Integrated Demand Management: Annotated Bibliography

October 2020

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NASA Airspace Operations and Safety Program
Air Traffic Management - eXploration (ATM-X) Project, Integrated Demand Management Subproject

Contents

Introduction

NASA has developed the Integrated Demand Management (IDM) concept over a five-year long project lifespan. During that time period, IDM researchers, both at NASA and outside organizations funded by NASA, published approximately forty conference papers and other technical publications associated with the IDM concept. In the following sections, these publications are cited and annotated for their content and their relevance to the IDM concept development.

Rather than organizing the reference list alphabetically, the citations are organized by topic and logical sequence of the work. References are distinguished as either research conducted as direct support for the IDM concept development, or outside research with broader perspectives that could benefit the IDM concept in general. Each reference is identified by "N" for research conducted and published by NASA's in-house researchers, or "O" for research conducted by outside organizations funded by the IDM project.

IDM Concept Development and Evaluation

The IDM concept originated from the desire to effectively integrate, or coordinate, two main traffic flow management capabilities: Traffic Flow Management System (TFMS) and Time-Based Flow Management (TBFM). IDM addressed imbalances between traffic demand and capacity through the coordinated use of the more strategic TFMS and its new Collaborative Trajectory Options Program (CTOP) capability, and the more tactical TBFM with its new capabilities that enable Extended Metering to feed the existing Arrival Metering.

The following section describes research regarding the IDM concept development. The concept was initially developed for clear weather, high traffic density scenarios to Newark airport. It was subsequently expanded for convective weather scenarios where the flights needed to be rerouted around the weather cells and into different meter fixes for the Newark and LaGuardia airports. These papers describe the concept development and evaluation through a series of human-in-the-loop (HITL) simulations. Additional benefits and feasibility analyses were conducted using a fast-time simulation capability.

Clear weather concept, benefits, and feasibility

N1) Smith, N. M., Brasil, C. B., Lee, P. U., Buckley, N., Gabriel, C., Mohlenbrink, C., Omar, F., Parke, B., Speridakos, C., Yoo, H. "Integrated Demand Management: Coordinating Strategic and Tactical Flow Scheduling Operations". AIAA ATIO 2016.

- Summary

  Under IDM operations, TFMS tools were used to pre-condition traffic into the TBFM region, enabling them to better manage delivery to the capacity-constrained destination. The IDM solution leveraged three capabilities, 1) CTOP, 2) Required-Time-of-Arrival (RTA) flight deck capabilities to support conformance to CTOP-planned TBFM entry times, and 3) TBFM metering to manage delivery to the capacity-constrained Newark airport.

- Relevance

  N1 describes the initial clear-weather IDM concept and results from an early proof-of-concept HITL experiment that focused on the Newark traffic problem. The concept was developed and refined with input from the FAA, airline stakeholders, and subject matter experts.

N2) Yoo, H. Brasil, B, Buckley, N., Mohlenbrink, C., Speridakos, C., Parke, B., Hodell, G., Lee, P. U. and Smith N. "Integrated Demand Management: Minimizing Unanticipated Excessive Departure Delay while Ensuring Fairness from a Traffic Management Initiative". AIAA ATIO 2017.

N3) Mohlenbrink, C., Parke, B., Yoo, H. Y., Brasil, C., Buckley, N., Speridakos, C., Muro, F., Hodell, G., Lee, P. U. and Smith, N. M. "Evaluation of Integrated Demand Management looking into Strategic & Tactical Flow Management", ATM 2017.

- Summary

  A follow-up HITL study to N1 was conducted for the clear-weather IDM concept and the results were published in N2 and N3. The follow-up study was better controlled experimentally so that potential benefits of IDM could be assessed more definitively. In this study, two IDM conditions were compared against a baseline condition, one with airborne speed control using Required Time of Arrival (RTA), and a second without RTA. Results indicated that the IDM concept delivered traffic more efficiently by shifting the delays from airborne to ground for both RTA and non-RTA conditions while maintaining a target throughput rate. Assessment of the RTA capability showed that there was an improvement of the scheduled entry times into the TBFM region by using RTA, but without an observable benefit to the overall concept. Results also suggested that with good predictability of airport capacity, excessive TBFM ground delay can be minimized by applying more strategic CTOP delay, increasing predictability for the airline operators. Finally, delays that are frequently imposed on short-haul flights in current day operations due to saturation in the overhead stream, commonly referred to as "double penalty", were significantly reduced. Overall findings indicated that the implementation of an IDM concept under clear weather conditions can improve NAS system performance.

