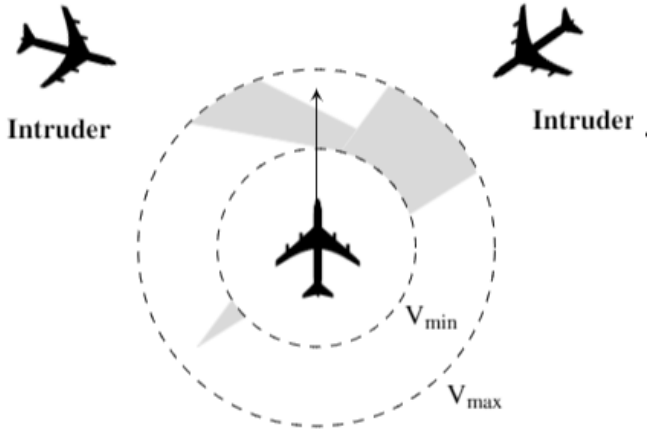
VO [1]



MVP [2]



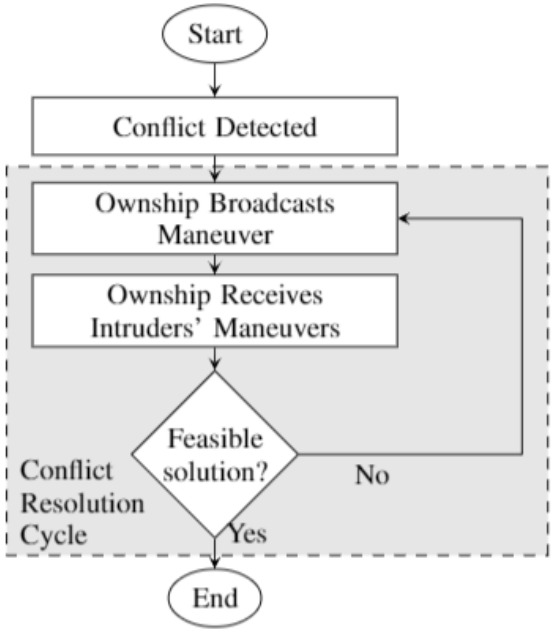
SSD [3]



[1] A. Chakravarthy and D. Ghose, “Obstacle avoidance in a dynamic environment: a collision cone approach,” IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans, vol. 28, no. 5, pp. 562–574, 1998.
[2] J. Hoekstra, R. van Gent, and R. Ruigrok, “Designing for safety: the ‘free flight’ air traffic management concept,” Reliability Engineering & System Safety, vol. 75, no. 2, pp. 215–232, feb 2002.
[3] S. V. Dam, M. Mulder, and R. Paassen, “The use of intent information in an airborne self-separation assistance display design,” in AIAA Guidance, Navigation, and Control Conference. American Institute of Aeronautics and Astronautics, aug 2009.

Conflict Resolution Models (2)

Coordination [1]



Cost [2]

$$\begin{cases} F = w_l \Delta P_L + w_v \Delta V + w_d D_{th} + \delta P \\ w_l + w_v + w_d = 1 \end{cases}$$

ΔP_L - variation of total path length
ΔV - variation of velocity
D_{th} - distance to threats
P - penalty for crossing an intruder's PZ
w - weight coefficients

[1] J. Yang, D. Yin, Y. Niu, and L. Shen, "Distributed cooperative onboard planning for the conflict resolution of unmanned aerial vehicles," Journal of Guidance, Control, and Dynamics, vol. 42, no. 2, pp. 272–283, feb 2019.
[2] S. Hao, S. Cheng, and Y. Zhang, "A multi-aircraft conflict detection and resolution method for 4-dimensional trajectory-based operation," Chinese Journal of Aeronautics, vol. 31, no. 7, pp. 1579–1593, jul 2018.

