NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

A Machine Learning Framework for Predicting Air Traffic Conflict Resolution Strategies for Conformal Automation

Yash Guleria, Phu N. Tran, Duc-Thinh Pham, Sameer Alam
Air Traffic Management Research Institute (ATMRI)
Nanyang Technological University, Singapore

Nicolas Durand
Ecole Nationale de l'Aviation Civile
7 av. 'Edouard Belin, 31055 Toulouse Cedex, FRANCE

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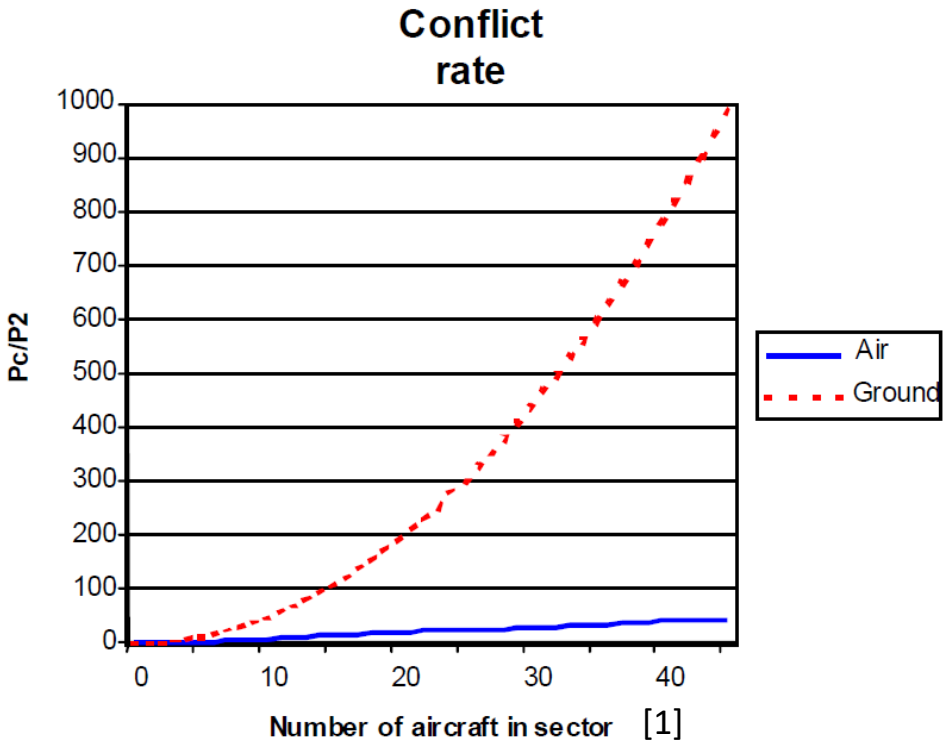
I. MOTIVATION

Motivation



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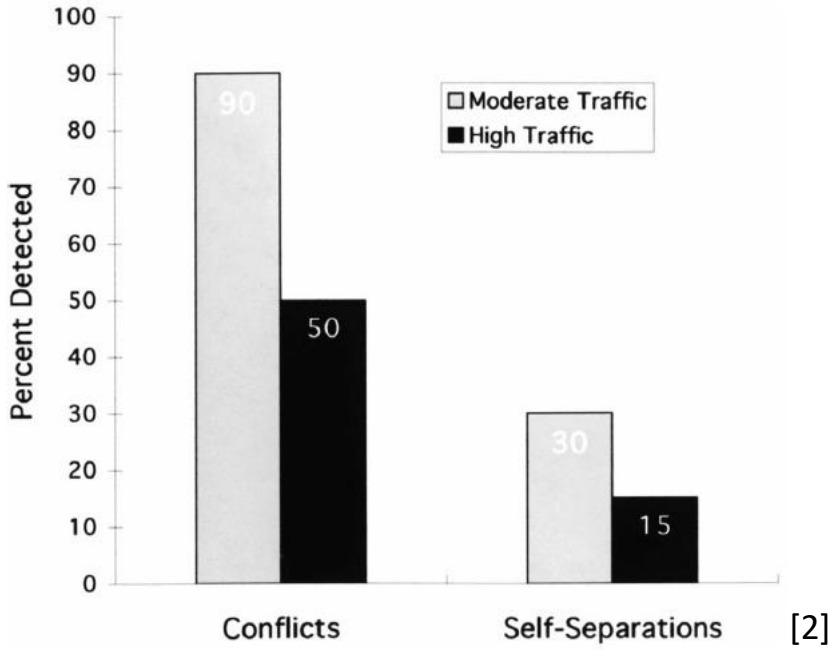
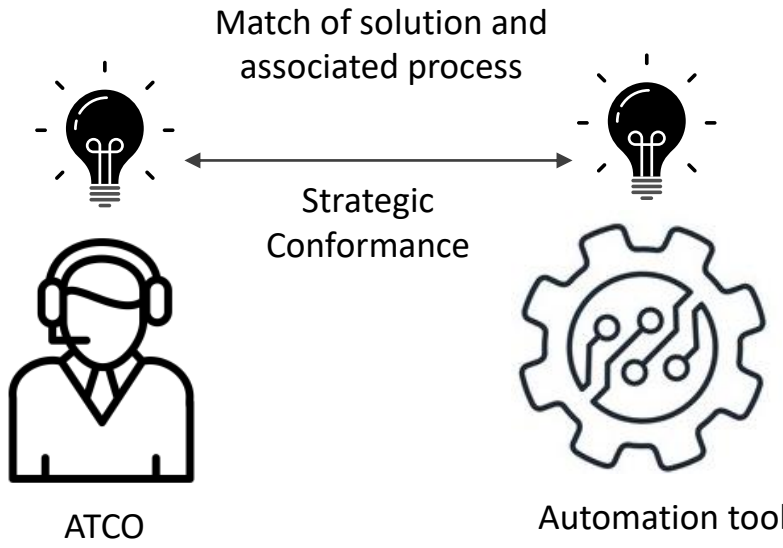


[2]

- Perceived rate of conflict ∝ number of aircraft in sector.
- Sector capacities limited by ATCOs' cognitive capabilities.
- Acceptance of automation tools a major limitation.
- Existing tools lack the 'human' element necessary for acceptance.

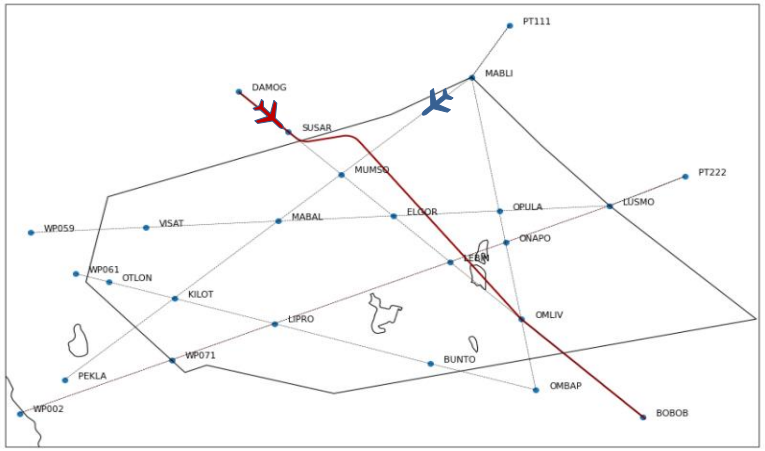
Motivation: Strategic Conformance



- Strategic conformance:
  - Degree to which automation's problem-solving style matches that of the individual human.
  - Two components: Conformance in terms of the solution (the product) and conformance in terms of the associated process(underlying strategy).