- Relevance

  Evaluation of the initial clear-weather IDM concept in an early proof-of-concept HITL experiment suggested that the concept could show multiple benefits including better predictability and delay distribution, as well as reducing the excessive departure delays for short-haul flights. The outcome of these studies provided the foundation of the clear-weather IDM concept that was later delivered to the FAA.

N4) Evans, T. and Lee, P. "Analyzing Double Delays at Newark Liberty International Airport". AIAA Aviation 2016.

- Summary

  N4 by Evans and Lee (2016) examined the causes of 'double delays' experienced by short-haul flights through an analysis of arrival operations at Newark Liberty International Airport (EWR) from June through August 2010. A deep dive into the data revealed that contributors to double delays include, 1) upstream flights departing before their Expect Departure Clearance Times (EDCTs), 2) differences in the rates used for setting EDCTs and TMA Scheduled Times of Arrival, 3) differences in the expected arrival demand based on EDCTs and the arrival demand entering TMA, and 4) shorter en route times between takeoff and entry into TMA than assumed in the calculation of flight EDCTs. These factors undermine the sequencing and spacing underlying flight EDCTs. Data mining techniques were used to confirm that each of these factors contribute to the occurrence of double delay and/or high internal departure scheduling delay.

- Relevance

  This evaluation was conducted prior to the initial HITL simulation studies (N1-N3) to examine if the excessive departure delays by short-haul flights, reported by the airline stakeholders that we interviewed, were present in the operational data. The analyses in this paper confirmed that a "double-penalty" for short-haul flights was present. These results provided the basis to test if the clear-weather IDM concept could minimize the double-penalty by preconditioning the traffic demand coming into TBFM and allowing short-haul flights to depart without excessive departure delays. The subsequent HITL studies confirmed the hypothesis that IDM could reduce these delays in high sustained traffic demand conditions.

N5) Arneson, H., Evans, T., Li, J., and Wei, M. "Automated Simulation in Support of Integrated Demand Management". AIAA Royal Aeronautical Society Flight Simulation, 2017.

N6) Arneson, H., Evans, A., Kulkarni, D., Lee, P. Li, J. and Wei, M. "Using an Automated Air Traffic Simulation Capability for a Parametric Study in Traffic Flow Management". Aviation 2018.

- Summary

  N5 by Arneson et al. (2017) described an automated simulation capability that was developed to support the IDM concept development. The capability closely mimicked existing HITL capabilities, automating both the human components and collaboration between operational systems, and speeding up the real-time aircraft simulations. Using the capability described in N5, N6 discussed two experiments performed to study 1) the impact of varying levels of airline participation in CTOP via submission of Trajectory Option Sets (TOS) on ground delay and flight time, and 2) the impact of departure uncertainty on TBFM delays. Results of the first study suggest that as CTOP participation increases, average ground delays decrease for all airlines. Results of N6 suggest that excessively high average departure errors and variability in departure error can make the prioritization of TBFM internal departures in TBFM metering and scheduling infeasible while a normal range of departure errors that exist in current day operations can be handled by air traffic controllers to manage the resulting delays.

- Relevance

  N5 and N6 describe the feasibility assessment of clear-weather IDM using a fast-time simulation capability built for IDM. The feasibility analyses of departure errors (N6) provided insights into the magnitude of the departure errors that would make IDM infeasible. The outcome of the results was positive, in that a nominal range of departure errors did not disrupt the IDM concept. The study also showed the magnitude of errors that resulted in airborne delays that would be too large for air traffic controllers to handle.

Convective weather concept, benefits and feasibility

The following three papers describe the IDM concept development for convective weather scenarios, in which the flights were rerouted around weather cells and into different meter fixes for Newark and LaGuardia airports. These papers describe the concept development and evaluation in a series of human-in-the-loop (HITL) simulations.

N7) Smith, N. "Integrated Demand Management - Stakeholder Engagement: Demonstrating Benefits of Submitting Multiple Trajectory Options", ARMD/AOSP Technical Seminar, 2018.

N8) Yoo, H. Brasil, C., Buckley, N., Hodell, G., Kalush, S., Lee, P. U. and Smith N. M. "Impact of Different Trajectory Option Set Participation Levels within an Air Traffic Management Collaborative Trajectory Option Program". AIAA ATIO 2018.

N9) Hodell, G., Smith, N., Brasil, C. Yoo, H., Buckley, N., Kalush, S., Gabriel, C., and Lee. P. U. "Demonstrating Early Adopter Benefits of Submitting Multiple Trajectory Options for Airlines". AIAA AVIATION Forum and Exposition, 2020.

