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Yanjung Wang	Nanjing Univ.	CN
Amber Woodburn	Ohio State	US
Seth Young	Ohio State	US
Yu Zhang	U. South Florida	US

Table of Contents

Track 1

Human Performance

Investigation of Relationship Between Trust in Automation and Human Personality Traits Among Air Traffic Controllers

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Abstract— The constant growth of air traffic will lead to greater complexity of the Air Traffic Controller (ATCo) tasks. The greater complexity is followed by increasing workload that will affect ATCo's task performance. To cope with that it is necessary to develop a new generation of the Air Traffic Control and Air Traffic Management automation technology, both airborne and ground-based. The proper use of automated technologies should be ensured by the appropriate level of ATCo's trust in automation. The research examines the relationship between ATCo's level of trust in automation and its personality traits when one specific contemporary system is being used by two air traffic control centers. It was found that ATCo's trust in an automated system depends on their age and work experience, as well as on the personal traits that stand out for their openness to new things, both in technology and in everyday situations. The research participants understand how the system behaves by using all appropriate methods to provide the outcome, but they still rely on themselves in the ultimate decision making. They define system's reliability as the most important system's characteristics.

Track 2

Decision Support

Solution Space Design for Continuous Descent Operations under Prediction Uncertainties

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Abstract— When planning and predicting a flight trajectory, uncertainties are inherent both in the current values of various influencing factors and in their evolution. These uncertainties can turn initially "optimized" trajectories into impossible or at least less attractive solutions at their activation time. In order to support a more robust trajectory optimization strategy, this paper investigates how those uncertainties affect the trajectory formation process and proposes a solution space, in which the planned optimized trajectories should be found. The trajectory optimization problem needed to design such a solution space is formalized as a multi-phase optimal control problem and is numerically solved with the pseudo-spectral method, which transcribes the continuous problem with discretized representation points. When solving given differential equations with the discretized points, the optimal number of discretized points is determined to grant accuracy of the optimization results. The solution space considers expected prediction errors of wind and temperature from a given reference case. Consequently, uncertain wind conditions cause a larger solution space and more variation in fuel burn than temperature errors. The designed solution space (especially the earliest and latest top of descent locations) gives pilots and air traffic controllers a good reference within which their aircraft is expected to navigate despite prevailing uncertainties. We believe that such additional information supports pilots and air traffic controllers when they robustly plan and execute continuous descent operations thus also improves the throughput on runways.

Predicting the Propagation of Trajectory Uncertainty during Climb

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Abstract— Robust Trajectory Prediction is one of the key enablers for the aspiring development towards Trajectory-based Operations. With increasing look-ahead times and the need for automation, the impact of uncertain input variables to the Trajectory Prediction must be understood. In this study, some uncertain input variables are provided as input probability density functions for the aircraft mass and speed intent (multiple phases with constant Calibrated Air Speed or Mach number) by a neural network. A Monte-Carlo simulation is used to predict 10,000 climb phases with a look-ahead time of 600 seconds for six different aircraft types. The resulting Trajectory Uncertainty is analyzed to proof that the stochastic characteristics of the input can be used to predict the Trajectory Uncertainty. Despite the moderate look-ahead time, about 80% of the resulting trajectory uncertainty fails the test for normality. However, the cross-over altitude is Normal distributed with the given input. The findings are applicable to decision support tools, if the uncertainty in the Trajectory Prediction shall be included.

Track 3

System Performance

Deep Trajectory Clustering with Autoencoders

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Abstract— Identification and characterisation of air traffic flows is an important research topic with many applications areas including decision-making support tools, airspace design or traffic flow management. Trajectory clustering is an unsupervised data-driven approach used to automatically identify air traffic flows in trajectory data. Long-established trajectory clustering techniques applied for this purpose are mostly based on classical algorithms like DBSCAN, which depend on distance functions capturing only local relations in the data space. Recent advances in Deep Learning have shown the potential of using deep clustering techniques to discover hidden and more complex relations that often lie in low-dimensional latent spaces. The goal of this paper is to explore the application of deep trajectory clustering based on autoencoders to the problem of flow identification. Thus, we present two clustering techniques (artefact and DCEC) and show how they embed trajectories into the latent spaces in order to facilitate the clustering task.

What's the Relationship Between Aircraft Taxi Speed and its Pollutant Emissions?

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Abstract— Aircraft taxi speed has an important effect on airport operational efficiency, fuel consumption, and pollutant missions. In order to achieve the shortest taxi time, aircraft prefer taxiing at the fastest speed, but this does not mean that the pollutant emissions are also optimal in most cases. In the context of vigorously advocating "green civil aviation," the relationship between taxi speed and pollutant emissions (i.e., emission quantity and emission cost) needs further study to achieve the aim of lower pollutant emissions. Therefore, based on the aircraft taxi speed model and aerodynamics model, this paper establishes a multi-objective optimization model of taxi speed with consideration of pollutant emissions. Then, the light (CRJ-900), medium (A320), and heavy (A333) aircraft were selected to reveal the relationships between taxi speed, pollutant emission quantity/cost on a given route at Shanghai Hongqiao Airport. The study results show that: (1) For pollutant emission quantity, the faster average taxi speed, the less pollutant emissions of A333; while for A320 and CRJ-900, the pollutant emissions decrease first and then increase with the increase of the average taxi speed; (2) For pollutant emission cost, the faster average taxi speed, the higher pollutant emission cost of all three aircraft, which increases slowly first then rapidly; (3) The optimal taxi speed profile can be generated according to the specific demand of the airport stakeholders to seek a balance between economic benefits and environmental benefits. It also has a certain significance for the study on taxiing scheduling and planning.

A Collision Risk Assessment Method for Runway Threshold Management: A Case Study of Singapore Changi Airport

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Abstract— Airports are indispensable infrastructures in an air transportation system with runways being the most critical component serving departures and arrivals. With constant increase in demand of air traffic, much effort has been made to manage the runway capacity to improve the throughput of airports. Apart from operational changes, there is a significant investment in runway infrastructure improvements such as new runway development/extension. However, many runways suffer from long runway thresholds due to safety constraints in face of approach path obstacles, which leads to reduction in Landing Distance Available (LDA). This paper proposes a method to manage the runway threshold by computing and assessing the collision risk of a given flight approach path with an obstacle profile. To do so, we develop the arrival flight profile along with its altitude distribution using ADS-B data. We then factor in the height of obstacles with reference to the obstacle surface profile. The convolution of two distribution is then used to assess the collision risk between the aircraft on approach path and the obstacle for better management of runway threshold. The proposed model is applied at Singapore Changi Airport, which has a long runway threshold due to the ship movements in the Strait of Singapore, which are considered as safety risks to the landing aircraft. Results suggest that, for CAT I/II approaches, with aircraft having aerodrome reference code 3/4, the runway threshold for runway Singapore Changi Airport 20R can safely be reduced by approximately 100 meters, while meeting the safety requirements.

Identification of Significant Impact Factors on Arrival Flight Efficiency within TMA

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Abstract— An important step towards improving the flight performance within Terminal Maneuvering Area (TMA) is the identification of the factors causing inefficiencies. Without knowing which exact factors have high impact on which performance indicators, it is difficult to identify which areas could be improved. In this work, we quantify the flight efficiency using average additional time in TMA, average time flown level and additional fuel consumption associated with the inefficient flight profiles. We apply statistical learning methods to assess the impact of different weather phenomena on the arrival flight efficiency, taking into account the current traffic situation. We utilize multiple data sources for obtaining both historical flight trajectories and historical weather measurements, which facilitates a comprehensive analysis of the variety of factors influencing TMA performance. We demonstrate our approach by identifying that wind gust and snow had the most significant impact on Stockholm Arlanda airport arrivals in 2018.

Capacity Management based on the Integration of Dynamic Airspace Configuration and Flight Centric ATC solutions using Complexity

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Abstract— This paper presents a new capacity management concept where Dynamic Airspace Configuration (DAC) and Flight Centric ATC (FCA) are dynamically applied together during the Air Traffic Flow and Capacity Management (ATFCM) pretactical phase. An airspace delineation methodology is also introduced aiming at identifying when and where DAC or FCA can perform better. This methodology entails the establishment of a dynamic vertical boundary that divides the airspace in two different parts where DAC and FCA are deployed. In addition, the geometrical complexity metric has been considered to measure the traffic demand and the sector capacity as an evolution of the current use of entry counts or occupancy counts.