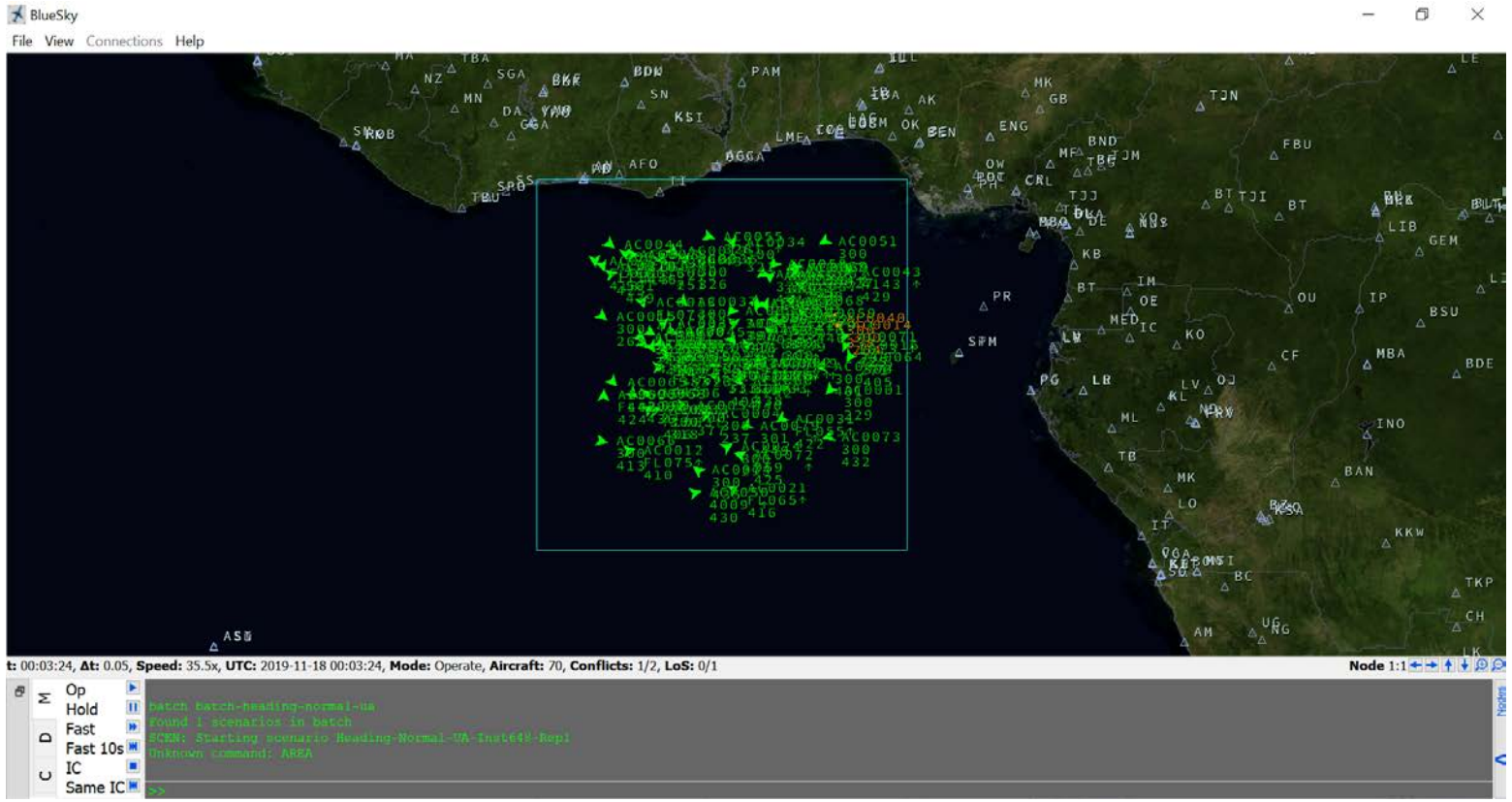
Previous Research

- MVP, SSD [1]:
  - Blueksy [2]
  - Densities: 9 – 27 aircraft / 10 000 NM^2 [2]
  - Instantaneous aircraft: 93 – 277 aircraft
  - LosS: < 20
  - Conflicts: MVP < 15000; SSD < 8000
- Coord [3]:
  - Safe separation of 48 UAVs in a space of 22 NM^2 [2]
- Cost [4]:
  - Safe separation for 5 manned aircraft in a 54 NM^2 scenario [3]

[1] L. Piedade, “Aircraft conflict prioritization and resolution using the solution space diagram,” Master’s thesis, Instituto Superior Tecnico, 2018. [Online].
[2] J. Hoekstra and J. Ellerbroek, “Bluesky ATC simulator project: an open data and open source approach,” in Conference: International Conference for Research on Air Transportation, 2016.
[3] J. Yang, D. Yin, Y. Niu, and L. Shen, “Distributed cooperative onboard planning for the conflict resolution of unmanned aerial vehicles,” Journal of Guidance, Control, and Dynamics, vol. 42, no. 2, pp. 272–283, feb 2019.
[4] S. Hao, S. Cheng, and Y. Zhang, “A multi-aircraft conflict detection and resolution method for 4-dimensional trajectory-based operation,” Chinese Journal of Aeronautics, vol. 31, no. 7, pp. 1579–1593, jul 2018.

Experiment

- BlueSky - The Open Air Traffic Simulator



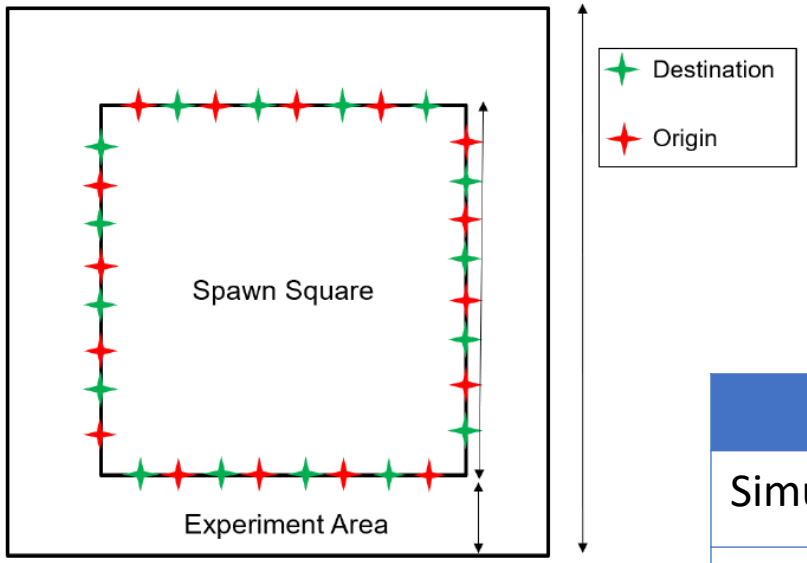
Experiment (2)