- Summary

  N7 by Smith (2018) was presented at the NASA Aeronautics Research Mission Directorate (ARMD) Technical Seminar in 2018. The presentation describes the overall IDM concept for convective weather scenarios, including a simple use case of flights using TOS to efficiently reroute around convective weather. The presentation also describes HITL studies that evaluated the IDM concept in convective weather. The results of the studies are highlighted in N8 and N9. N8 by Yoo et al. (2018) conducted a parametric study that varied TOS participation levels at Newark airport and described the impact on throughput and delay. N9 by Hodell et al. (2020) was a demonstration of a realistic "what-if" traffic scenario at

LaGuardia airport for airline stakeholder participants that illustrated the impact of different TOS participation levels on individual airlines, as well as the NAS system. The overall results suggested there are both system-wide and individual airline benefits associated with TOS participation. First, there were significant throughput and delay benefits that resulted from partial TOS participation. Second, all airlines benefited when a subset of the airlines submitted TOS, but airlines that submitted TOS benefitted more than those that did not.

- Relevance

Evaluation of the convective-weather IDM concept in an early proof-of-concept HITL experiment suggested that the concept could show throughput and delay benefits to both individual airlines that submit alternative trajectories via TOS, as well as other airlines that do not submit TOS. The outcome from these studies provided the foundation of the convective-weather IDM concept that is being delivered to the FAA.

N10) Yoo, H., Evans, A., Kulkarni, D., Lee, P., Li, J., Wei, M. and Wang, Y. "Benefit Assessment of the Integrated Demand Management Concept for Multiple New York Metroplex Airports". SciTech 2020.

- Summary

N10 assessed the realizable benefits of implementing IDM procedures during clear and convective weather using a fast-time simulation capability and realistic operational traffic and weather data. Benefits of the IDM concept were assessed using a newly developed automated simulation capability called 'Traffic Management Initiative Automated Simulation (TMIAutoSim).' Using TMIAutoSim, IDM was evaluated with realistic traffic across various weather scenarios over three months of traffic and weather data. Results for the clear weather scenarios showed that IDM operations reduced last minute, unanticipated departure delays for short-haul flights within TBFM control boundaries with minimal to no impact on throughput and total delay. For the convective weather scenarios, IDM significantly reduced delays and increased throughput to the destination airports.

- Relevance

The HITL studies in the IDM project demonstrated improved schedule predictability and reduced the "double-penalty" for short-haul flights in clear weather scenarios, and improved throughput and reduced delays in convective-weather scenarios. The results from N10 generalized the potential benefits demonstrated by past HITLs to a wide range of traffic and weather scenarios, thereby confirming that benefits seen in past HITLs could be replicated and revealing the magnitude of the benefits under different traffic and weather conditions.

Impact of TBFM Settings

The IDM concept originated from the desire to integrate, or coordinate, TFMS/CTOP and TBFM. A large amount of research was devoted to understanding and enhancing CTOP capabilities to be used effectively in this concept. However, the project also devoted significant efforts to tune TBFM to effectively handle traffic demand that was pre-conditioned by CTOP. The effort mostly focused on adapting the latest TBFM capabilities, including Extended Metering (XM), rather than developing new capabilities or conducting controlled studies. As a result, fewer publications for TBFM related research were written. However, the following paper represents one controlled TBFM study that was conducted.

N11) Parke, B., Mohlenbrink, C., Brasil, C., Speridakos, C., Yoo, H. Y., Omar, F., Buckley, N., Gabriel, C., Lee, P. U. and Smith, N. M. "Reducing Departure Delays for Adjacent Center Airports using Time Based Flow Management Scheduler: Checkbox ON or OFF?", DASC, 2016.

- Summary

  N11 by Parke et al. (2016) compared two TBFM options that set the prioritization of short-haul departures to be scheduled either in front of the aircraft that are already airborne vs. behind all airborne aircraft entering the TBFM freeze horizon. The results showed that IDM reduces overall delays when short-haul departures are prioritized over airborne flights, but there was a small additional cost in the form of increased airborne delays. Participants recommended a hybrid approach to selectively change the prioritization depending on the traffic situations.

- Relevance

  The assumption that short-haul departures must be prioritized over the airborne flights in TBFM is key for IDM to ensure efficient traffic delivery to the target airport. However, there are potential cultural barriers to changing the prioritization of short-haul departures over airborne flights, as well as the possibility of unmanageable airborne delays resulting from this change. This study quantifies the potential risk and suggests a hybrid approach that combines the best of both prioritization modes.