Three 24 hours scenarios over the Hungarian airspace have been simulated in order to validate the improvements, in terms of capacity and cost-effectiveness, that the dynamic integration of both capacity management solutions may provide in comparison with the two solutions deployed separately. Results shows that when DAC and FCA are dynamically applied, a significant reduction in the number of overloads and underloads detected is achieved, what might lead to a higher capacity since more aircraft can be handled. Furthermore, a reduction in the controlling hours is also registered in this situation, what it is translated into a better cost-effectiveness solution.

Validation of Controller Workload Predictors at Conventional and Remote Towers

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Abstract— We do a field study on controller workload in a conventional tower and a Remote Tower environment (in both single and multiple mode) and give a proof of concept for the validation of indicators on their workload predictability. We analyze the number of ATCO tasks (e.g., arrivals, taxi), the communication times related to different ATCO tasks (and use them as weights for the ATCO tasks), and reaction times to SPAM queries. We show that—while the pure number of ATCO tasks is not a necessary condition for an increase in workload rating—indicators that integrate the communication time related to these ATCO tasks are, that is, each increase in workload rating is accompanied by an increase in these indicators.

Predicting Aircraft Landing Time in Extended-TMA using Machine Learning Methods

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Abstract— Accurate prediction of aircraft arrival times is one of the fundamental elements for air traffic controllers to manage an optimal arrival and departure sequencing on the runway, reduce flight delays, and achieve a good collaboration with airports and airlines. In this work, we analyze the feature engineering problem to predict Aircraft Landing Time (LDT) in Extended- TMA with machine learning models. Two main contributions are highlighted in this work. First, the impact of different features in LDT prediction is investigated. Second, a machine learning prediction model is presented to predict LDT. Our case of study is the E-TMA of Singapore Changi Airport (WSSS) with a radius of 100NM. Firstly, data analysis is conducted to check the availability of different resource data, as well as cleaning the raw trajectory data. Then, feature construction and extraction are discussed in details, machine learning prediction models are proposed to address the LDT prediction. The experimental results show that 4 sets of features play a significant impact on LDT prediction for primary runway-in-use, they are: (1) Control intent: traffic demand, current traffic density, and adjacent flow; (2)Weather: surface wind; (3) Trajectory: the position of aircraft; (4) Seasonality: parts of a day and a week. Moreover, comparing three Machine Learning algorithms, in our study case, Extra- Trees is the best prediction algorithm compared with other machine learning models in terms of Root Mean Square Error (RMSE) and Mean Absolute Error (MAE). It is also found that Machine learning models perform much better than the current operational system. In summary, two main conclusions are drawn from the present work. First, predicting the aircraft LDT is strongly correlated with the TMA density at the flight operation time. Second, feature selection with domain knowledge and expert opinions is very important, and with good features, the model is less sensitive to the choice of machine learning algorithm.

Trajectory Clustering of Inbound Aircraft based on Feature Representation and Selection

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Abstract— Trajectory clustering is an efficient way to identify the prevailing inbound patterns, which could help to improve both individual flight and system-level efficiency. Most of the existing trajectory clustering methods mainly relied on the framework of partition-and-group or the hierarchical clustering strategy. In this paper, we proposed a new trajectory clustering method that focused on the feature representation and selection for the inbound trajectories. Firstly, the representative features of the inbound trajectory were extracted. Secondly, the irrelevant and redundant features were eliminated based on Laplacian Scores and Spearman's correlation coefficients. Thirdly, since each trajectory can be represented as a sample with the same size of features, various standard clustering algorithms could be applied for identifying the prevailing patterns. Furthermore, we carried out case studies by using the trajectories of inbound flight landing on Shanghai Pudong International Airport. The results indicated that the proposed method could not only distinguish the important features for inbound trajectories but also identify the prevailing inbound patterns effectively and efficiently.

Dynamics of Disruption and Recovery in Air Transportation Networks

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Abstract— Flight delays occur in the air transportation system when disruptive events such as weather, equipment outage, or congestion create an imbalance between system capacity and demand. These cycles of disruptions and subsequent recoveries can be viewed from a dynamical systems perspective: exogenous inputs (convective weather, airspace restrictions, etc.) disrupt the system, inducing delays and inefficiencies from which the system eventually recovers.We study these disruption and recovery cycles through a state-space representation that captures the severity and spatial impact of airport delays. In particular, using US airport delay data from 2008-2017, we first identify representative disruption and recovery cycles. These representative cycles provide insights into the common operational patterns of disruptions and recoveries in the system. We also relate these representative cycles to specific off-nominal events such as airport outages, and elucidate the differing disruption-recovery pathways for various off-nominal events. Finally, we explore temporal trends in terms of when and how the system tends to be disrupted, and the subsequent recovery.

Flightpath 2050 door-to-door travel time goal: A comparative study on Europe and China

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Abstract— SESAR Flightpath 2050 sets several ambitious goals for European transportation in the year 2050. One of these goals concerns door-to-door travel time, which aims at having “90% of travellers complete their journey, door-to-door within four hours”. This goal, however, is missing a clear baseline, i.e., “How good is the current door-to-door accessibility?”. In order to find answers to this question, this study develops a model to assess the door-to-door accessibility for Europe and China at a high resolution. Urban center data is integrated into a radiation model for passenger travel flow estimation; a multimodal door-to-door travel framework is established, combining rail with air transportation, to estimate door-to-door travel times. Accessibility indicators are proposed to measure the satisfaction of travel demand for each urban center and the complete region/country. Results show that transport infrastructure at the current stage has already the potential to meet the ambitious four-hour goal in both regions. Contrary to intuition, large urban areas have a more urgent need to improve accessibility with respect to the given goal, induced by their large travel demand, compared to smaller urban areas.

Macroscopic Fundamental Diagram for Air Traffic: Preliminary Theoretic Results and Simulation Findings

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Abstract— In this paper we derive a model of air traffic system performance that describes the relationship between the occupancy of aircraft in the airspace and the effective output of the system – the Macroscopic Fundamental Diagram (MFD) model. We define the necessary variables, analytically derive the functional form of the MFD and validate the model using BlueSky open-source air traffic simulator.

Track 4

Automation and Air Vehicle Integration

Full-scale Pre-Tactical Route Prediction

Machine Learning to increase pre-tactical demand forecast accuracy

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Abstract— The objective of this paper is to present an artificial intelligence-based methodology to predict the Flight plans that will be received during the pre-tactical phase of the Air Traffic Flow and Capacity Management (ATFCM) process. For this purpose, input features equivalent to those of EUROCONTROL's PREDICT solution are fed to a Multinomial Logistic Regression algorithm over pre-clustered air routes in order to determine which route cluster is the most likely to be filed by an airspace user within each OD-pair. Results show that this procedure is capable of outperforming the current PREDICT solution in almost 40% of the 5,699 OD pairs considered and reducing current solution's error by 11%, showing good and scalable prediction capabilities.

Assessment of Optical Markers for On-Board Autonomous Localization of eVTOLs during Landing

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Abstract— Knowing confidently and reliably your position is the basis for autonomous and safe operations of air taxis in the emerging urban air mobility market. Especially during landing satellite based navigation alone is not sufficient. Additional accuracy and integrity are required. Computer vision can profit from the information rich visual environment and is potentially suited to provide localization but algorithms need to adhere to the strict requirements in manned aviation. In this paper we propose an optical localization system on the basis of the artificial fiducial ArUco markers similar to QR-codes for the landing of eVTOLs. The proposed localization system consists of a landing pad design based on ICAO regulations enhanced with an arrangement of markers that should allow localization during approach at any height. The presented system was then evaluated in graphical simulations such as VTK and AirSim. Furthermore, we artificially induced errors into the detection algorithm to test for error detection and correction capabilities. Finally, small-scale real world experiments were conducted to verify our observations. We found that 2 meter sized markers can be detected from as far as 60 meters even under varying weather influences and that centimeter accuracy can be reached although the error increases with distance to the landing pad. Additionally, we can show the validity/suitability of the markers as trustworthy reference points, have reason to believe that detection errors can be compensated within the application and potentially detect integrity violations. While this study reveals the potential of the system and laid the basis for its practical and economic use, it is the starting point for the development of a holistic navigation system that will make use of additional environment information and needs to be verified by large scale real world tests..