- Boeing 747-400
- DJI Mavic Pro

	Min Flight Distance [NM]	Max Flight Distance [NM]
	200	250
	15	20

		Traffic Density (aircraft / 10000 NM^2)	Instantaneous Aircraft	Spawned Aircraft
Manned	Low	32	648	3070
	Medium	37	768	3640
	High	45	911	4317
Unmanned	Low	12000	1080	4629
	Medium	13856	1247	5345
	High	16000	1440	6172

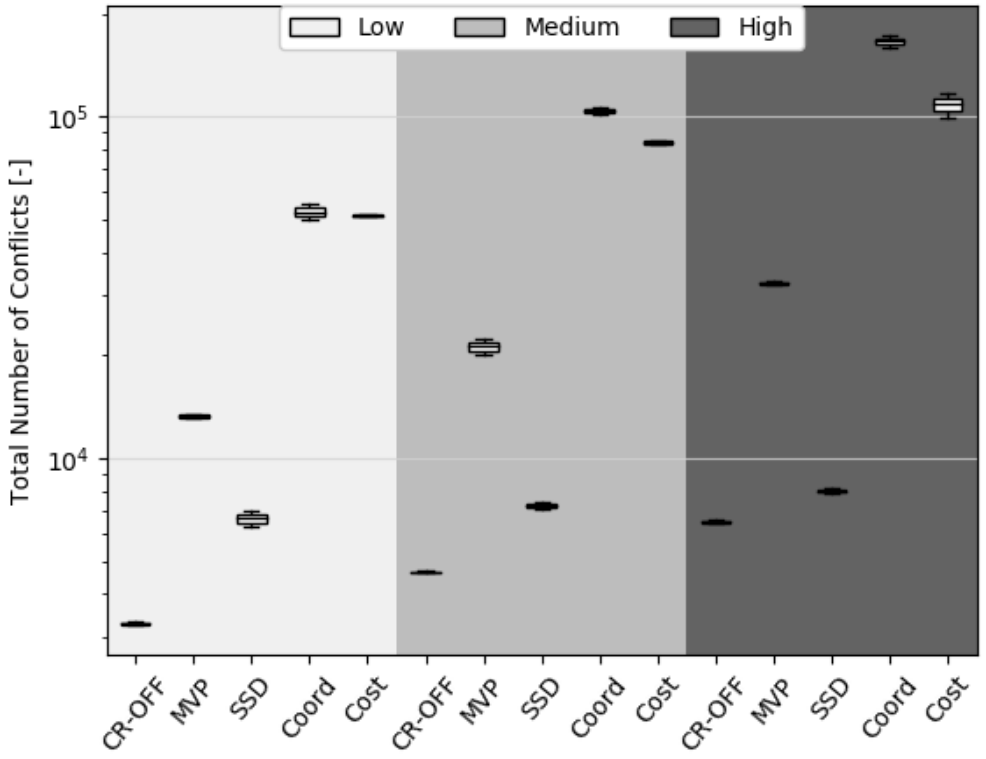
Experiment (3)



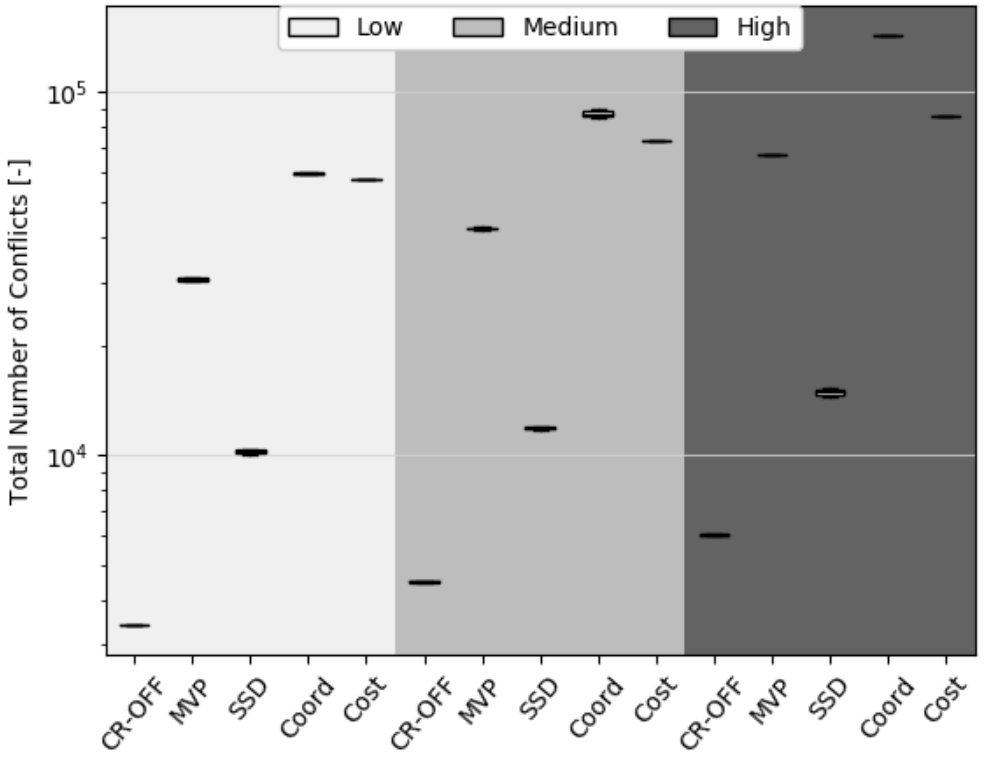
	Manned	Unmanned
Simulation Area $[NM^2]$	202500	900
Experiment Area $[NM^2]$	405000	1800
Altitude [ft]	36000	300