Impact of RTA Capability

During the first couple of years of the IDM project, the RTA capability was an utilized to control scheduled times into CTOP FCAs for en route aircraft. Using RTAs to better control traffic demand into CTOP FCAs once aircraft were airborne made sense and had the support of airline stakeholders. However, HITL results in N2 and N3 suggested that the RTA capability did not seem to add benefits to the overall throughput and delay metrics. Following paper examines why RTA may not have been beneficial in the HITL experiments.

N12) Yoo, H. Mohlenbrink, C. Brasil, B, Buckley, N., Globus, A. Smith N. and Lee, P. "Required Time of Arrival as a Control Mechanism to Mitigate Uncertainty in Arrival Traffic Demand Management". DASC 2016.

- Summary

  The objective of N12 was to explore the use of Required Time of Arrival (RTA) on the flight deck as a control mechanism on arrival traffic management to improve traffic delivery accuracy by mitigating the effect of traffic demand uncertainty. The uncertainties are caused by various factors, such as departure error due to the difference between scheduled departure and actual take-off time. The Crossing Time (CT) performance (i.e. the difference between target crossing time and actual crossing time) of the RTA for uncertainty mitigation during cruise phase was evaluated under the influence of varying two main factors, wind severity (heavy wind vs. mild wind), and wind error (1 hour, 2 hour, and 5 hour wind forecast errors). The results of the study showed that the delivery accuracy improvement was achieved by assigning RTA, regardless of the influence of wind severity or the wind forecast inaccuracy, but the relative improvements were modest compared to the impact of departure errors.

- Relevance

  RTAs were expected to improve IDM operations, however the HITL evaluation of the concept revealed no appreciable benefits to the final throughput and delay outcomes associated with RTAs. Instead, the results suggested that in nominal conditions, the largest time error was due to departure errors which minimized the impact of RTA improvements.

CTOP Capability Enhancements and Use Cases

The papers referenced so far have described the overall IDM concept development and evaluation process. The following sections describe papers that explored ways to enhance and expand CTOP capabilities by using various algorithms and decision support tools to automatically calculate and generate TOS, Relative Trajectory Costs (RTCs), and other functions.

Trajectory Option Set Generation

One of the key functions in CTOP is the ability for airline operators to submit alternate preferred trajectories for a given flight using the Trajectory Option Set (TOS) mechanism. However, the workload for the airline dispatchers to generate alternate trajectories that are acceptable to the air traffic controllers (ATCs) may be too prohibitive to allow routine usage of CTOP. Therefore, we have researched ways to automatically generate TOS routes using algorithms and historical data.

N13) Arneson, H., Bombelli, A. and Segarra-Torne, A. and Tse, E. "Analysis of convective weather impact on pre-departure routing of flights from Fort Worth Center to New York Center". AIAA Aviation 2017.

O1) Hall W., and Hunter G., "Trajectory Optimization and the Clearable Route Network," AIAA Aviation Forum. 2018.

- Summary

  Reroute options can be automatically generated by clustering historical trajectory data. N13 by Arneson et al. (2017) specified reroute options by examining historical data to determine which reroute options were used under similar weather and traffic conditions using clustering methods. In O1, Hall and Hunter (2018) described the design, construction, and use of Clearable Route Network, an empirically derived database of feasible routes. Clearable Route Network provided a set of options for rerouting tools to search over. O1 also discussed the use of Clearable Route Network in a prototype TOS generator, which could be useful for users responding to CTOP initiatives.

- Relevance

  One of the key barriers for using CTOP effectively the lack of ability to generate available trajectory options easily for airline TOS submissions. Developing effective methods for generating the TOS routes automatically could be a great enabler for implementing CTOP initiatives in the field.

N14) Evans, T. and Lee, P. " Predicting the Operational Acceptance of Route Advisories". AIAA Aviation 2017.

N15) Evans, T., Lee, P. "Using Machine-Learning to Dynamically Generate Operationally Acceptable Strategic Reroute Options". ATM Seminar, 2019.

- Summary

  Once reroute options are identified using clusters of historical data, the route options can be filtered down to ones that are likely to be accepted by the ATCs. In N14, Evans and Lee (2017) developed a predictor of ATC acceptability for reroute advisories. The capability was based on applying data mining techniques to flight plan amendment data reported by the FAA. In N15 by Evans and Lee (2019), the techniques in N14 were expanded further to demonstrate a dynamic approach to automatically generating pre-departure and airborne TOSs that have a high probability of operational acceptance in convectie weather scenarios. The approach used supervised machine learning algorithms then estimated the probability of operational acceptance using predictors trained on historical flight plan amendment data under different traffic and weather scenarios.