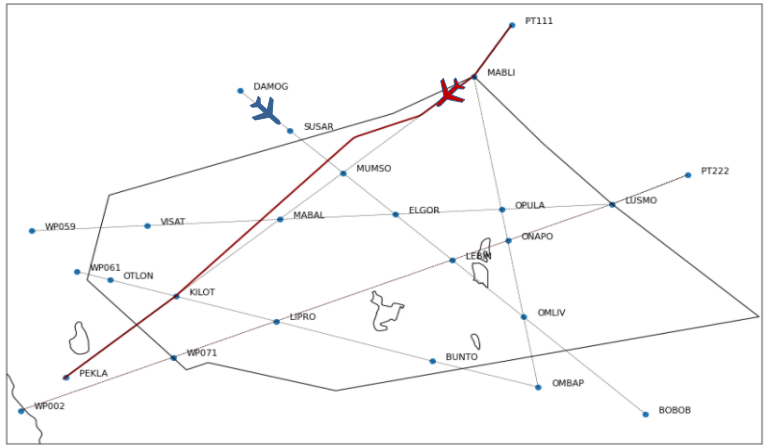
Strategic Conformance in Conflict Resolution

End product conformance: conformance in terms of providing conflict resolution only.

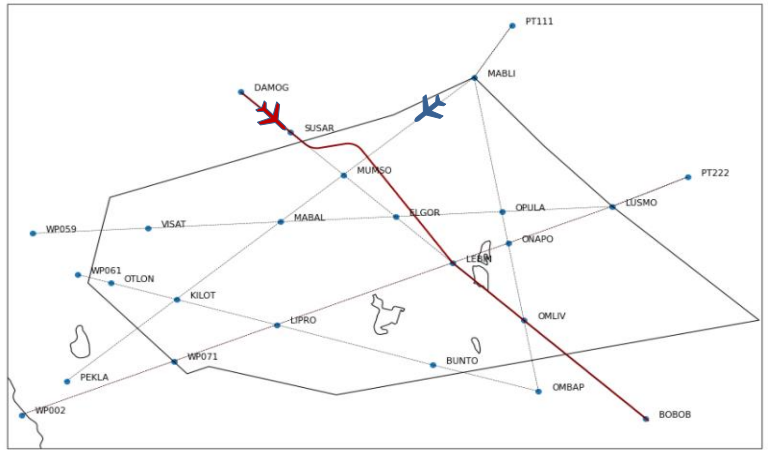


ATCO's conflict resolution preference

Strategic conformance: conformance in terms of conflict resolution and the underlying strategy



Resolution by Model 1



Resolution by Model 2

- Air traffic environment is complex, inherently stochastic with associated uncertainties.
- Difficult to accommodate these attributes with mathematical models, thus we adopt a data-driven approach.

II. Problem Formulation

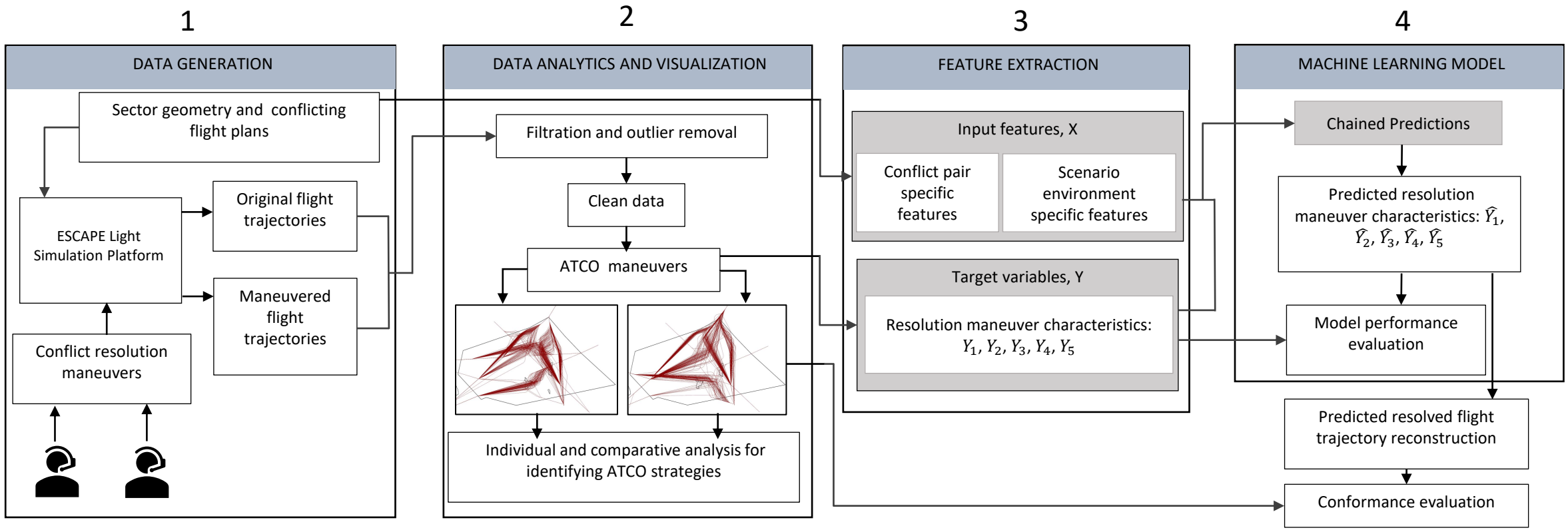
Project Objectives

To develop a machine learning-based strategic conformant automation tool for air traffic conflict resolution.

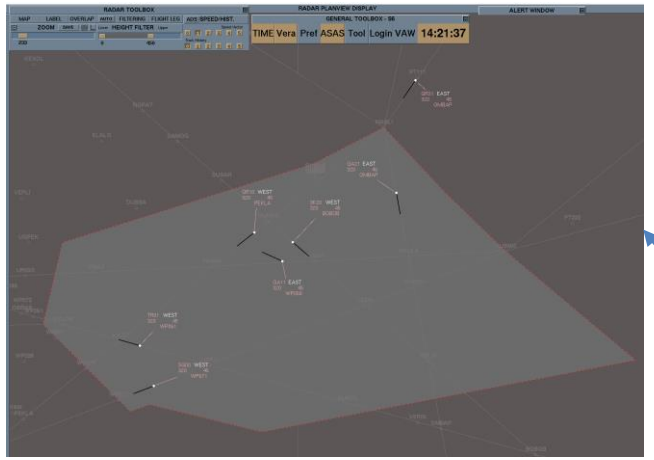
- Sub-questions:
  - How to identify the ATCOs' strategies used in conflict resolution?
  - What is the optimal representation of ATCOs' strategies in conflict resolution?
  - What is a suitable machine learning model to predict the identified strategies?