Results (Safety - Conflicts)

Manned Aviation

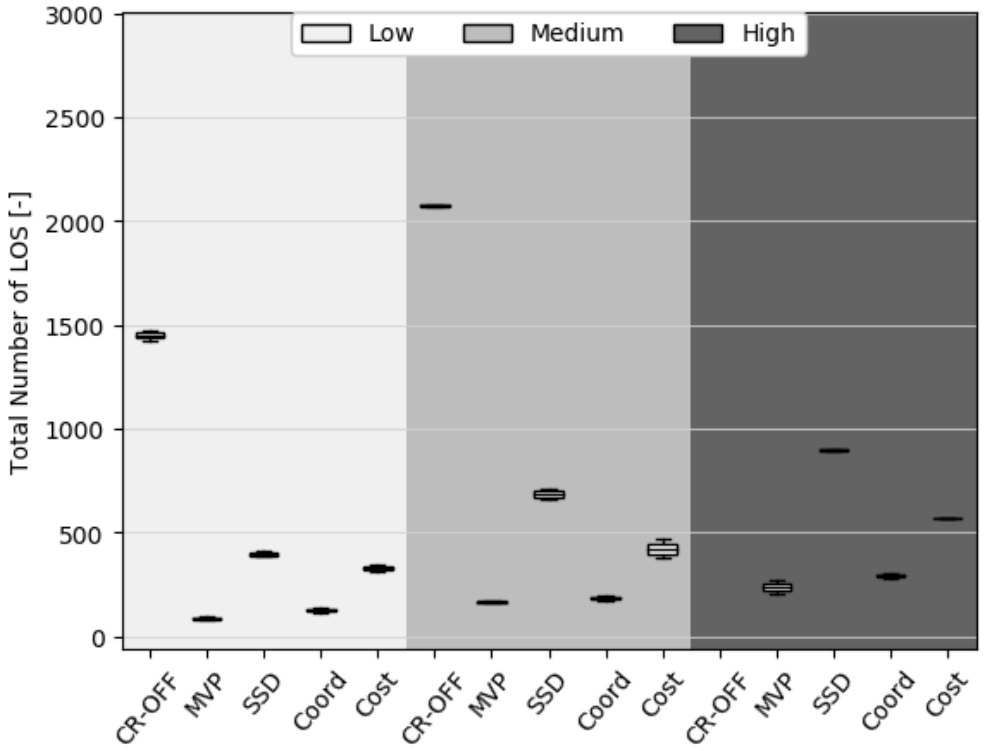


Unmanned Aviation

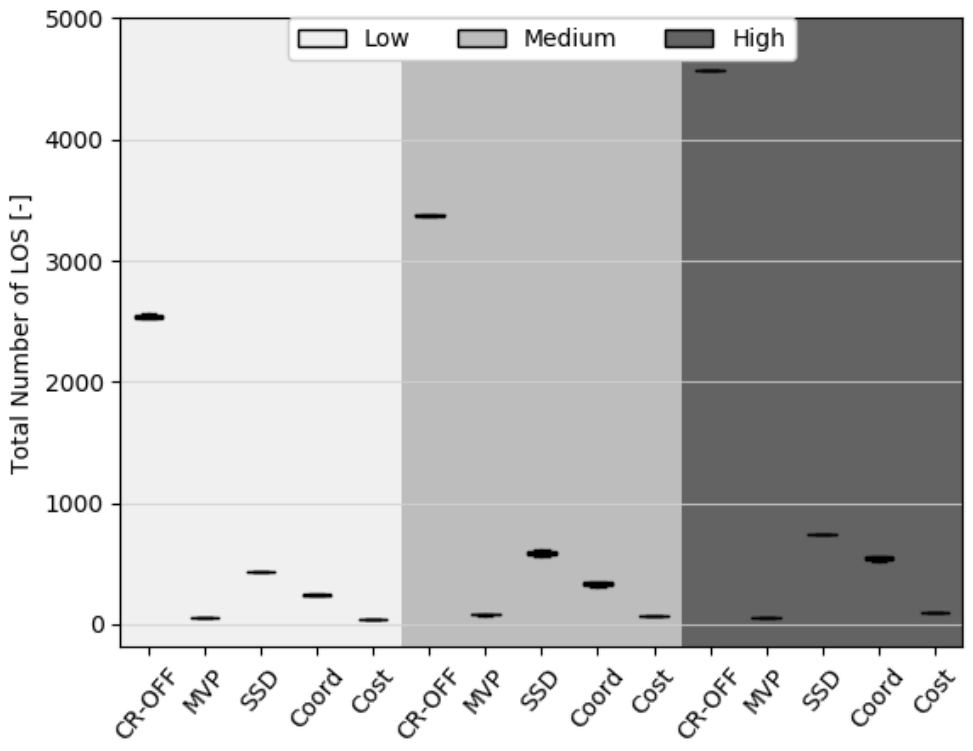


Results (Safety – Losses of Separation)