- Relevance

  If TOS routes submitted by the airline operators are not operationally acceptable to the ATCs, the routes will be rejected, and the associated benefits will not be realized. These papers leveraged the work by N13 to examine available trajectory options and develop predictors for ATC acceptability of each option. For CTOP to automatically generate available trajectory options for TOS submission, algorithms and methods are needed to 1) generate TOS route candidates and 2) determine which of the route options would be acceptable to the ATCs given the associated weather, traffic, and airspace constraints. The methods described in these papers provided a foundation for how these route options could be generated algorithmically and quickly without many manual interventions.

Relative Trajectory Cost

One of the key attributes of CTOP is the application of TOS, in which participating air carriers can specify their preferences for rerouting options. Preferences are stated via Relative Trajectory Costs (RTCs). For a given flight, the air carrier submits one RTC value for each alternate route in the TOS. The CTOP resource allocation algorithm uses the RTC values to infer which route the air carrier would like the flight to take, given the amount of ground delay it would receive on each of the routes.

N16) Kulkarni, D. "Analysis of Impact of RTC Errors on CTOP Performance". NASA/TM-2018-219943. 2018.

O2) Hoffman, R., Hackney, B., Kicinger, R., Wei, P. and Zhu, G. Ball, M. “Computational Methods for Flight Routing Costs in Collaborative Trajectory Options” Programs AIAA Aviation Forum. 2018.

- Summary

  N16 by Kulkarni (2018) demonstrated how RTC values are assigned in the current concept of operations and how errors in specifying RTC values negatively impacted CTOP performance. Incorrect RTC values could potentially impact overall system delays and throughput significantly. In O2 by Hoffman et al. (2018), the authors suggested flight cost functions and methods that an air carrier could be used to generate the RTCs. The paper articulated this RTC-setting problem as a mathematical formulation, and showed that even for simplified cost functions, the current language that the air carriers are required to use for communicating RTCs leads to suboptimal results. It then proposed a new language that air carriers could use to communicate routing preferences that allows them to more accurately express routing costs and alleviate the need to solve a mathematical problem. Also, it provided an approximation method to solve the RTC-setting problem, which could give satisfactory results while the new language is being considered for adoption.

- Relevance

  These papers explored the impact of RTC values on overall CTOP performance. They outlined the current method of setting RTC values and described potential shortcomings. The outcomes from the studies demonstrated the need for further research and possibly new methods for setting RTC values to improve CTOP performance.

O3) Tereshchenko, I., Hanson, M. Hoffman, R., and Hackney, B. "Relative Trajectory Cost Prediction for Trajectory Option Set Generation in CTOP Simulations" AIAA Aviation Forum. 2018.

O4) Tereshchenko, I. and Hanson, M. "Relative Trajectory Cost Estimation for CTOP Applications Using Multivariate Nonparametric Finite Mixture Logit" ICRAT 2018.

- Summary

  O3 presented statistical models describing the behavior of airlines who submitted alternate flight trajectories under highly dynamic weather conditions. Observational data for airline reroutes were mostly limited to Airspace Flow Program (AFP) initiatives, which have been used since 2006. Using the observed responses made by airlines in AFPs, utility functions of different route options in AFPs with respect to flight time, ground delay, arrival delay, presence of international connections, and non-AFP delays were inferred. The paper described the tradeoff that airlines face between flight time and arrival delay. Finally, the percentage of AFP-controlled flights that do not have an available reroute option due to unobserved restrictions was estimated. O4 extended the modeling approach to infer utility functions of different route options in AFP with respect to flight time and arrival delay using a finite mixture latent class choice model and identified three distinct classes of flights that differ by their response to AFP.

- Relevance

  In exploration of better RTC predictions and estimations, these papers examine RTCs from an academic perspective, with an end goal of providing theoretical models for underlying mechanisms.

Decision Support Tools

Although CTOP is a powerful tool that can significantly enhance traffic flow management in the NAS, the complexity of managing multiple FCAs within a single CTOP, as well as managing multiple interacting CTOPs, provides a significant challenge that is difficult to manage without the help of automation and new decision support tools (DSTs). In the following set of papers, NASA researchers, as well as Mosaic-ATM and Metron with funding and technical support from NASA, developed multiple prototype DSTs and algorithms to support CTOP-based decision making by traffic flow managers. Some tools were designed as enhancements to CTOP to improve FCA management, while others were stand-alone analytic and modeling tools to assess predicted demand, capacity, TOS, FCAs, and other CTOP-related parameters.