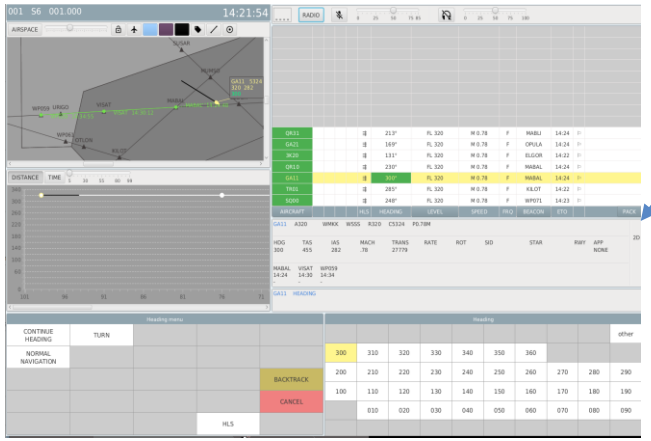
III. Methodology

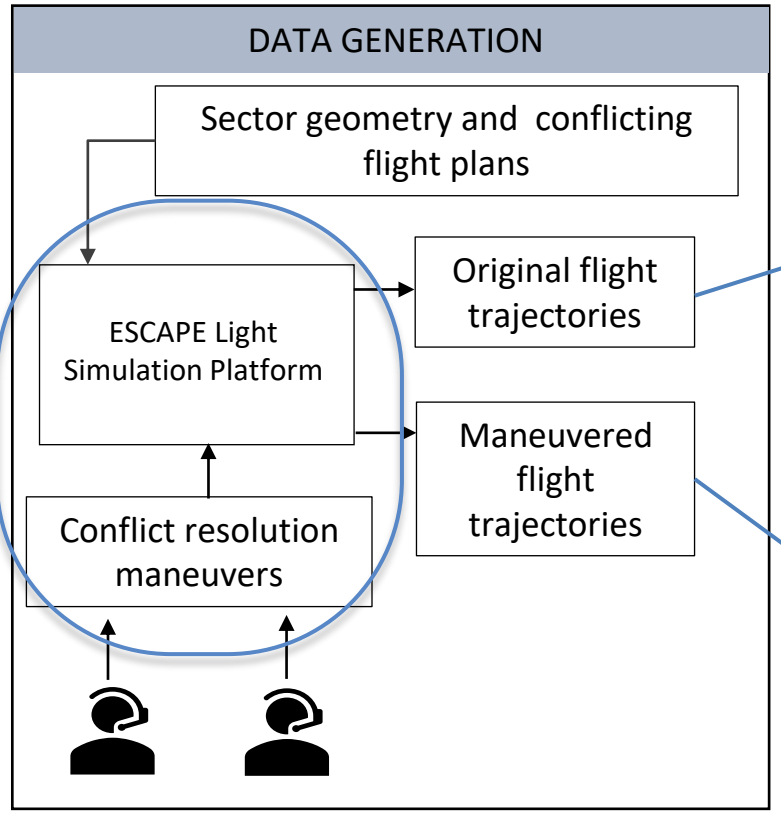
Methodology: Concept Diagram

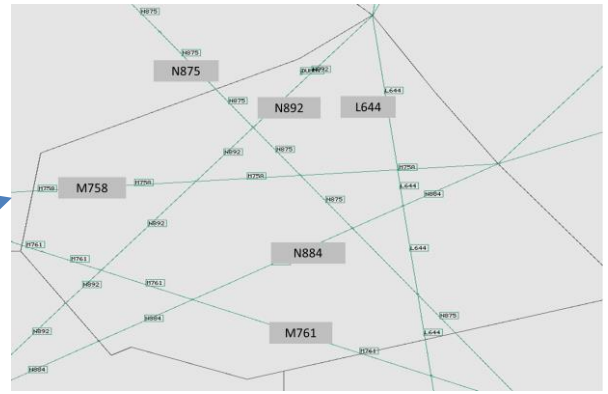


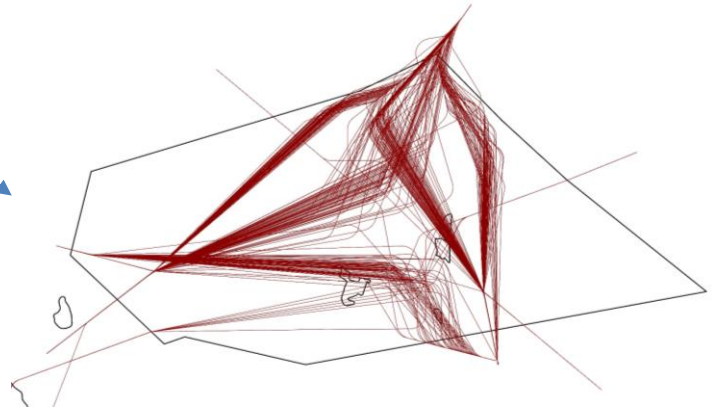
Module 1: Conflict Data Generation





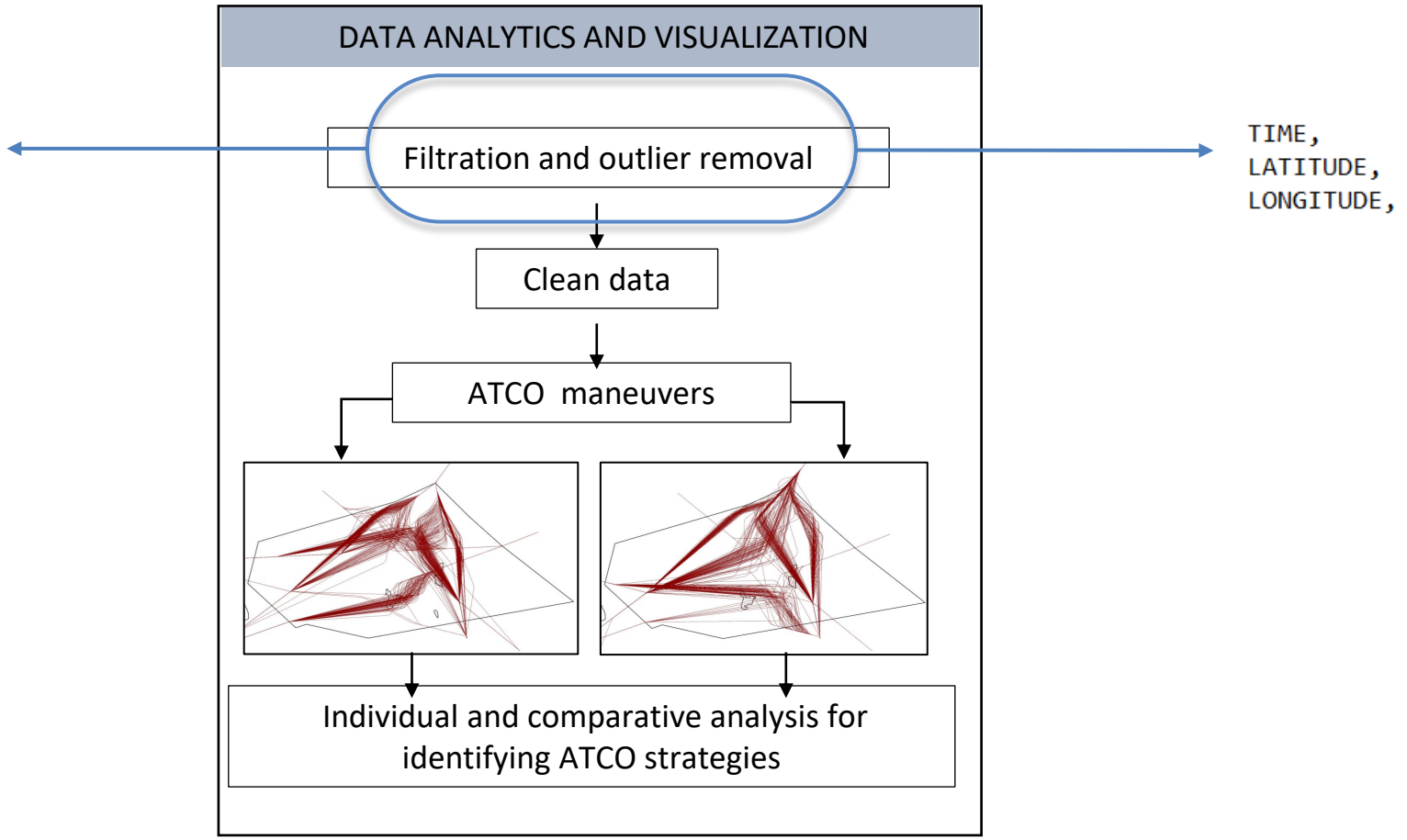






Module 2: Data Analytics And Visualization

1. TIME,
2. AREA_ID,
3. STATION_ID,
4. OTID,
5. LATITUDE,
6. LONGITUDE,
7. ALTITUDE,
8. VALID_MODE_C,
9. FLIGHT_LEVEL,
10. ANGLE,
11. GROUND_SPEED,
12. ROC,
13. ATTITUDE,
14. VALID_SSR_CODE,
15. SSR_CODE,
16. SIMULATED_FLAG,
17. MANOEUVRING_FLAG,
18. END_OF_TRACK_FLAG,