Manned Aviation

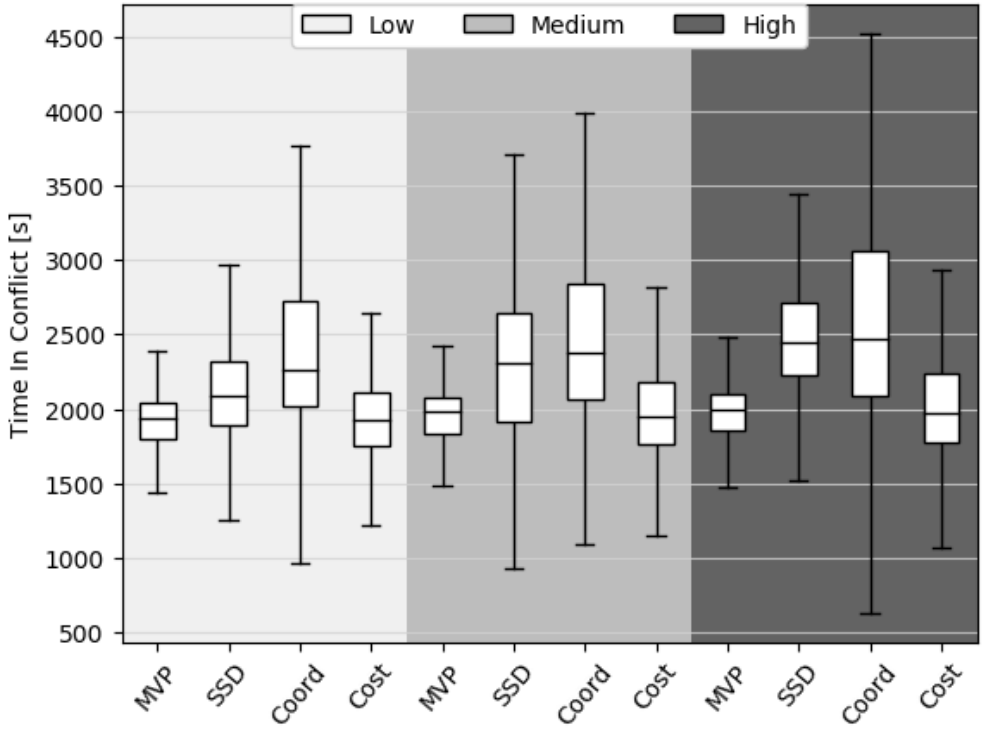


Unmanned Aviation

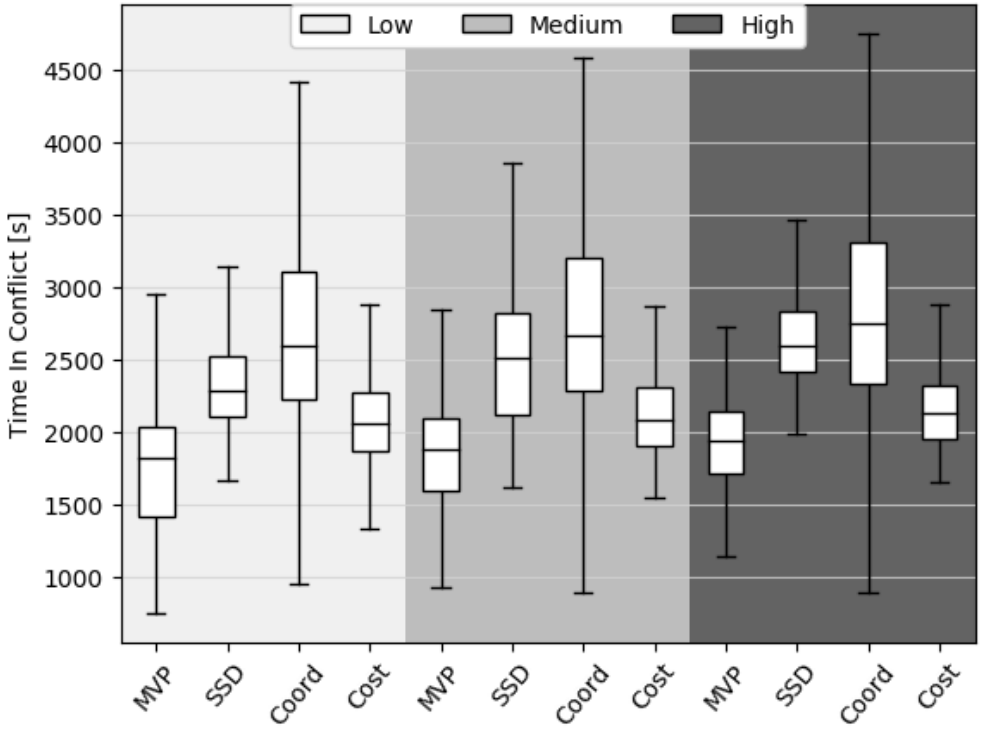


Results (Safety – Time in Conflict)