N17) Hodell, G., Yoo, H. Brasil, C., Buckley, N., Gabriel, C., Kalush, S., Lee, P. U. and Smith N. M. "Evaluation of Multiple Flow Constrained Area Capacity Setting Methods for Collaborative Trajectory Options Program," DASC 2018.

- Summary

  IDM uses fix balancing to manage air traffic across multiple FCAs with a common downstream constraint as well as constraints at the respective FCA locations. FCA capacity rates can be set manually but generating capacities for multiple interdependent FCAs could potentially over-burden a user. A new enhancement to CTOP called the FCA Balance Algorithm (FBA) was developed at NASA Ames Research Center to improve the process of capacity allocation. The FBA evaluates predicted demand and capacity across multiple FCAs and dynamically generates capacity settings for the FCAs that best meet capacity limits for all identified constraints. When compared to an operation in which traffic flow manager participants manually set FCA capacities into the CTOP interface, the FBA was faster, required less task load, and reduced task difficulty. Participants described many benefits to using the FBA, such as ease of use, precision, and low risk of human input error. Overall, the results suggested that the FBA automation enhancement to CTOP maintains system performance while improving human performance.

- Relevance

  Within the current CTOP, each flight can only meet one FCA constraint if it crosses multiple FCAs during the flight. The FBA enhancement proposes a method to manage demand across multiple FCAs that are upstream and downstream from each other by setting the FCA capacities to meet both upstream and downstream constraints. The FBA also demonstrates the impact of possible automation support for CTOP operations that can reduce the mental burden and task difficulty for human operators.

O5) Kaler C., Hall W., Brinton C., Fernandes A., and Hunter G., "Collaborative Trajectory Options Program within the NAS Flow Advisory Manager," AIAA Aviation Forum, 2018.

O6) Hall W., Capozzi B., Hunter G., M. Klopfenstein, and Klein S., "Development and Analysis of Decision Support for the Collaborative Trajectory Options Program (CTOP)," AIAA Aviation Forum. 2018.

O7) Final Report on Decision Support Tools Mosaic-ATM NRA: Collaborative Trajectory Options Program: Modeling, Decision Support, Optimization and Simulation NRA 2019.

O8) Final Report Mosaic-ATM NRA: Collaborative Trajectory Options Program: Modeling, Decision Support, Optimization and Simulation NRA 2019.

O9) Final Report on Decision Support Capabilities Metron NRA: Collaborative Trajectory Options Program: Modeling, Decision Support, Optimization and Simulation NRA 2019.

- Summary

  O5 by Kaler et al. (2018) described the National Airspace System (NAS) Flow Advisory Manager (NFAM) and its use as a DST spanning tactical and strategic horizons. In tactical flow management, NFAM monitors capacity, demand, flows and restrictions in the NAS, recommending the issuance, amendment or removal of restrictions such as miles-in-trail (MIT). In strategic flow management, NFAM forecasts capacity and demand, recommending strategic restrictions such as CTOP. O6 by Hall et al. (2018) discussed how NFAM was expanded to introduce the CTOP Recommender, an optimization and modeling approach to identify situations in which it is appropriate to use CTOP to manage traffic flows, and to develop effective CTOP parameters to use in those situations. In O7, the above tool capabilities and other functions that Mosaic-ATM has developed was reported in their final report to NASA. O8 described how the DSTs could be used to support CTOP operations. In O9, Metron corporation developed an analogous CTOP modeling and simulation tools, which is included in their final report to NASA.

- Relevance

  Mosaic-ATM and Metron have had a long history with traffic flow management capabilities in general, especially with CTOP. In collaboration with NASA, they have expanded existing DST capabilities to enhance predictive modeling of traffic demand and capacity, as well as recommended FCAs and CTOP setups. These are third-party tools, using readily available data from SWIM, creating a pathway to provide modeling and analytical tools for traffic flow managers to make informed decisions.

CTOP Use Cases

O10) Smith, P., Evans, M., Spencer, A., Hoffman, R., Myers, T., Kicinger, R., Hackney, B. "Integrated Application of the Collaborative Trajectory Options Program" DASC 2019.