The Effect of Intent on Conflict Detection and Resolution at High Traffic Densities

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Abstract— The use of drones for applications such as package delivery, in an urban setting, would result in traffic densities that are orders of magnitude higher than any observed in manned aviation. Such densities not only make automated conflict detection and resolution a necessity, but it will also force a reevaluation of aspects such as centralised vs. distributed, coordination vs. priority, or state vs. intent. This paper investigates the use of intent in tactical conflict detection and resolution at high traffic densities in unmanned aviation. Experimental results show that combining both current state and future intent information improved overall safety. Adding intent enables the detection, in advance, of conflicts resulting from future changes of state. A conflict resolution maneuver is optimal for safety when all aircraft deviate only minimally from their current state to solve the conflict. Consequently, they could deviate from the broadcast intent information. Therefore, state projection into the future must still be kept to prevent very short-term conflicts when intruders do not follow their original intent.

An Autonomous Free Airspace En-route Controller using Deep Reinforcement Learning Techniques

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Abstract—Air traffic control is becoming a more and more complex task due to the increasing number of aircraft. Current air traffic control methods are not suitable for managing this increased traffic. Autonomous air traffic control is deemed a promising alternative. In this paper an air traffic control model is presented that guides an arbitrary number of aircraft across a three-dimensional, unstructured airspace while avoiding conflicts and collisions. This is done utilizing the power of graph based deep learning approaches. These approaches offer significant advantages over current approaches to this task, such as invariance to the input ordering of aircraft and the ability to easily cope with a varying number of aircraft. Results acquired using these approaches show that the air traffic control model performs well on realistic traffic densities; it is capable of managing the airspace by avoiding 100% of potential collisions and preventing 89.8% of potential conflicts.

A two-stage algorithm for aircraft conflict resolution with trajectory recovery

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Abstract— As air traffic volume is continuously increasing, it has become a priority to improve traffic control algorithms to handle future air travel demand and improve airspace capacity. We address the conflict resolution problem in air traffic control using a novel approach for aircraft collision avoidance with trajectory recovery. We present a two-stage algorithm that first solves all initial conflicts by adjusting aircraft headings and speeds, before identifying the optimal time for aircraft to recover towards their target destination. The collision avoidance stage extends an existing mixed integer programming formulation to heading control. For the trajectory recovery stage, we introduce a novel exact mixed-integer programming formulation as well as a greedy heuristic algorithm. The proposed two stage approach guarantees that all trajectories during both the collision avoidance and recovery stages are conflict-free. Numerical results on benchmark problems show that the proposed heuristic for trajectory recovery is competitive while also emphasizing the difficulty of this optimization problem. The proposed approach can be used as a decision-support tool for introducing automation in air traffic control.

Segmentation of Low-altitude Airspace in Highly Constrained Environments

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Abstract— With the rapid adoption of the operational concept of Unmanned Aerial Systems (UAS) within metropolitan areas, there is an increased focus on the spatial extent that Unmanned Aircraft (UA) can navigate within an acceptable level of risk. Unlike high-altitude airspace, low-altitude urban airspace is inherently constrained by the dense distribution of static obstacles. This study shows that not only the volume but also the entire topology of navigable airspace is highly subject to changes based on operational constraints such as separation requirements. We highlight that complex topology (highly obstructed) and simple topology (sparsely structured) coexist throughout urban airspace and that highly-obstructed spaces with abundant narrow passages are particularly affected by the increased level of operational constraints. We identify and examine such topological features through segmentation, which divides airspace into smaller segments that are connected only via relatively narrow passages. A multi-scale representation of airspace segments is derived based on two parameters related to operational requirements: the containment radius of a vehicle and the maximum number of vehicles that can pass through a passage simultaneously without collision. The proposed segmentation approach can be used to determine the vertical and lateral dimension of persistently available airspace, and can also form a useful basis for network design and airspace management.

Track 5

Environment and Energy Efficiency

Detecting and Measuring Turbulence from Mode S Surveillance Downlink Data

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Abstract— Instability in the movement of air masses in the atmosphere can result in turbulence. Most often, turbulence causes discomfort to passengers but it can occasionally affect their safety as well. Turbulence experienced by aircraft can be difficult to predict, especially for clear air turbulence (CAT) which occurs in the absence of any visual clues. Pilots may report turbulence when they fly through turbulent areas; their input contributes to the issuance of weather advisories (SIGMETs) that contain meteorological information concerning the safety of all aircraft. This paper presents a novel method to detect turbulence experienced by aircraft based on Mode S data, emitted by transponders in reply to BDS 6,0 requests (heading and speed reports) sent by Secondary Surveillance Radars. The method is first validated on a few flights labelled manually by the authors flying around Europe. Then, a large-scale reconstitution of turbulent areas over Europe on ten days across different seasons in 2018 is compared with SIGMETs emitted during the same time interval. This method may be an encouraging entry point for Air Navigation Service Providers so as to gain a better awareness of the turbulence situation, by simply requesting this type of information from aircraft flying in their airspace.

FPCA applied to flight paths optimization

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Abstract— In this paper, we detail the steps that lead to optimized trajectories according to a selected criterion, in a low dimensional space. After presenting the main techniques for optimizing flight paths, as well as methods for reducing the size of the state space, we precise the modeling of our problem. We use the Karhunen-Loève transformation, or Functional Principal Components Analysis (FPCA), as our main tool to model the state space. We also select the constraints undergone by our airplane: here, we decide only to consider the impact of the wind. For its simplicity, the Simulated Annealing (SA) is chosen in order to find the optimized trajectory. Thus, once the modeling is finished, we launch our simulations and proceed to an analysis of our results.

Track 6

Fuel and Emissions

Comparison of Fuel Consumption of Continuous Descent Operations with Required Times of Arrival

Path Stretching vs. Powered Descents

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Abstract— Continuous descent operations (CDOs) with required times of arrival (RTAs) have proven to deliver major environmental benefits in terminal maneuvering areas (TMAs) without degrading capacity. When traffic density is high, air traffic controllers (ATC) have to delay flights and assign an RTA different from the aircraft's estimated time of arrival (ETA). In such case, aircraft may have to follow a non-optimum speed profile and possibly be forced to fly powered descents instead of neutral CDOs. Furthermore, ATC may also stretch the planned route to keep the safety of the operation. In that case, aircraft might be able to fly neutral CDOs, but at the expense of flying a longer route. In this paper, the differences in fuel consumption between powered descents and path stretching are quantified. A simplified scenario has been defined in which an Airbus A320 is approaching a generic airport with a finite number of arrival routes (i.e. distances to go), and several fictitious RTAs. Then, an optimal control problem has been formulated and solved in order to generate several trajectories meeting the assigned RTAs. In terms of fuel consumption results show that, for RTAs later than the ETA, although in the beginning path stretching represents a higher fuel consumption, in the end flying powered descents is the strategy that consumes more fuel. For RTAs earlier than the ETA, path stretching shows lower consumption values. The methodology presented in this paper could help to define a ground supporting tool to help ATC to decide which would be the best decision under the trajectory based operations paradigm.

Track 7

Trajectory Management and Optimization

Morphing STARs vs drones and weather in TMA

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Abstract— We present an optimization framework for computing STARs that slowly change over time, while always avoiding a set of moving obstacles in TMA. The framework is applied to two types of obstacles: a drone intruder and hazardous weather. We demonstrate the output of our algorithms on synthesized drone intrusion incidents and real storm cells in Stockholm Arlanda terminal area.

Coupling Mathematical Optimization and Machine Learning for the Aircraft Landing Problem

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Abstract— The Aircraft Landing Problem (ALP) consists in sequencing aircraft on available runways, and scheduling their landing times taking into consideration various operational constraints. It is an NP-hard problem and an ongoing challenge for both researchers and air traffic controllers. A straightforward solution widely used in practice consists in scheduling aircraft using the simple "First-Come First-Served" (FCFS) sequence. However, it rarely provides optimal solutions, especially in large congested airports.

In this work, we propose a heuristic approach based on optimistic planning to solve the problem. We model the ALP as an environment of states, actions, transitions and costs, then explore the resulting search tree so as to identify a near-optimal sequence of actions within a limited time budget. In a previous contribution, we used the "First-Come First-Served" (FCFS) rule in the computation of the costs, to estimate the cost of the cheapest path (sequence of actions) from a given state. Now, we investigate a baseline model based on linear regression, and two different machine learning (ML) models trained on a large number of optimized solutions. These models can quickly and accurately estimate the cheapest-sequence cost, which helps the search to identify a near-optimal branch more efficiently.