Manned Aviation

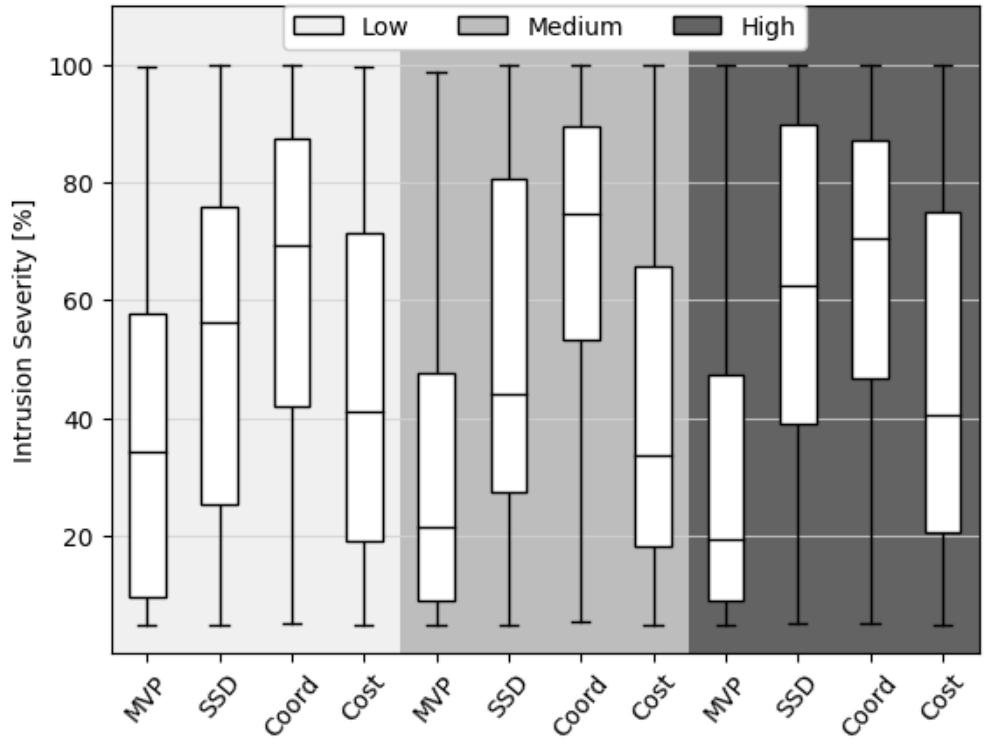


Unmanned Aviation

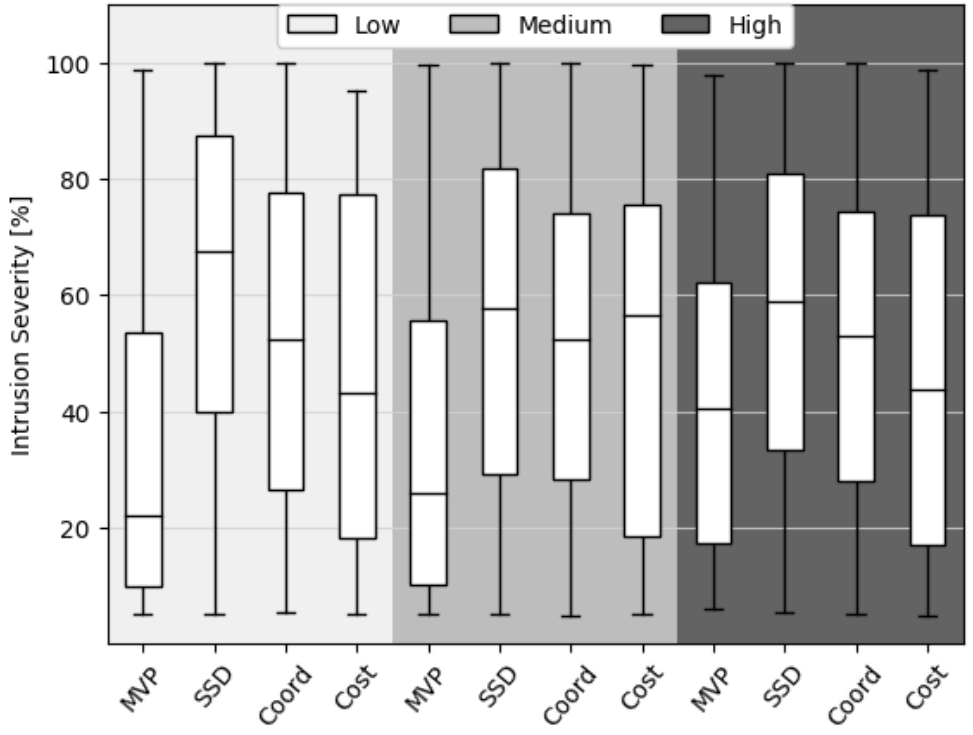


Results (Safety – Intrusion Severity)