- Summary

  O10 by Smith et al. (2019) conducted an interview study to explore novel use cases to support more effective pre-departure reroutes using CTOP to reduce departure delays. The study included discussions of how the CTOP could be integrated with Playbook plays, TBFM, and Pre-Departure Reroute tool (PDRR), along with airport surface management system. The concept and procedures were demonstrated and evaluated using data generated by Metron CTOP DST.

- Relevance

Metron explored several CTOP use cases beyond IDM. These use cases demonstrated potential benefits of using CTOP alone in various phases of flight. The IDM concept requires effective use of both CTOP and TBFM. Adoption of better practices of both tools is predicated on wider use of each tool alone. The use case in this paper demonstrates the possibility of using CTOP more widely in the departure phase of flight.

Demand Modeling and Capacity Rate Settings

A challenge to effective strategic demand / capacity management is the ability to better model the predictive demand and capacity. MIT-LL, Metron, and Mosaic-ATM are organizations that have worked on state-of-the-art predictions for weather impacted capacity and traffic demand. They have used their expertise to explore ways to apply the best predictive capabilities in the field to IDM.

N18) Wang, Y., "Prediction of Weather Impacts on Airport Arrival Meter Fix Capacity," SAE Int. J. Adv. & Curr. Prac. in Mobility 1(2):343-351, 2019.

N19) Kulkarni, D. "Models of Maximum Flows in Airspace Sectors in the Presence of Multiple Constraints". DASC 2017.

O11) Tereshchenko, I. and Hanson, M. "Causal Demand Modelling for Applications in En Route Air Traffic Management." ATM Seminar 2019.

- Summary

  N18 by Wang (2018) introduced a data driven model for predicting airport arrival capacity with 2-8 hour look-ahead forecast data. The proposed approach, based on machine-learning methods, predicts the weather impact at Newark arrival meter fix throughput. Sector forecast coverage is used to envision the weather impact on airport arrival meter fix flow, and the validation is accomplished by using Convective Weather Avoidance Model (CWAM) with 0.5 to 2-hour, and Collaborative Convective Forecast Product (CCFP) with 4 to 8-hour look-ahead forecast data. N19 by Kulkarni (2017) examined different approaches to using historical data to create and validate models of aircraft counts in sectors and other airspace regions in the presence of multiple constraints. O11 by Tereshchenko and Hanson (2019) created empirical models of individual airline decision making to predict airspace demand changes that result from traffic management initiatives and develops cost ratios of airborne vs. ground delays for each airline.

- Relevance

  Using operational traffic data to model realistic target airport and meter fix throughput rates allows the development of ecologically valid demand and capacity limits for a target airport used in the simulation environment. The analyses of traffic data to model airline decision making helps to better predict demand during TMIs.

O12) Jones, J. C., DeLaura, R., Pawlak, M., Underhill, N. and Troxel. S. "Predicting & quantifying risk in airport capacity profile selection for air traffic management" in the 14th USA/Europe Air Traffic Management Research and Development Seminar (ATM2017), Seattle, WA.

O13) Jones, J. C. and DeLaura, R. "Methods for Planning Airport Acceptance Rates," in *17th AIAA Aviation Technology, Integration, and Operations Conference*, Denver, CO, 2017.

O14) Jones, J. C., DeLaura, R., and Glina, Y. "Learning Airspace Flow Rates through Fast-time Simulation.," in 18th AIAA Aviation Technology, Integration, and Operations Conference, Atlanta, GA, 2018.

O15) Jones, J. and Glina, Y. "Estimating Flow Rates in Convective Weather: A Simulation-Based Approach," in *In 13th USA/Europe Air Traffic Management Research and Development Seminar.*, Vienna, Austria, 2019.