19. SPI_FLAG,
20. UPDATE_KIND,
21. TRACK_ORIGIN,
22. OFID,
23. CALLSIGN,
24. BAROMETRIC_ALTITUDE,
25. POSITION_ACCURACY,
26. ACAS_OPERATIONAL,
27. NAVIGATION_AIDS,



Strategy Representation

- ATCO strategy (S) : A sophisticated planning skill.
- Mathematical representation:
- A sequenced tuple, $S = (C, T, D, D_c, M)$

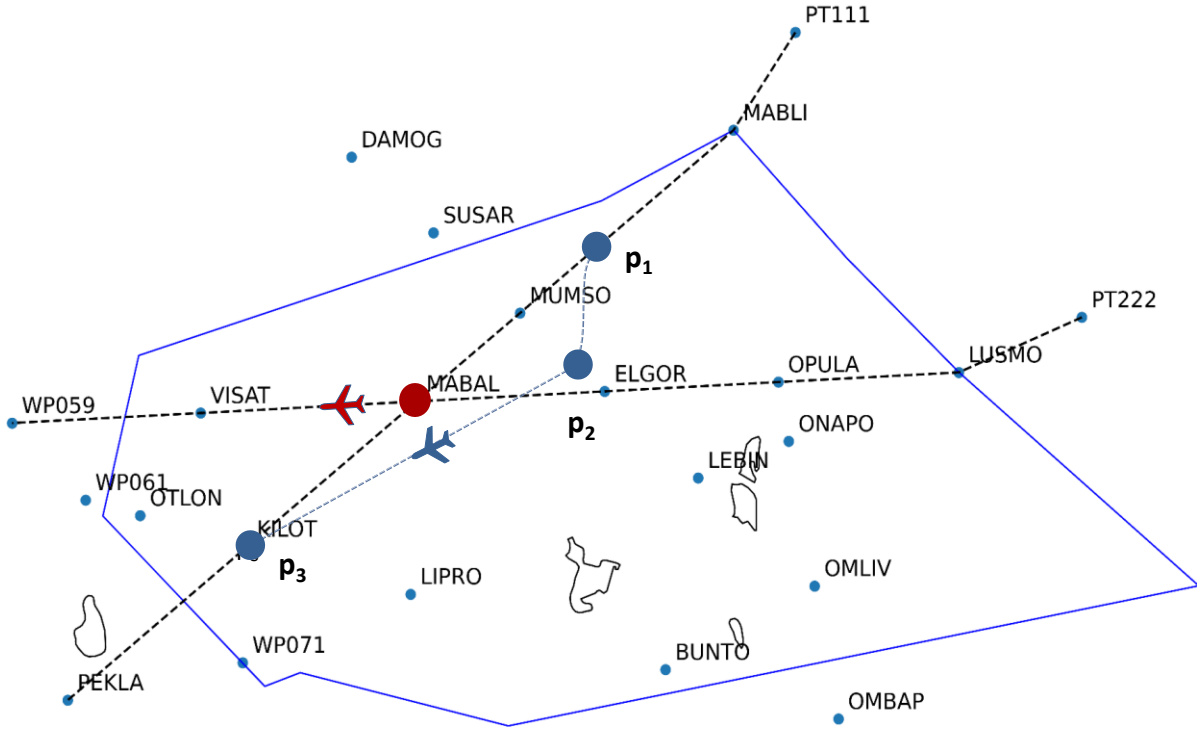
$C \subset \{ownship, intruder\}$

$T \subset \{T_{sim}, \ldots T_{LOS}\}$

$D \subset \{Left, Right\}$

$D_c \subset \{0, \ldots D_{Bound}\}$

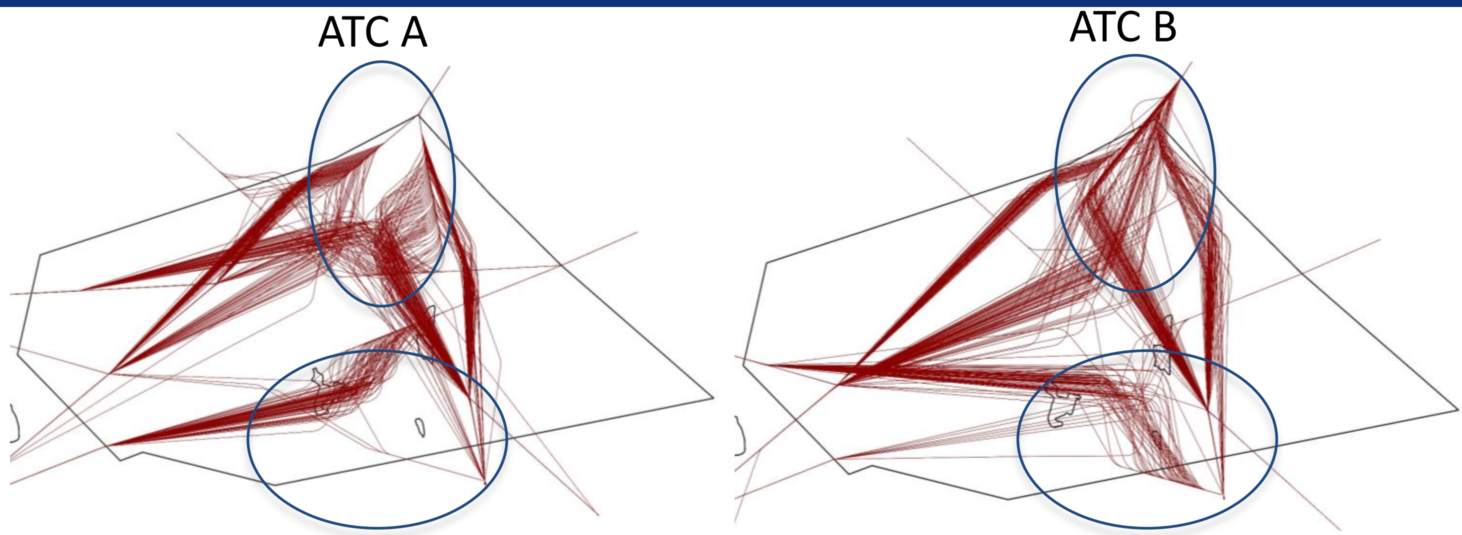
$M \subset \{List\ of\ waypoints\ available\ after\ T\}$