Numerical experiments are performed on our publicly available data set, and show that using machine learning models in our heuristic search does not only ameliorate the previous results in terms of percentage improvement, but also reduces the optimality gap within a computation time that is compatible with on-line operations.

Short-Term Trajectory Prediction Using Generative Machine Learning Methods

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Abstract— Aircraft trajectory prediction is at the heart of the air traffic control (ATC) system. An accurate prediction of aircraft's future locations is essential for the air traffic controllers (ATCOs) to maintain the situational awareness of the traffic and to have proper strategies of congest management and separation assurance, which in turn contribute to a safe and efficient operation of the airspace. In this work, we propose a machine learning method for short-term aircraft trajectory prediction on a sector-based basis. Historical trajectories (from ADS-B data) are divided into clusters based on their spatial behaviors in the sector. Then, for each of the trajectory clusters, a predictive model is trained for future location prediction of the aircraft following the corresponding pattern. In the prediction phase, given the information of an aircraft when it is approaching the sector, our model first predicts the general pattern of the aircraft's trajectory in the sector, and based on the predicted pattern, the most appropriate predictive model is chosen to predict the aircraft's future locations. The whole future trajectory of the aircraft within the sector can also be generated. The evaluation shows that our model can achieve an average trajectory-wise error as low as 1.06 NM at 5-minute look-ahead time and 1.69 NM at 10-minute prediction horizon. The mean absolute error of the total travel time in the sector ranges from 9.8 seconds to 26.5 seconds depending on the trajectory pattern.

Obstacle Clustering and Path Optimization for Drone Routing

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Abstract— To enable safe and efficient Unmanned Aircraft Systems (UAS) operations at low altitudes, it is necessary to conduct airspace management and operations for UAS traffic. This study focuses on deterministic clustering-based drone routing, with specific emphasis on the trade-off between horizontal and vertical travel costs. The routing problem is simplified to a 2D problem that we solve at several altitude candidates. Altitude candidates were generated based on clustered static obstacles in low urban airspace. Fast-Marching algorithm is performed to generate the shortest path at each altitude candidate. The optimal altitude is determined by weighing the vertical cost for ascent and descent over the horizontal cruising cost at certain altitude. Experiments are conducted to choose proper number of clusters and weight given to building height in the clustering procedure, and different shortest path algorithms are compared. Larger scale of Unmanned Aerial Vehicles (UAV) missions are simulated, based on which we analyze the relationship between optimal travel altitude and shortest cruise path, and estimate the UAV cost function.

Analysis and Design of Trajectory-Based Operations under Wind Forecast Uncertainty

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Abstract— The Trajectory-Based Operations (TBO) concept is a key part of the FAA's and EUROCONTROL's programs to make flight operations more efficient and predictable, while maintaining operational flexibility. TBO relies on four dimensional (4D) trajectories that are managed by specifying a sequence of metering points. Each metering point is associated with a controlled time of arrival (CTA) that must be met by the aircraft within a specified time tolerance. Although the TBO concept has been around for a while, prior literature has not addressed design aspects, such as identifying metering point locations and their impact on the system performance. In this paper, we show how a prior analytical model for TBO can be adapted to account for wind forecast uncertainty, and other operational constraints. We investigate the influence of different system parameters such as wind forecast uncertainty, distance between metering points, and CTA tolerance. The analysis reveals interesting trade-offs between various performance metrics such as throughput, fuel burn and delay. Based on this analysis, we propose a framework for locating metering points to satisfy traffic demand, while being fuel efficient.

Aircraft Flight Plan Optimization with Dynamic Weather and Airspace Constraints

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Abstract— Flight planning is the process of producing a flight plan which describes a proposed aircraft trajectory. This task is typically performed ahead of departure with the intent of minimizing operating costs, while accounting for weather, airspace, traffic, and comfort considerations. Recent improvements in cockpit connectivity present new opportunities for flight crews to continuously re-assess the trajectories once in the air using the latest information sets (weather observations and forecasts, traffic). In turn, this enables flight crews to proactively respond to the uncertain evolution of the weather by steering the aircraft along optimal trajectories. This also brings new challenges as flight crews are ill-equipped to continuously process vast amount of information to perform the trajectory optimization. A framework is therefore proposed to automate the fusion of various sources of information (severe weather, winds aloft, restricted airspace) to feed a trajectory optimizer that continuously updates the aircraft trajectory. This relies on the implementation of the A* algorithm with the objective to minimize cruise fuel burn and emissions. Use-cases are investigated by comparing continuously updated trajectories with actual flight trajectories retrieved from the FAA Traffic Flow Management Systems through consumer-oriented websites. Promising results are observed with fuel burn savings reaching 8%.

Probabilistic 4D Flight Planning in Structured Airspaces through Parallelized Simulation on GPUs

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Abstract— The Air Traffic Management system is evolving to deal with efficiency, capacity, safety and environmental challenges. Progress along these fronts requires the development of trajectory planning and prediction tools that can deal with a complex and uncertain meteorological and operational context and go beyond the deterministic planning paradigm that underlies the technologies currently in place in ATM. In this work, we introduce a novel flight planning methodology to generate weather-optimal 3D flight plans in structured airspaces. By leveraging general-purpose computing on graphics processing units, we can simulate and evaluate multiple trajectory options under multiple scenarios in parallel, allowing us to provide quick iterations to a stochastic optimization algorithm. Our computational experiments show that our implementation can provide efficient solutions in seconds, as required in practical settings, while allowing for simple integration of future extensions thanks to its simulation-based nature.

Track 8

Advanced Modeling

Interactive Trajectory Modification and Generation with FPCA

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Abstract— Moving object analysis is a constantly growing field with numerous concrete applications in terms of traffic understanding, prediction and simulation. While many algorithms and analytic processes exist, there are still areas of investigation with novel trajectory analysis methods. As such, the geometric information analyses data with respect to its statistical distribution along extracted dimensions. This opens new ways of gaining a better understanding of large and complex trajectory data sets while providing flexible data manipulations. In this paper, we report our investigations with the development of an interactive methodology based on the geometric information analytic process where users can analyze trajectories sets, cluster and deform them maintaining the actual statistical properties of the investigated trajectories. As a contribution, this paper shows how geometric information can provide novel support for trajectory analyses taking into account the statistical properties of the investigated clusters. We also provide recommendations of good usage of such techniques with actual examples validated by a a domain expert of air traffic flow analysis.

Resilient Arrival Runway Occupancy Time prediction for decision-making tool in Barcelona (LEBL) airport

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Abstract— When trying to maximise the use of the airport airside, it becomes a key factor for tower Air Traffic Controllers (ATCos) to optimise the runway occupancy time for landing aircraft (AROT) while maintaining the required safety levels and/or reducing unsafe events such as missed approaches and runway incursions. Accurate tools to detect and predict unsafe events are becoming necessary in order to assist ATCos in their tasks. In aviation, there are many different data sources and the paradigm of data sharing between different stakeholders is not fully implemented. This paper proposes the use of novel machine learning techniques to model AROT prediction in Barcelona airport (LEBL), using ten models trained with more than 270.000 flights, exploiting different airport and Air Navigation Service Provider (ANSP) data sources to design a resilient decision-making tool that assists tower ATCos in real operation environment to optimize runway occupancy while increasing the safety level by decreasing human error.

Comparative Analysis of Machine Learning and Statistical Methods for Aircraft Phase of Flight Prediction

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Abstract— Phase of flight (POF) prediction estimates the future state of aircraft along planned trajectories, allowing the prediction of potential conflicts as well as optimization of air space, controlled by the Federal Aviation Administration. In this paper, we present a study conducted to develop three different POF forecasting machine learning models and a statistical regression model using four-dimensional GPS and RADAR Track data from 57 flights provided by an En Route Computer System. The investigated machine learning models include Long Short-Term Memory Recurrent Neural Network (LSTM-RNN), Support Vector Machine (SVM), and Neural Ordinary Differential Equations (NODE). These were developed to forecast the horizontal and vertical POF of the current aircraft for the next time step. The results in this study indicate that LSTM-RNN models are more suitable for POF prediction than SVM and statistical regression models, with NODE being a promising model for future trajectory prediction research.