Manned Aviation

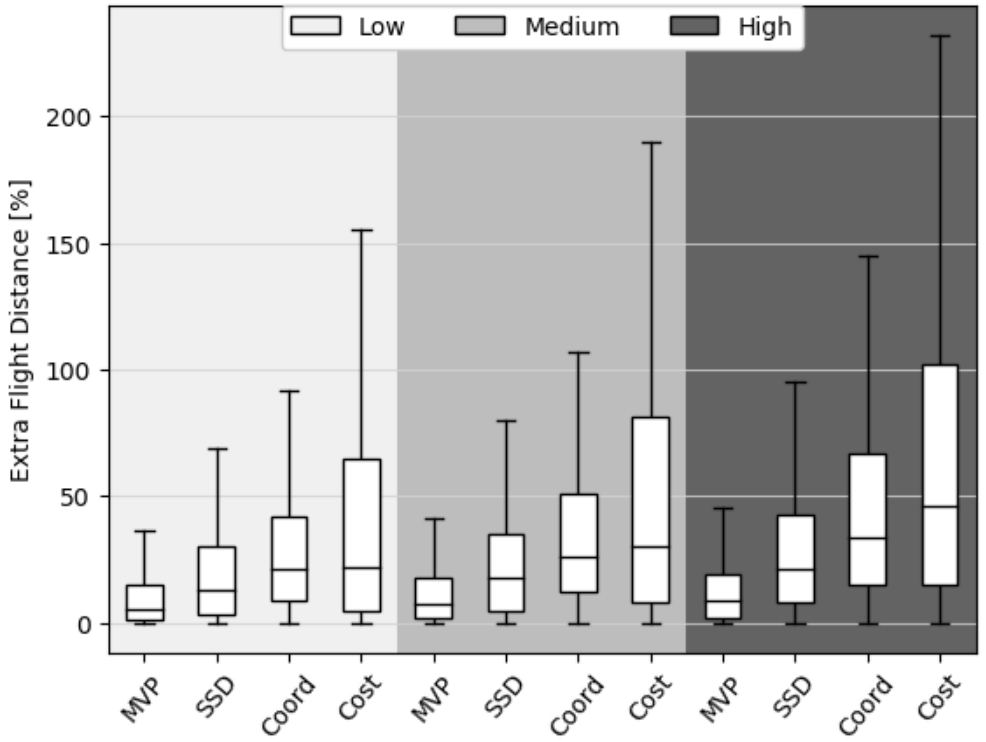


Unmanned Aviation

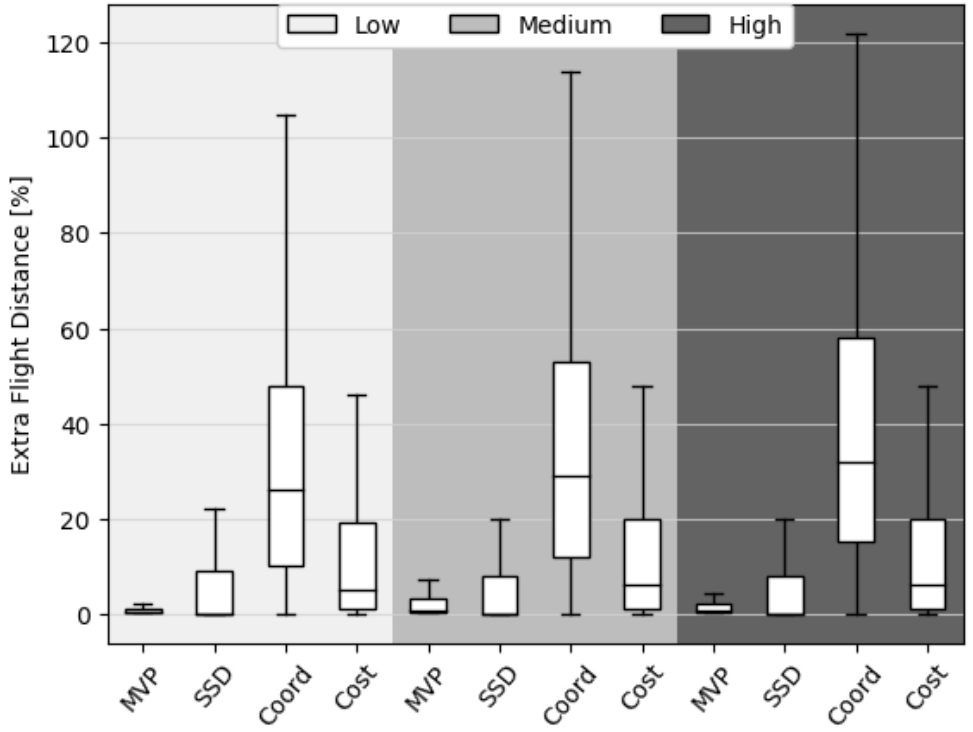


Results (Efficiency –Extra Flight Distance)