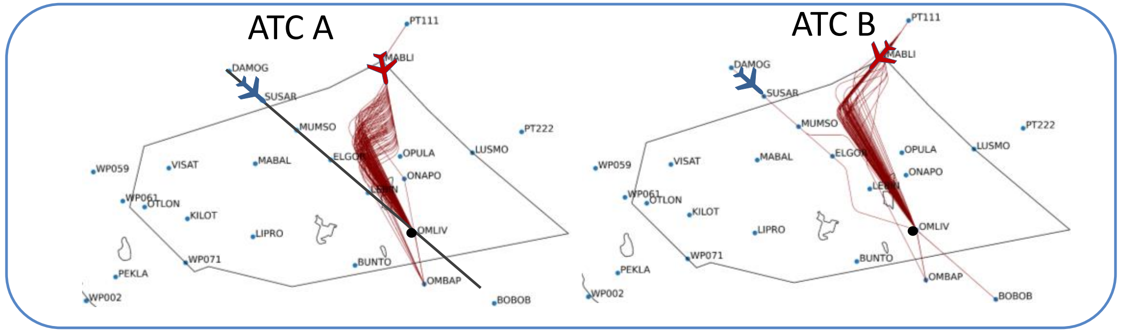


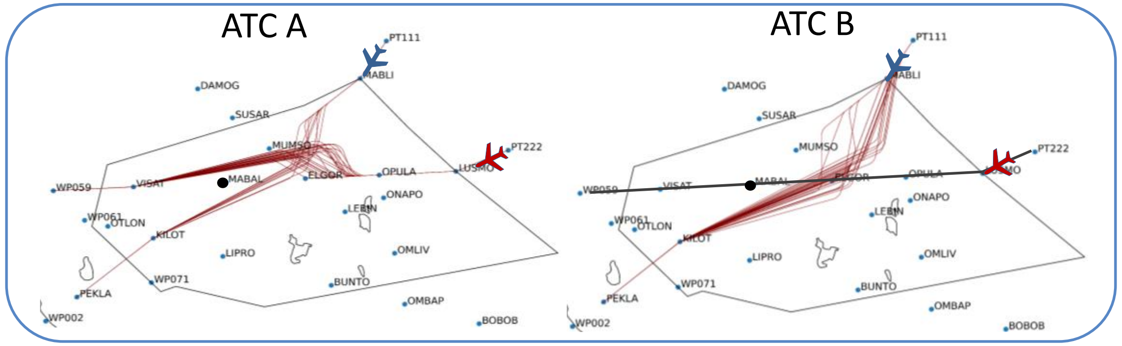
-------	Original flight path
-------	Maneuvered flight path
●	Conflict waypoint
p_1	Maneuver initiation point
p_2	Max cross track deviation point
p_3	Merging waypoint

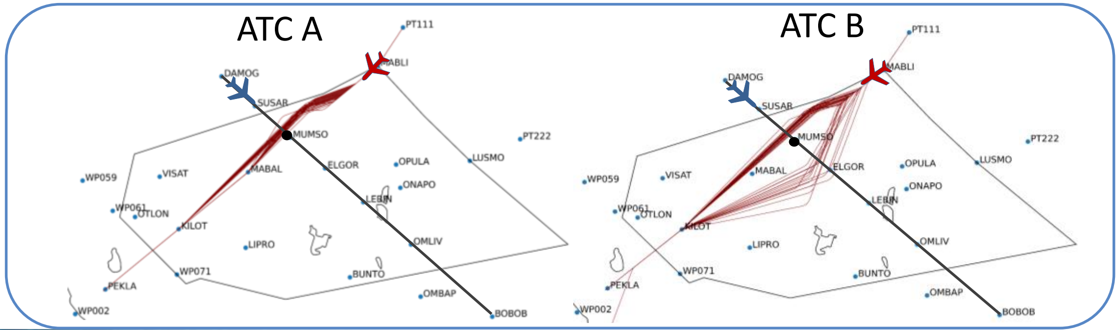
Strategy Identification

- In terms of 5 components:
  - Choice of aircraft to maneuver.
  - Maneuver initiation time
  - Maneuver direction
  - Maximum cross-track deviation
  - Merging distance.





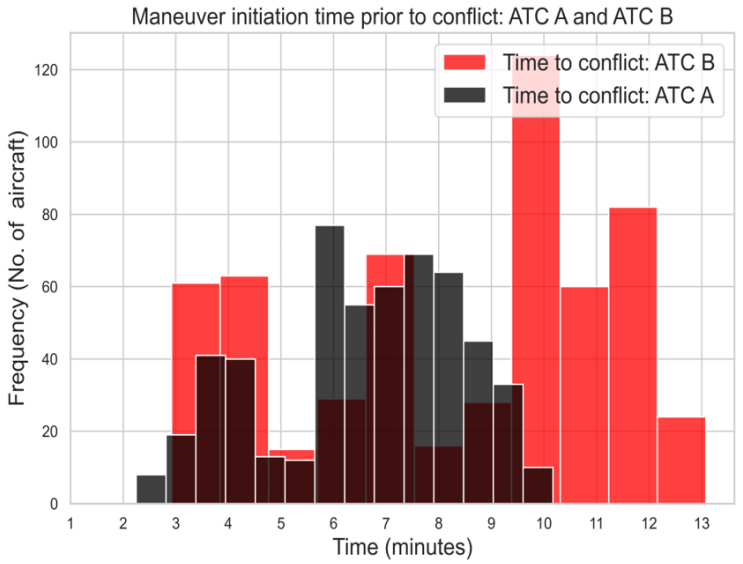




Strategies: Data Analysis

- Delayed maneuvers Preference by ATC A, with lower CTD and merging distance.
- ATC B's preferences include significantly early maneuvers, with larger CTD.
- Aircraft separation achieved by both ATCOs comparable.