Taxi-speed Prediction by Spatio-Temporal Graph-based Trajectory Representation and Its Applications

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Abstract— Airport surface movement systems require aircraft taxing speed as a key input to perform ground movement optimization and path planning processes. With the increasing availability of surface movement data from systems such as A-SMGCS, a data-driven framework using a spatio-temporal graph-based trajectory representation is proposed in this paper to predict aircraft taxing speed. The proposed framework includes a data preparation module for converting track points data to graph-based representation and a developing predictive model module for learning taxi-speed model. The Random Forest algorithm is selected as our predictive model. The model predicts the aircraft taxi-speed with an error of ±1.08 m/s for taxi-out procedure and ±0.97 m/s for taxi-in procedure, when compared with the actual taxi-speed from A-SMGCS data, respectively. Further, three applications of our approach are discussed which are taxi-speed profile, unimpeded taxi time and potential conflict detection. The results of our methods outperform all baseline methods. In detail, for generating taxi-speed profile, our method obtains the error ±1.38 m/s while for computing unimpeded taxi time, our method outperforms the baseline model with the mean absolute percentage error is 11.03% for the taxi-in and 16.8% for taxi-out procedure, respectively.

Model Generalization in Arrival Runway Occupancy Time Prediction by Feature Equivalences

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Abstract— General real-time runway occupancy time prediction modelling for multiple airports is a current research gap. An attempt to generalize a real-time prediction model for Arrival Runway Occupancy Time (AROT) is presented in this paper by substituting categorical features by their numerical equivalences. Three days of data, collected from Saab Sensis' Aerobahn system at three US airports, has been used for this work. Three tree-based machine learning algorithms: Decision Tree, Random Forest and Gradient Boosting are used to assess the generalizability of the model using numerical equivalent features. We have shown that the model trained on numerical equivalent features not only have performances at least on par with models trained on categorical features but also can make predictions on unseen data from other airports.

Probabilistic Prediction of Time To Fly using Quantile Regression Forest

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Abstract— The air traffic is mainly divided into en-route flight segments, arrival and departure segments inside the terminal maneuvering area, and ground operations at the airport. In our contribution we will focus on the prediction of arrival procedures, in particular the time to fly from turn onto final approach course to threshold, which supports utilizing available capacity more efficiently. Most prediction methods developed so far provide a sole point estimate for the time to fly. We see the need to cover the uncertain nature of aircraft movement by the implementation of an probabilistic approach. This becomes very important in cases where the air traffic system is operated at its limits to prevent safety critical incidents, e.g. separation infringements due to very tight separation. Our approach is based on the Quantile Regression Forest technique that is able to provide a measure of uncertainty of the prediction, instead of a single value only. While the data preparation, model training and tuning steps are identical to classic Random Forest methods, in the prediction phase, Quantile Regression Forests provide a quantile function to express the uncertainty of the prediction. After developing the model, we further investigate in the interpretation of the results and provide different ways of deriving a probability function from it. We found, the Skew Normal Distribution provides an affirmative fit to reflect the characteristics of uncertainty in prediction. With this contribution, there becomes a tool available that allows to predict time to fly more sophisticated, depending on the specific needs of the use case.

In-flight aircraft trajectory optimization within corridors defined by ensemble weather forecasts

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Abstract— Today, each flight is filed as a static route not later than one hour before departure. From there on, changes of the lateral route initiated by the pilot are only possible for safety reasons. Thus, the initially optimized trajectory of the flight plan is flown, although the optimization may already base upon outdated weather data at take-off. Global weather data as those modeled by the Global Forecast System does, however, contain hints on forecast uncertainties itself, which is quantified by considering so-called ensemble forecast data. In this study, the variability in these weather parameter uncertainties is analyzed, before the trajectory optimization model TOMATO is applied to single trajectories considering the previously quantified uncertainties. TOMATO generates, based on the set of input data as provided by the ensembles, a 3D corridor encasing all resulting optimized trajectories. Assuming that this corridor is filed in addition to the initial flight plan, the optimum trajectory can be updated even during flight, as soon as updated weather forecasts are available. In return, flights would have to stay within the corridor the corridor to provide planning stability for Air Traffic Management. Although the corridor restricts the re-optimized trajectory, fuel savings of up to 1.1 %, compared to the initially filed flight, could be shown.

Categorizing Flight Paths using Data Visualization and Clustering Methodologies

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Abstract— This work leverages the U.S. Federal Aviation Administration's Traffic Flow Management System dataset and DV8, a recently developed tool for highly interactive visualization of air traffic data, to develop clustering algorithms for categorizing air traffic by their varying flight paths. Two clustering methodologies, a spatial-based geographic distance model, and a vector-based cosine similarity model, are demonstrated and compared for their clustering effectiveness. Examples of their applications reveal successful, realistic clustering based on automated clustering result determination and human-in-the-loop processes, with geographic distance algorithms performing better for enroute portions of flight paths and cosine similarity algorithms performing better for near-terminal operations, such as arrival paths. A point extraction technique is applied to improve computation efficiency.

Predicting Go-around Occurrence with Input-Output Hidden Markov Model

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Abstract— In this work, we propose a probabilistic graphical model – Input-Output Hidden Markov Model (IO-HMM) – to make sequential predictions of go-around probabilities for a flight approaching its destination airport. We compare the performance of the IO-HMM against four popular machine learning models trained at every nautical mile to the landing runway threshold on a collection of metrics. Our experiment with approximately 100,000 flights in the JFK airport suggests that the IO-HMM in general outperforms other models due to its capability of capturing the inherent temporal structure of the entire flight sequence.

En-route Arrival Time Prediction using Gaussian Mixture Model

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Abstract— Accurate trajectory prediction is required to realize safe and efficient aircraft operations. In this paper, a new framework for predicting arrival time of en-route aircraft using Gaussian Mixture Model (GMM) is proposed. The proposed method fits the historical trajectory data with GMM whose variable is a set of arrival times at the significant points along a specific air route. The flight times to the defined points along the air route are computed conditioned on the observed flight times for the previous points that the aircraft has already passed by. The form of prediction output from the proposed model is the probability distribution which would increase its applicability to various fields due to its probabilistic nature. The performance of the proposed method is demonstrated by applying it to real flight data in Incheon Flight Information Region (FIR).

Track 9

Airline Operations and Quality of Service

Integrated Operations Control at Hub-Airports with Uncertain Arrival Times

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Abstract— Airline operations are subject to a number of stochastic influences which result into variable ground and block times for same flights on different days. Our research explores how airline hub operations control centers may benefit from an integrated decision support system for disrupted situations. In this paper, we study the sensitivity of an optimal set of schedule recovery measures towards uncertain arrival times. The calculation of recovery measures is based upon an integrated and iterative scheduling and optimization algorithm, which incorporates uncertainties for arrival flights as a function of a given look-ahead time. Potential recovery measures include stand re-allocation, quick-turnaround, quick passenger transfer, waiting for connecting passengers, cancellation of passenger connections, stand-by crews and taxi-in prioritization. Within a simulated scenario, 20 aircraft are analyzed during a morning peak at Frankfurt Airport given their estimated arrival times (including potential arrival delays). The analysis of simulation results reveals an almost identical set of optimal recovery measures selected under high uncertainty circumstances and from post-operational point-of-view, which indicates high solution stability.

Towards a more complete view of air transportation performance combining on-time performance and passenger sentiment

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Abstract— This paper aims at presenting a novel approach to airline sentiment analysis processing using Twitter data. By transforming trained sentiment classifiers into regressors, the daily sentiment distribution obtained can be represented as a trimodal Gaussian Mixture leading to a simple but efficient classification algorithm. These classes can be considered as daily sentiment scores. This classification applied to passenger generated tweets and airline generated tweets for five major US airlines highlights major difference in experience between passengers and airlines. This methodology also confirms the existing gap between flight performance and passenger experience and the necessity of considering and implementing passenger centric metrics.

Optimal Gate Assignment Under Consideration of the Ground Infrastructure

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Abstract— Besides safety, the main philosophy of a five-star airport is to ensure the highest achievable level of quality in terms of comfort and passenger transfer efficiency, measured by short paths and low connecting times. In the event of critical connecting times, an optimal assignment of gates may decide whether passengers reach their onward flights or not. In this paper, we address the modeling and solving of the Airport Gate Assignment Problem with a focus on the properties of a five-star hub airport. Besides general ground infrastructure properties, we also discuss the gate assignment under consideration of the aircraft wingspan. Finally, we will use a model of the Terminal 2 at Munich Airport as a basis for case studies. The underlying problem is a binary quadratic optimization problem, and we will discuss techniques for solving the problem by means of fast solution procedures. In the near future, an extension will be introduced that will consider the selection of seats depending on the passenger's preference, the estimated connecting time and the yields generated by reservation fees.