Manned Aviation

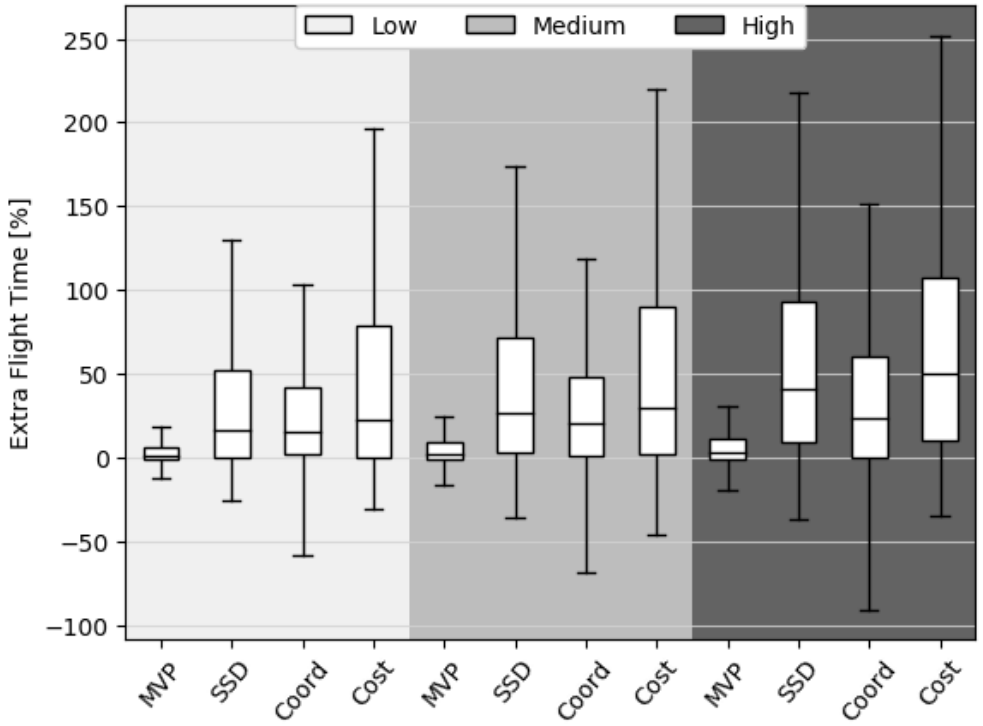


Unmanned Aviation

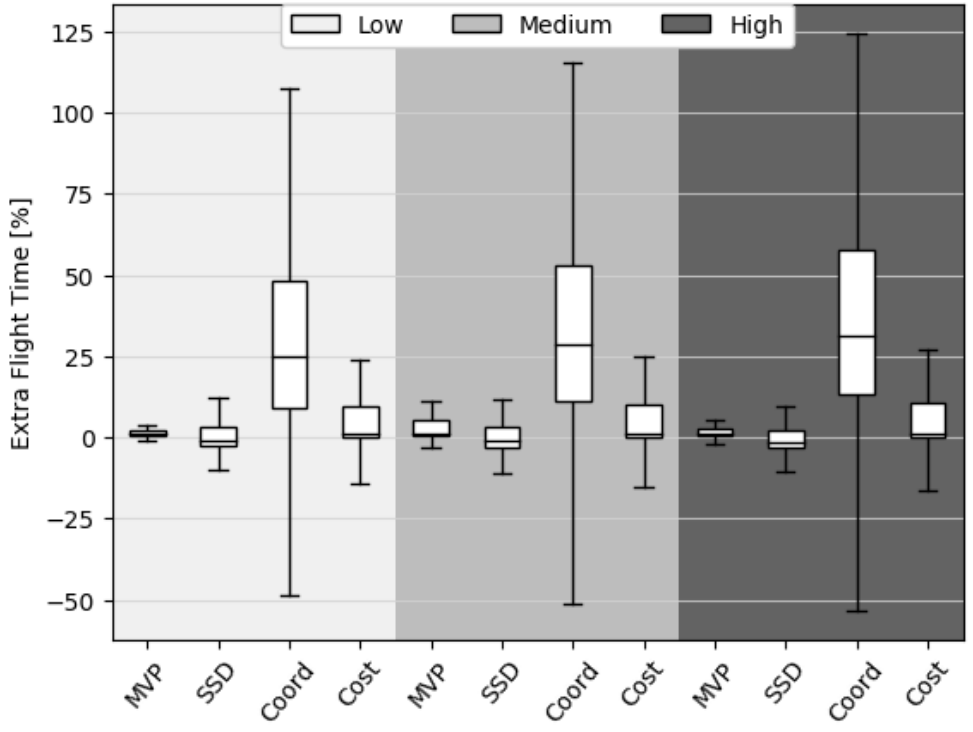


Results (Efficiency –Extra Flight Time)

Manned Aviation



Unmanned Aviation



Discussion

- A standardized simulation library should be developed so CD&R models can be fairly tested under the same conditions.
- No disparity found between manned and unmanned environment. Smaller minimum separation and velocities in unmanned aviation help prevent losses of separation.
- VO based methods showed better results safety-wise. *MVP*: minimum path deviations for CR reduced the effect of resolution maneuvers on flight efficiency while still guaranteeing minimal losses of separation.
- The efficiency of CR models depend on the aircraft performance limits, trajectories and simulation environment.

Thank you!