Average	ATC A	ATC B
MIT (minutes)	6.62 min	8.7 min
CTD (Nm)	10.98 Nm	16.97 Nm
Merging Distance	61.81 Nm	72.75 Nm
Aircraft separation achieved	8.49 Nm	8.82 Nm



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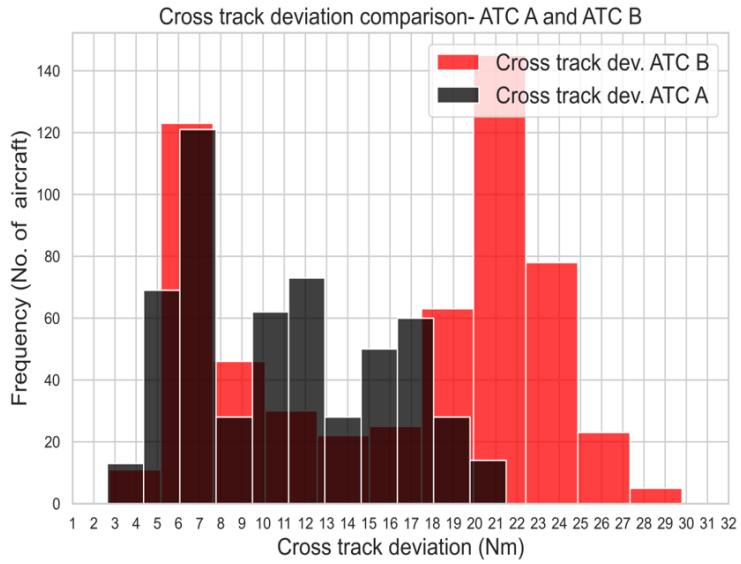

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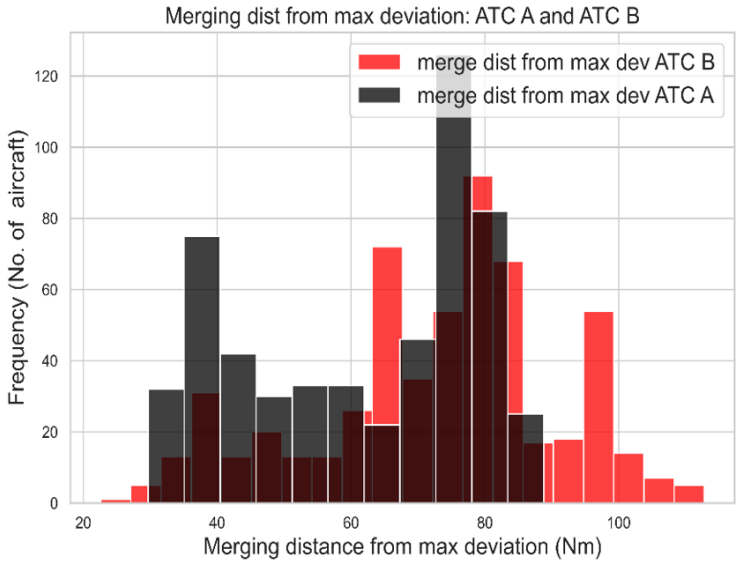

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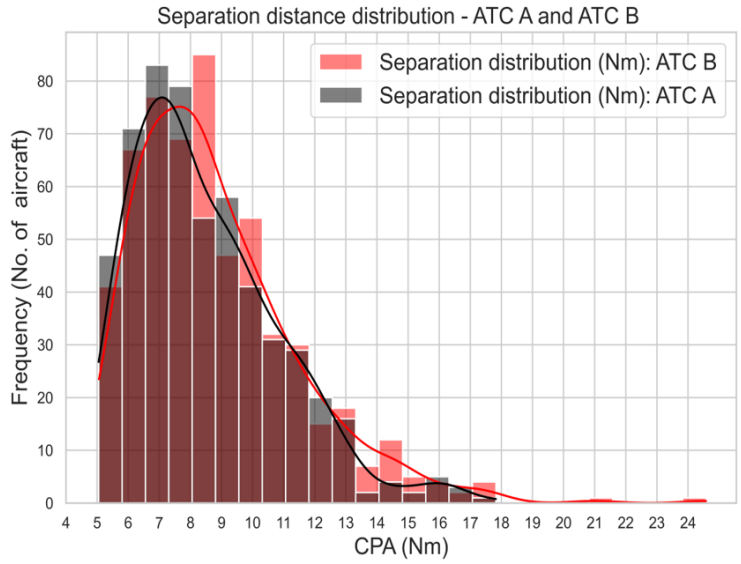
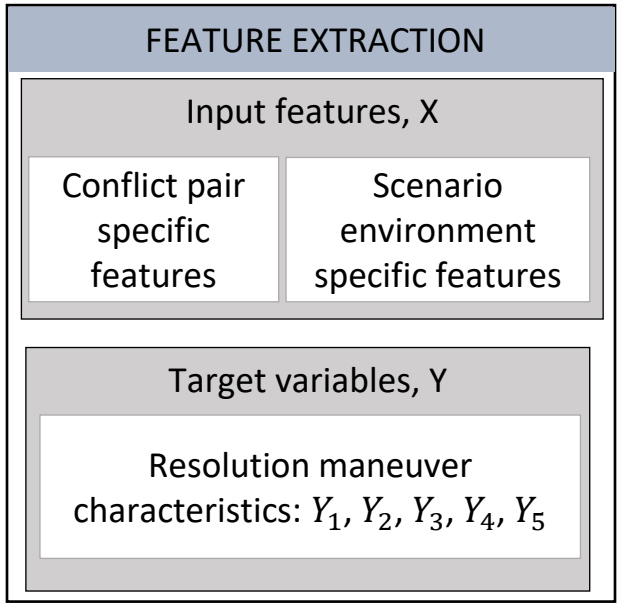


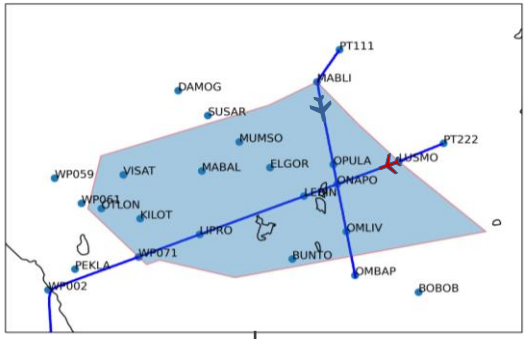
(d)

Module 3: Feature Extraction

- 3 categories :
  - Conflict pair features
  - Surrounding environment features
  - Resolution maneuver features