Robust Integrated Airline Scheduling with Chance Constraints

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Abstract— During planning and execution of their flights, airlines face complex decision-making processes: The operation of all aircraft according to a minimum-cost plan poses tremendous difficulties even for medium-sized airlines. Accordingly, the airline scheduling problem is historically decomposed into a collection of four subproblems: Schedule design, fleet assignment, aircraft routing, and crew pairing problems. The decomposition into subproblems reduces the required computational costs; the airline performance, however, often greatly deteriorates, given the sub-optimality of the solution or, in the worst case, infeasible solutions. With the incorporation of robustness into scheduling, solving the problem becomes further intractable. In this study, we design an integrated robust scheduling problem, which integrates the first three steps into a complex optimization problem, while considering chance constraints to ensure the overall on-time performance. An exact column generation-based algorithm and a fast hybrid algorithm that combines variable neighborhood search with column generation are developed to efficiently solve the problem. Based on a real schedule from a Chinese airline, the benefits of this fully integrated robust model and computation results are presented and validated. Our results demonstrate that the proposed hybrid algorithm can quickly derive high quality solution within an optimality gap of no more than 0.7%.

Track 10

Safety

Estimation of Flight State with a Collision Alert Radar

Based on FMCW Reflections of the Landscape for General Aviation

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Abstract—Although the main goal of a newly developed Collision Alert Radar is to observe airborne targets, it was found that reflections of the ground are received by the radar. The radar is carried on board of the aircraft, and the ground reflections may be used to detect flight information with respect to the terrain, something which is not possible with existing hardware. In this paper a method is developed which makes use of range and Doppler information from ground reflections, in order to provide the pilot with height and velocity information. The method was tested on a local flight in the Netherlands, with a prototype of the radar on-board. State results were compared to those of a GPS tracker on board. It was found that the horizontal and vertical components of the velocity were found with a standard deviation of about 3 m/s, and the height estimates had a standard deviation of 23 m. Also, a discrepancy of 36 m between the GPS and radar height estimates was found, which was caused by a fault in the GPS earth surface model, which was no problem for the radar. It is concluded that the quality of radar state estimates is approaching that of GPS measurements. The rapid developments in microwave sensing techniques can help the radar to surpass the quality of GPS in the coming years. If that happens, state estimation by radar can become an option for pilots who do not want to be dependent on the correctness of a terrain model, but who measure the terrain shape independently.

Aircraft performance-based redesign of airport obstacle limitation surfaces

The horizontal obstacle limitation surfaces

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Abstract— Air traffic within highly frequented terminal manoeuvring areas is characterized by a high number of climbing and descending aircraft, varying in size, speed and distance between each other. So collision risk is increased compared to En-route airspace. Additional collision risk with ground based, fixed obstacles have to be taken into account. To protect aircraft from obstacle on ground during procedures in the vicinity of an aerodrome, the first obstacle limitation surfaces were implemented in the 1950's. From today's view current navigation procedures and actual aircraft performance are without clear correlation to the dimensions and shapes of the applied obstacle limitation surfaces. To avoid over and under protecting of specific terminal manoeuvring areas, obstacle limitation surfaces have to be redesign. We present a methodology of obstacle limitation surface redesign and focus on the horizontal surface. This area aims to protect aircraft on non-standardized flight procedures and is characterized by no nominal flight tracks. In consequence, here obstacle limitation surfaces design criteria focus on aircraft performance data, fitting to manoeuvres that can occur within this airspace. As result, new horizontal surfaces are designed and dimensioned in dependence to the ICAO's approach speed category and maximum cross wind components as key influencing parameters for aircraft turning radius. To ensure more practicability of obstacle limitation surface, the paper presents a 2nd optional iteration stage of the surface design. This stage takes local conditions into account, e.g. wind components. As a result, aerodrome-specific downsizing of the horizontal surfaces enables a benefit for urban planning.

Track 11

Complexity and Information

Boundary Searching of Unmanned Aircraft System Operations Near Airports

A Data-Driven Analysis of Airspace Utilization

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Abstract—The demand for UAS operations is increasing in recent years, as well as the traffic volume of civil aviation. The operations of both traffic modules are based on the utilization of airspace resources. Currently Unmanned Aircraft Systems (UAS) are not allowed to operate close to airports, where potential conflicts between UAS and manned aircraft happens. This rule is constraining the application of UAS. Therefore, it is necessary to study the current airspace utilization pattern near airports, before the boundary determination of UAS operation to allow the UAS accessing airspace safely without conflicts. In this paper, a data-driven analysis on historical trajectories below 10,000 feet at Changi Airport in Singapore was carried out. Trajectory data have been clustered to recognize the utilization patterns of airspace. Discussions on the boundary of UAS operation were presented based on both current airspace utilization patterns and the estimated capacity together with predictions of traffic demand in 2025. As this is the first research study to present the initial concept, more operational and other factors should be considered in the future study for the generation of potential boundary of UAS operations.

Track 12

Information Management

Validation of GPS by Ground Scanning Radar

Generated with an on-board wide-angle FMCW radar for General Aviation

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Abstract—Many pilots in General Aviation use electronic add-ons aids in flight, which rely on satellite navigation information. This navigation information is often a single point of failure which is undesirable since the pilot relies on the information.

This paper presents the results of research whether a novel mobile radar station can be used to validate the navigation results from the GPS. The radar transmits signals to the ground, and compares the locations of the reflections to a digital map such as Google maps.

A test flight was performed with a radar system on board. Fifteen different methods for processing the images were investigated, and it was found that Ridge Operators and Entropy Detection are good methods to extract similar features in Google and radar images. These algorithms were always successful in picking the single correct GPS coordinate out of a pool of 300 false ones within 150m of the correct answer, except when the aircraft was making a turn and the radar was pointed to the sky.

It is concluded that a ground-scanning radar on board can be used to validate the results of a GPS, provided that the radar can observe recognizable features that can be compared to a digital map. The type of image processing used to extract the data is crucial for the application.

Analyzing Aircraft Surveillance Signal Quality at the 1090 Megahertz Radio Frequency

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Abstract—Due to the increasing demands for real-time air traffic monitoring, the 1090 megahertz radio frequency has become the most utilized communication channel for aircraft surveillance purposes. Several services are using the radio frequency at the same time, which are Mode A/C communications and Mode S communications. These different types of communications are not coordinated, meaning that the quality of a communication channel can deteriorate with the increasing number of aircraft in the airspace. This deterioration may further worsen with the increasing number of aircraft that comply with the Automatic Dependent Surveillance-Broadcast requirement, which is implemented based on Mode S Extended Squitter.

In this paper, we conduct experiments to determine the quality of 1090 megahertz radio frequency by analyzing the low-level signals using an open-source software-defined radio. First, we implement the demodulation of Mode A/C and Mode S signals from the raw in-phase and quadrature signals with a high sampling rate. Then, several methods are employed to study the occupancy of the communication channel and the garbling severity of the signals, as well as the error rate in ADS-B signals. All results show that the radio frequency is experiencing high communication load during day time air traffic operations. The results also suggest a need for a major redesign of the aircraft surveillance system in the future due to the current inefficient utilization of this radio frequency.

Track 13

Unmanned Aerial Systems

Droneport Placement Optimization and Capacity Prediction

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Abstract— Increasing demand for Unmanned Aerial Vehicles (UAVs, or drones) in urban airspace brings many concerns about safety issues. Take-off, approach and landing phases of drones have a strong occurrence possibility of accidents and incidents. Concerning the potential safety issues of thousands of drones taking off and landing in the metropolitan areas, we conceive a facility called droneport to accommodate and manage assorted drones in a protected space, which is suitable for applying air traffic control to departing and approaching drones. This paper presents several contributions to the concept of droneport: (1) The Holt-Winters' seasonal method was adopted to forecast future delivery drone demand based on historical online retailer data. (2) A multi-objective optimization model was established to determine the optimum placement and number of droneports considering both costs and societal value from three aspects: maximizing e-commerce demand coverage, minimizing drone service distance and maximizing area coverage. (3) Gaussian noise was introduced to the optimization model to make the measurement of service distance more practical. (4) The future capacity of each droneport was estimated. A real-world case study was carried out for Singapore. Developed on the forecasted demand distribution, the optimization result with 7 droneports and a 10 km radius of operation showed a 99% demand coverage and 93% subzone coverage. Overall, this paper presented an intuitive and efficient optimization model for the placement of droneports with predicted drone demand and forecasted the capacity of each droneport.