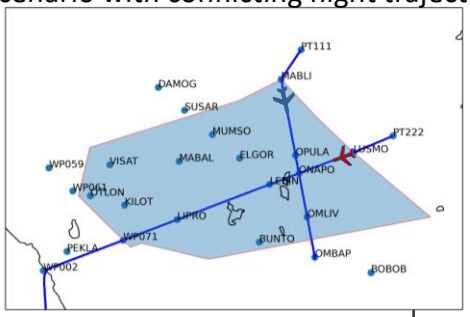


Scenario with conflicting flight trajectory

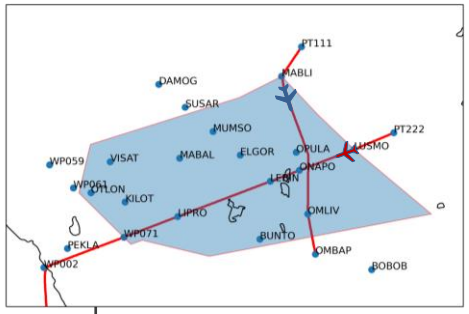


Conflict pair features

Scenario with conflicting flight trajectory



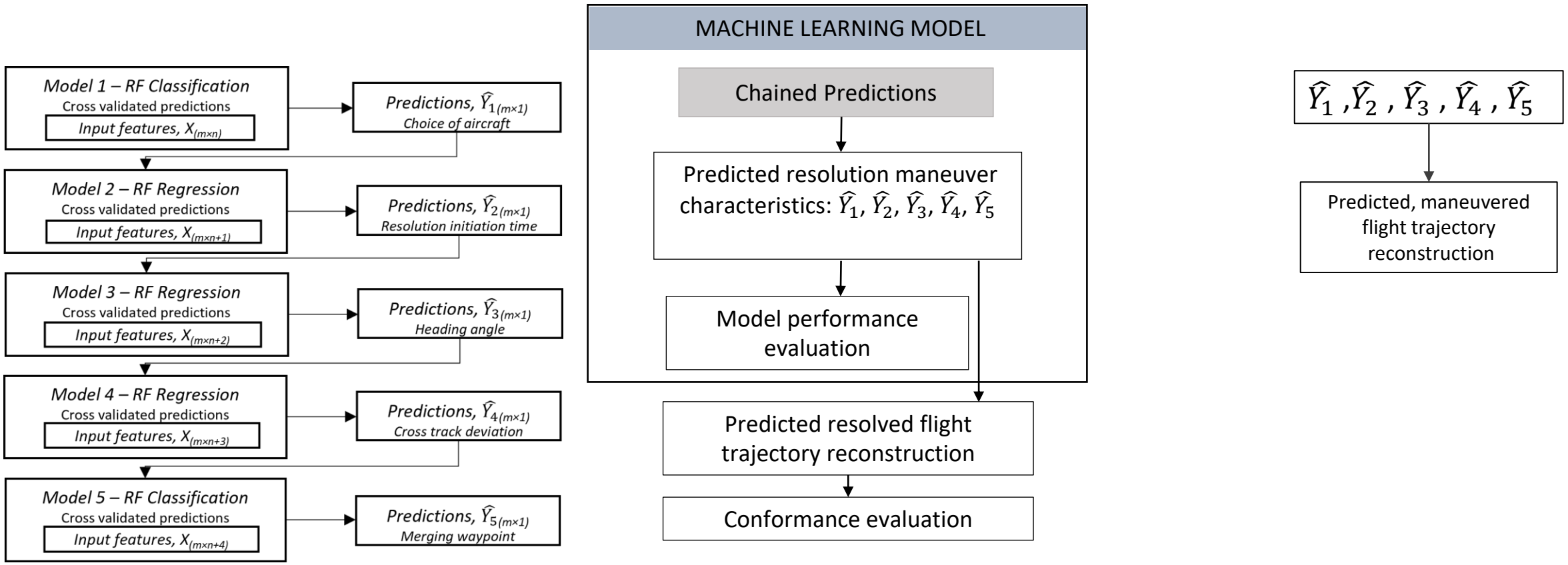
Scenario with resolved conflict



Comparison at each time step

Conflict resolution features

Module 4: Machine Learning Model



- Chained predictions with random forests classifier and regressors models.
- 5-Fold cross-validation was used.

IV. Results And Discussions

V. Results: ML model performance comparison

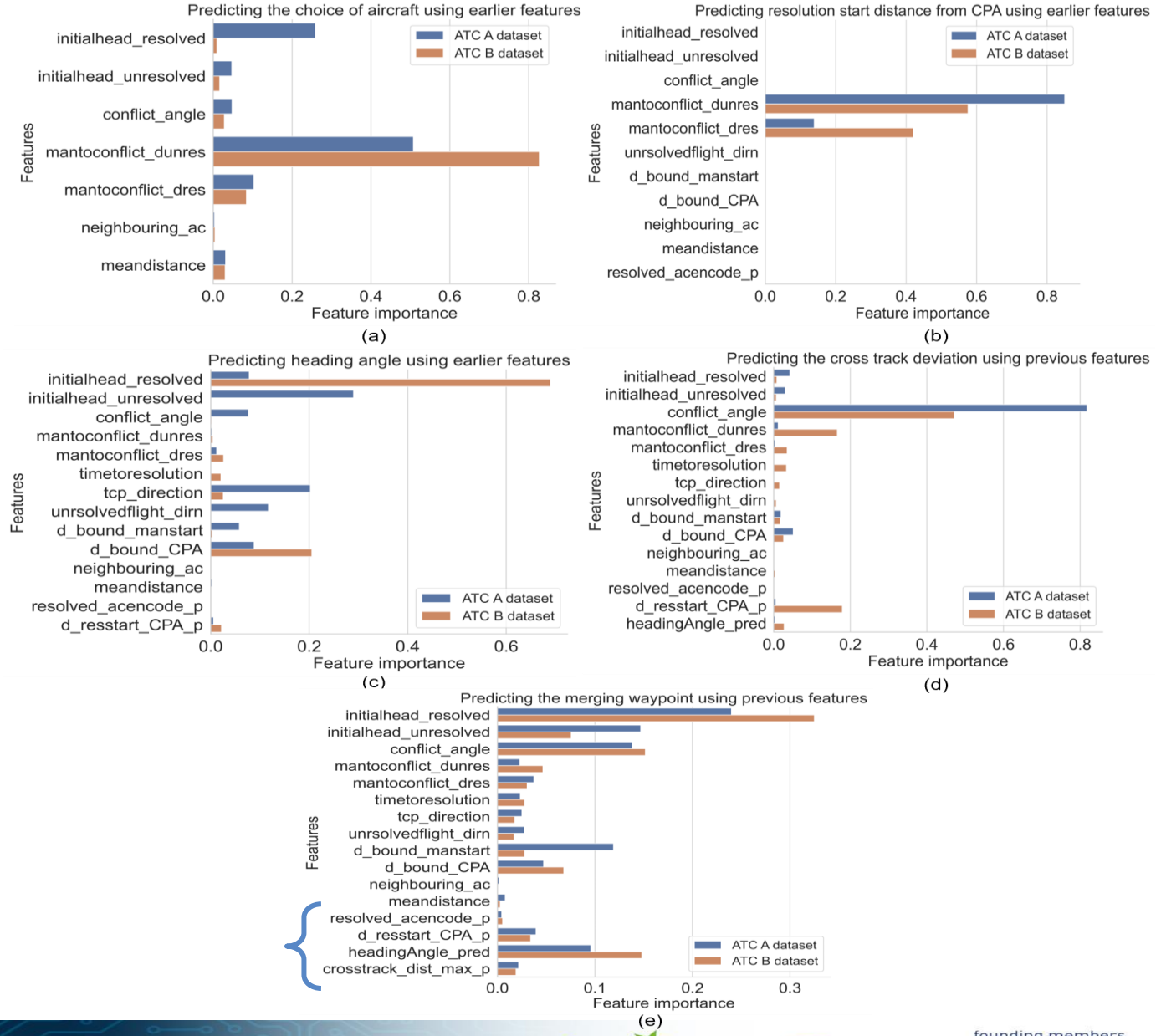
- A comparison between tree based and kernel based machine learning models.

	MODEL PERFORMANCE (ATC1 , ATC2)		
METRIC	**R.F**	**XGBoost**	**SVM**
Classification accuracy: choice of aircraft (%)	95.1, 93.7	95.01, 95.07	92.45, 92.8
MAE: dist. To maneuver from CPA (Nm)	0.38, 0.52	0.47, 0.45	0.77, 1.39
MAE: heading angle (°)	5.15, 3.66	5.36, 3.15	5.70, 5.55
MAE: Max. cross track deviation (Nm)	1.18, 1.63	1.29, 1.69	1.24, 1.59
Classification accuracy: choice of merging waypoint (%)	93.6, 99.2	92.09, 98.8	93.3, 98.8

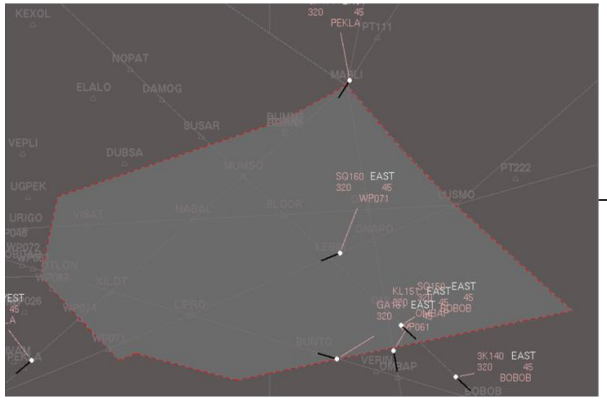
- Although comparable model performance, tree based models perform better than the kernel based methods in the prediction task.
- Random forest model has slightly better performance for majority of the metrics.

Feature Importance

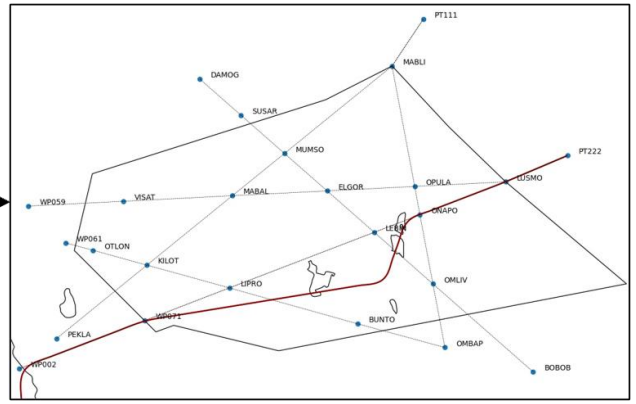
- On the same conflict data, feature importance values differ for the two ML models.
- Since, the data encapsulates ATCO strategies, another implication is that ATCOs might prefer the corresponding features more in decision making.
- Predictions made by previous models have significant importance in predicting the merging waypoint, thus validating the use of chained predictions model



Model Predicted Trajectory Reconstruction

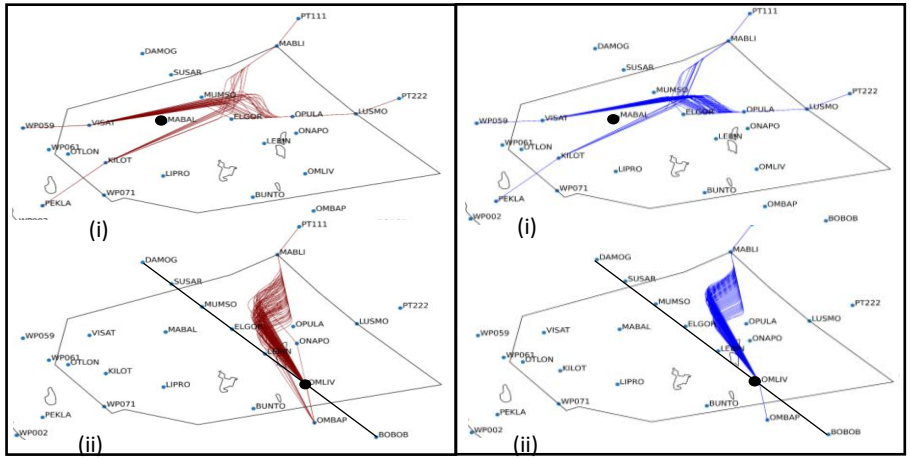


Chained predictions

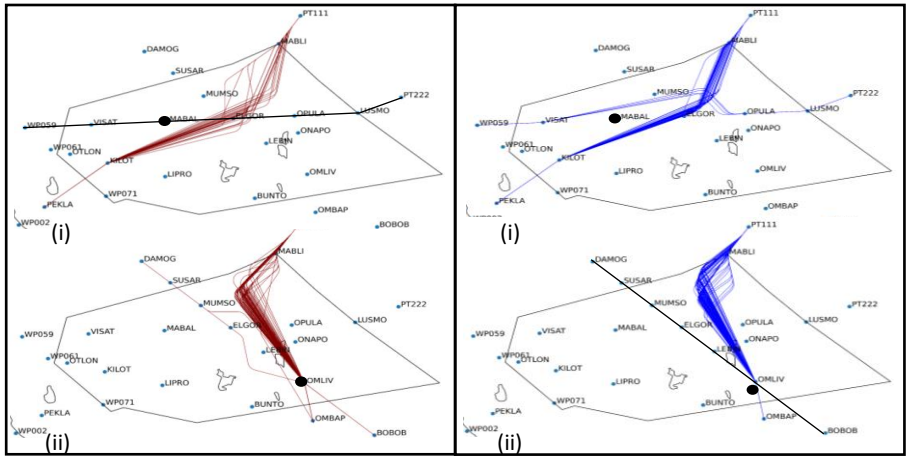


COMPARISON OF ACTUAL STRATEGY TUPLE WITH THE PREDICTED STRATEGY TUPLE.

	Original strategy tuple, S	Predicted strategy tuple, $\hat{S}$
C	SQ160	SQ160
T	6.26 minutes	6.19 minutes
D	Left	Left
D_c	14.82 Nm	12.32 Nm
M	WP071	WP071



ATC A : original (left) and predicted (right) maneuvered trajectories



ATC B : original (left) and predicted (right) maneuvered trajectories

V. Conclusions

Conclusions:

- Significance:
  - The framework enables accurate prediction of the ATCOs' conflict resolution strategies.
  - The model-predicted trajectories have close conformance with the trajectories obtained from ATCOs' conflict resolution maneuvers.

- Potential advantages:
  - Increased acceptance of automation tools in safety-critical areas such as air traffic conflict resolution.
  - Overall increase in efficiency through better management of traffic.
  - Usage as tools for training novice ATCOs.

Limitations And Future Work

- Limitations:
  - Conflict resolution assurance is not guaranteed.
  - For model performance validation, the same set of conflict scenarios were used.
- Proposed extensions for future work:
  - Address the current limitations.
  - Increase the number of participants in the experiments.
  - Upscale the experiments to include secondary maneuvers in more complex traffic scenarios.

Key References:

1. J. Hoekstra, R. Ruigrok, and R. Van Gent, “Free flight in a crowded airspace?” *Progress in Astronautics and Aeronautics, vol. 193, pp. 533–546, 2001*
2. S. M. Galster, J. A. Duley, A. J. Masalonis, and R. Parasuraman, “Air traffic controller performance and workload under mature free flight: Conflict detection and resolution of aircraft self-separation,” *The international journal of aviation psychology, vol. 11, no. 1, pp. 71–93, 2001*
3. C. Westin, “Strategic conformance: Exploring acceptance of individual-sensitive automation for air traffic control,” *Ph.D. dissertation, 2017. [Online]. Available: https://doi.org/10.4233/uuid:49c6fe9d-2d29-420a-91a2-a97e2049e15e*

Thank you