Track 14

Network Management

The Air Traffic Flow Management Problem with Interdependent Flight Schedules

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Abstract— This paper extends the Balakrishnan and Chandran's trajectory-based optimization model for large-scale air traffic flow management problems (ATFM) to account for connecting flights. This paper then proposes a nested column generation approach to solve the ATFM problem, determining the optimal space-time trajectories and airline (group) decisions in the presence of network and flight connectivity constraints, as well as airspace and airport surface capacity constraints. The algorithm is scalable as it is parallel, and has been tested on a large-scale instance using scheduled flight data for the ASEAN region, showing that it is capable of solving realistic-sized problems with thousands of flights.

Air Traffic Flow Management under Uncertainty in Terminal Maneuvering Area

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Abstract— In the air traffic control system, the Terminal Maneuvering Area (TMA) is one of the most complex area in which the flight operations are easily influenced by the inevitable uncertainties such as inaccurate aircraft performance, navigation accuracy, pilot operations. This research addresses the sequencing problem in TMA under uncertainty and aims to improve air transport safety and efficiency at a tactical level. The uncertainty is managed by introducing probabilities to the temporal information at specific points for each flight. Flight by flight conflict is then measured with probability on each designated point taking all the possible arrival times into consideration. By minimizing the total probability of conflict in the network, appropriate safety margin can be imposed. A meta-heuristic simulated annealing optimization algorithm is proposed, and the solution is obtained based on the real flight data of 2 hours in Paris Charle-De-Gaulle airport. A simulation is conducted to verify the performance of our proposed model while considering the deterministic model as a baseline case. Both the candidate solutions are disturbed in terms of TMA entry time and the timestamp for each flight are conditionally deviated from the predicted ones. Final results show the advantage of the proposed model in absorbing the conflicts while experiencing the disruptions.

A Percolation Theory Based Approach for Identification of Bottleneck Links in an Airway Network

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Abstract— The ever increasing demand for air travel is likely to induce air traffic congestion which will elicit great economic losses. As air traffic congestion usually originate and propagate from a small region in an airway network, it is becoming important to identify the bottleneck links of an airway network. In this paper, we characterize the organization of air traffic flow as a percolation process. From a percolation process, it can be observed that the global air traffic is dynamically formed by clusters of local air traffic flows which are connected by the bottleneck links. We developed a data driven method to identify such bottleneck links in an airway network based on percolation theory. This method aims to identify links, at the percolation threshold, whose malfunction potentially disintegrate the global air traffic flow into large isolated local flows. These links are identified as bottleneck links since they reduce the efficiency of air traffic flow in the airway network and induce air traffic congestion. With the proposed method, we have carried out a case study on Singapore airway network using one month ADS-B data. Results show there appears to be a presence of airway links that may be bottlenecks in Singapore airway network. When the bottleneck links are dysfunctional, large-scale local traffic flows are unable to exchange freely which can lead to global traffic congestion. This provides an approach to manage air traffic congestion with minor adjustments such as improving the flight efficiency on the bottleneck links.

An Arrival Scheduling Model for Incorporating Collaborative Decision-Making Concepts into Time-Based Flow Management

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Abstract— This paper proposes a flight scheduling scheme – 2-opt-swap, which assigns controlled times of arrival (CTAs) for flights reaching the Freeze Horizon and allows certain slot swapping between different flights with the goal of reducing total controlled arrival delay cost over all carriers. The allowable swaps are predicated on models of carrier preferences following a Collaborative Decision-Making paradigm. Monte Carlo simulations were designed to prove the benefits of this new CTA scheduling scheme, compared to a baseline model of first-come-first-served discipline, which is currently used in Time-Based Flow Management.

Tradeoffs between Efficiency and Fairness in Unmanned Aircraft Systems Traffic Management

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Abstract— The growing use of drones and other Unmanned Aircraft Systems (UAS) is expected to make airspace resources more congested, necessitating the use of UAS Traffic Management (UTM) initiatives to ensure safe and efficient operations. The core functions of UTM are to prevent the loss of airborne separation and to mitigate congestion at departure or arrival points. These functions can be achieved through revising the schedule by assigning airborne delays (speed changes or path stretches) or ground delays (delayed takeoff times) to aircraft. Our work evaluates the fairness aspects of delay assignment while attempting to achieve more efficient UTM. Dynamic and high traffic demand, variability in UAS operators' preferences, and differences in vehicle capabilities can adversely impact the fairness of the revised schedule. We show through computational experiments that, for certain fairness metrics, significant improvements in fairness can be attained with very little decrease in system efficiency. We also quantify the tradeoff between efficiency and fairness under dynamic demand, when trajectories are incorporated in a rolling horizon framework.

Doctoral Symposium

Chair: Seth Young

Effects of aviation liberalization and level of democracy on air connectivity and related economic consequences: Evidence from Africa

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Abstract— The link between air connectivity and democracy has received some attention recently, with a study by the International Air Transport Association showing that there is a clear correlation between air connectivity and democracy in various regions of the world. This paper investigates the triangular relationships between air connectivity, democracy and aviation liberalization and economic consequences of their interactions. It adds value to literature by demonstrating the direct effects of democracy on liberalization and quality of air connectivity in Africa. The PLS-SEM result shows that democracy has a weak positive correlation with both aviation liberalization and air connectivity. However, the level of democracy has no significant direct effects on quality of air connectivity and aviation liberalization in Africa. At the country level, South Africa, Morocco, Egypt and Ethiopia are the top four countries possessed better air connectivity in the region but have been experiencing different cultures of democracy. This could imply that either the infant democracy in the region is unable to influence air connectivity or the direct effect of democracy on the aviation market is minimal. Moreover, liberalization significantly affects the quality of air connectivity and has reasonable indirect effects on the economic development of the continent. Furthermore, the positive impact of connectivity on economic development, on average, is more noticeable in the countries of former French colonies than British counterparts. In general, the study suggests that in the assessment of liberalization efforts and air connectivity in Africa, perhaps, the level of democracy may not be considered as a foremost component.

Examining the Air Travel Experiences of Individuals with Vision Disabilities

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Abstract— This qualitative study aims to examine the underexplored area of traveling with a vision disability. In particular, the study focuses on the lived experiences of vision impaired individuals in receiving disability assistance services during their air travel. The study employed a phenomenological approach with in-depth interviews for data collection and a combination of thematic analysis techniques for data analysis. Results of the study indicate five main categories of assistance-related issues that vision impaired participants frequently experience in their travel - personnel attitude issues, personnel training issues, system issues, policy issues, and physical accessibility issues. The study concludes that several ongoing issues related to staff training and management of disability assistance services need to be addressed to ensure an equitable travel experience for vision impaired individuals. The study offers valuable insights that could be useful in developing more effective training programs for personnel who provide disability assistance. Findings of this study also hold implications for existing airline policies and regulations as they relate to vision impaired travelers.

Decision Support System for Airline Operation Control Hub Centre (DiSpAtCH)

Initial research results and developed framework

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Abstract— If the global air traffic increases again over the next years, it will lead to additional stress on airports, air traffic controllers, and airlines. From an airline perspective, Operation Control Centre (OCC) must prepare them to handle not only more aircraft but also to solve operational disruptions in a much more complex environment than today. Based on research on Artificial Intelligence, Machine Learning, and the state of the art in Airline Operation Control Centre Research, a framework for a decision support tool (DST) is developed. The proposed DST (DiSpAtCH) aims to reduce the time, which is needed to find a feasible solution for a specific disruption situation. Furthermore, the feedback of the DST should increase the situational awareness of the current disruption situation and help the people in charge during the disruption management process within an OCC.

Does the attractiveness of the cabin crew affect the perception of customers? A neuromarketing perspective

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Abstract— With deregulation and liberalization, the airline industry has undergone a major change process and more competitive markets have emerged. Considering the importance of service quality, airlines have focused on service quality as one of the most important means of surviving in these competitive environments. So, it is essential to reveal which factors affect the perception of service quality. It has been argued that one of these elements is the attractiveness of cabin crews. Therefore, this study aims to investigate the role of cabin crews' attractiveness on service quality perception. Accordingly, it is planned to conduct EEG measurements on consumers by means of various service delivery scenarios and to obtain service perceptions related to service delivery through self-assessment. Then, it is aimed to analyze, interpret and discuss the obtained data, thus providing useful information to airline managers.

Improvement of Conflict Detection and Resolution at High Densities Through Reinforcement Learning

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Abstract— The use of drones for applications such as package delivery, in an urban setting, would result in traffic densities that are orders of magnitude higher than any observed in manned aviation. Current geometric resolution models have proven to be very efficient. However, at the extreme densities envisioned for such drone applications, performance is hindered by unpredictable emergent behaviour of interacting traffic. This paper describes a study that intends to investigate how reinforcement learning techniques can be used to complement geometric methods, thus improving conflict detection and resolution at high traffic densities. Different hybrid approaches are discussed, and preliminary results are shown for a hybrid model that uses geometric methods in the training phase of a Deep Deterministic Policy Gradient (DDPG) model.

Neural Network based Convection Indicator for Pre-Tactical Air Traffic Flow Management

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Abstract— A main objective of Air Traffic Flow Management is matching airspace and airport capacity with demand. Being able to accurately predict unexpected disruptions to the air traffic network, such as convective weather is essential in order to make better informed decisions and improve performance of the system. In this paper we demonstrate how machine learning can improve prediction of convective areas at time horizons necessary for the pre-tactical phase of ATFM. Data from numerical weather prediction forecast are merged with storm cell observations from satellite and used to train a neural network model to identify convective areas at time horizons up to 45 hours. Results show the neural network model outperforms an existing convection indicator in predicting thunderstorms.

Modelling and Simulation of APOC Operations

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Abstract— This work aims at developing an agent-based platform that allows to model and analyze decisions made by different stakeholders in an Airport Operations Centre. We will develop a methodology combining agent-based modelling and field/lab behavioral experiments for identifying the incentives behind the decisions of the stakeholders in an Airport Operations Centre environment. Once, the causal relationships have been identified, these will be translated into an agent-based environment so, it will be possible to have a virtual environment for identifying which incentives are the best for aligning the objectives of the center, considering the diversity of objectives present in the system. The causal-relationships identified in the study will be validated with a human-in-the-loop environment already developed under the SESAR program. This study is an interdisciplinary one which integrates simulation, decision making and behavioral science in the airport operations center environment.

A Data Collection Scheme to Support Applications for Capacity Enhancements at Small Airports

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Abstract— This paper describes a proposed a data collection scheme to support capacity estimation at small airports that serve primarily general aviation aircraft. Such airports do not have automated data collection systems, nor are they well represented in the existing suite of capacity estimation tools. Capacity estimation is an essential tool for applying for capacity enhancement funding. This paper describes the types of data that are necessary to participate in this process, as well as a scheme based on local, portable installations of Automatic Dependent Surveillance-Broadcast receivers to collect the raw aircraft type and trajectory data that would be necessary to generate these more refined data. The paper also outlines data processing steps that can be taken to deduce more sophisticated insights from the raw data.

Advanced Statistical Signal Processing for Next Generation Trajectory Prediction

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Abstract— Trajectory Prediction (TP) is fundamental in Air Traffic Management (ATM). This research focuses on TP for the execution phase of the flight. In contrast to exploit black-box machine learning-based solutions, we tackle TP as an estimation problem, resorting to mathematical tools arising from statistical signal processing. Our first goal is to find an optimal and robust 4D (3D space plus time) TP solution, and the real-time estimation of the aircraft's active guidance mode, observing flight data collected from Automatic Dependent Surveillance-Broadcast (ADS-B), and transponder selective mode (Mode S) transmissions. Notice that this work is at a very early stage and only preliminary results are available.

Topological Data Analysis on the Northeast Asian Air Route Network

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Abstract— Studying the properties of airport network of various countries based on complex network theory has been well researched over the past decade. However, there were only a few attempts made to utilize air route network with waypoints and air traffic service routes. In this study, three variations of networks – unweighted, distance-weighted, and demand-weighted air route networks of the rapidly growing Northeast Asian region are considered, and various node centrality measures are applied. Based on measured values, nodes sharing common characteristics are identified by mapper algorithm, one of the main approaches of topological data analysis. Mapper output network successfully grouped waypoints sharing common characteristics such as terminal nodes and nodes on busy air routes. Findings on the set of important waypoints provide key insights for effective regional airspace design.

How to assess the feasibility of sUAS applications in urban environment: geodemographic analysis of 3D urban space

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Abstract— The rapid growth of small Unmanned Aerial System (sUAS) in urban areas has garnered greater interest in its application in urban space. As a first step to assess the feasibility of sUAS and UAM in urban areas, the authors utilize a diverse set of urban airspace use data to model the interaction of urban dwellers and the 3D airspace. With the anticipated utilization of sUAS in urban airspace, a multi-dimensional understanding of such space is essential. In doing so, it is necessary to integrate and analyze two important elements that constitutes an urban environment: people (or human behavior) and man-made structures. In this study, highly urbanized areas – San Francisco, CA was analyzed for their urban space characteristics by considering both the daytime and nighttime population with the 3D geospatial information. We aim to evaluate the temporal variations of such interactions and geofence in populated urban regions. Regionalization is conducted using SKATER algorithms for clustering purpose. The outcomes have several unique information that can benefit drone delivery target area identification, landing location identification, demand prediction.

Classification of Runway Configurations for Capacity Analysis of Airports Serving Small Aircraft

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Abstract— In this paper we describe the development and application of GIS-based algorithms to automate and standardize the process of classifying runway configurations for United States' airports primarily serving small aircraft. Runway configurations are detected using data sources from the National Flight Data Center (NFDC). Identified runway configurations are then categorized by a defined classification schema through geocoding algorithms using geoinformatics software. The automated classification of thousands of such runway geometries will serve as an important input to developing capacity models specific to these smaller airports.

The Effect of Human Resources Management Practices in the Aviation Industry on Employees' Belonging to Work and Turnover Intention: Mediating Role of Perceived Supervisor Support

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Abstract— The importance of human resources in today's enterprise environment is an undeniable fact. The importance of human resources varies according to the dynamics of the industries. Enterprises in the aviation industry; whether it is an airline, airport operator, ground handler, they operate in the same technological environment with similar national and international regulations and similar enterprise models. Therefore, it can be said one of the most important factors that make enterprise successful in the industry is human resources. Human resources practices in enterprises are directly related to employees' motivation, efficiency, loyalty to the organization and turnover intention, consequently enterprise profitability. When the management organization studies on the aviation industry are analyzed, a limited number of studies on human resources practices, more specifically perceived supervisor support, exist. Motivated by this absence, this study focuses on human resource management practices in the aviation industry and the impact of these practices on employees' sense of belonging to work and turnover intention, with the mediating role of perceived supervisor support.

Airspace Design and Trajectory Planning for Urban Air Mobility (UAM) Traffic Management System

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Abstract— Given the gaps between UAM flights and commercial flights and sUAV, neither ATM nor UTM is suitable for UAM flights. Thus, it is critical to develop an air traffic management system for UAM, which enables safe and efficient operations of high-density UAM operations. In the perspective of UAM traffic management system, the two most important aspects that determine the future operation are safety and efficiency. In order to safely organize the traffic and maximize the capacity of urban airspace and flight efficiency, a framework of airspace management for UAM is proposed. In the framework, a low-altitude airspace system (defining flyable space and flight levels) and trajectory deconfliction schemes to resolve the conflicts while minimizing the total flying cost are developed.

Exploration of On-Demand Urban Air Mobility: Network Design, Operation Scheduling and Uncertainty Considerations

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Abstract— Traffic congestion has been one of the leading sustainability issues in transportation around the world. The emerging concept urban air mobility (UAM) is expected to provide a new solution by making use of the three-dimensional airspace to transport passengers and goods in urban areas. Among different constraints and challenges for promotion and commercialization of UAM, we will focus on optimal infrastructures location identification, facility capacities and aircraft fleet size and analyze corresponding transportation system performance as well as impact from uncertainties.