- Summary

  O12 by Jones et al. (2017) presented an approach for predicting airport acceptance rates under nominal weather conditions, as well as situations where an airport is affected by non-convective weather related disruptions. The paper also presented a new model for Ground Delay Program (GDP) planning under both demand uncertainty due to pop-up flights and capacity uncertainty. The proposed methodology could be used in a decision support system to allow traffic managers to effectively gauge the appropriate airport acceptance rates when applying the IDM concept to precondition demand for GDPs. O13 extended the methodology proposed by O12 by revising the approach for GDP planning to account for the effects of metering and demand uncertainty due to fleet mix variation. A set of scenarios generated by randomly sampling from a demand distribution was fed into a stochastic integer programming model that sets the airport acceptance rate by controlling both the departure times of flights on the ground and the metering spacing buffer for flights in the air. The paper showed that buffer spacings can have a significant impact on the overall cost of the GDP implemented by the approach and underscored the need for appropriately setting the buffer spacings between flights to optimize the value of implementing GDPs in conjuction with metering. A similar model could be adapted to help set the buffer spacings with TBFM to achieve better alignment with the planned arrival rate. O14 presented an approach for estimating airspace flow rates in terminal airspace in the presence of convective weather. The proposed approach used a fast-time simulation that utilized Lincoln Laboratory's Traffic Flow Impact decision support tool to estimate an upper bound of the en route flow rates in convective weather. The approach can be used to set the rates for an IDM application involving CTOP FCAs, as well as GDPs and AFPs. O15 extended the approach described in O14 by proposing a set of additional methods for accelarating the identification of optimal flow rates in convective weather through simulation. The paper presented four approaches for reducing the number of simulation trials needed to select a near-optimal set of rates at the arrival flows of an airport, 1) a random search, 2) a stochastic integer programming model, 3) a stochastic integer programming model with a random search, and 4) an epsilon greedy algorithm.

- Relevance

  MIT-LL has researched extensively on airport and airspace capacity modeling in response to winds and weather, but more research is needed to improve the overall predictive models. The first two papers extended MIT-LL's earlier work to include demand uncertainty and fleet mix variations and explored ways to present these uncertainties to human operators to provide information on the upper and lower bounds of the predicted capacity. The latter two papers took a different approach with fast-time modeling capability and optimization techniques to model weather constraints and TMIs in response to weather events. These efforts need further exploration to validate the results using operational data but the approach has been promising.

O16) Hoffman, R., Hackney, B., Wei, P. and Zhu, G. "Enhanced Stochastic Optimization Model (ESOM) for Setting Flow Rates in a Collaborative Trajectory Options Program (CTOP)." AIAA Aviation Forum. 2018

O17) Zhu, G., Wei, P., Hoffman, R., Hackney, B. "Aggregate Multi-commodity Stochastic Models for Collaborative Trajectory Options Program (CTOP)" ICRAT 2018.

O18) Zhu, G., Wei, P., Hoffman, R., Hackney, B. "Centralized Disaggregate Stochastic Allocation Models for Collaborative Trajectory Options Program (CTOP)" DASC 2018.

O19) Zhu, G., Wei, P., Hoffman, R., Hackney, B. "Saturation Technique for Optimizing Planned Acceptance Rates in Traffic Management Initiatives" IEEE Intelligent Transportation Systems 2018.

O20) Zhu, G., Wei, P., Hoffman, R., Hackney, B. "Risk-hedged Multistage Stochastic Programming Model for Setting Flow Rates in Collaborative Trajectory Options Programs (CTOP)" AIAA Science and Technology Forum and Exposition 2019.

- Summary

  O16 by Hoffman et al. (2018) described Enhanced Stochastic Optimization Model (ESOM), a model for setting flow rates during a CTOP TMI. Using CTOP to restrict traffic flow through FCAs is challenging due to the stochastic nature of weather and traffic demand predictions. ESOM provides traffic managers with time-varying flow rates at the FCAs that minimize total expected delay costs, taking into account forecasted traffic demand, airline routing preferences, and forecasted probabilistic weather. O17 by Zhu et al. (2018) proposed three stochastic programming models, 1) a two-stage static model in which ground delays are assigned at the beginning of the planning horizon, 2) a semi-dynamic model in which ground delays are assigned at scheduled departure times to take advantage of the latest capacity and scenario tree structure information, and 3) a dynamic model in which a flight can be ground-delayed multiple times by exploiting not only the scenario tree structure, but also en route time information. The results showed the superiority of stochastic solutions over deterministic ones, and the dynamic model performed better than the semi-dynamic one. In O18, Zhu et al. (2018) extended their prior work to create disaggregate models that determine different routes and delays for each flight to find the best system performance that can be achieved in terms of total route and delay costs. Three disaggregate stochastic programming models, including one static model and two dynamic models, were proposed and evaluated. Using disaggregate models can address questions, such as the efficacy of CTOP when some flight operations submit TOS while others do not. The shortcoming of the disaggregate vs. aggregate model is increase in computation time. In O19, Zhu et al. (2018) described how current traffic management initiatives (TMIs) sets the Planned Acceptance Rates (PARs) for the constrained airspace resources, then ran resource allocation algorithms to assign ground delays and/or reroutes to affected flights. This paper explored if optimal PARs exist that depend only on the physical airport or airspace capacity but not the demand. The paper showed that this conjecture held true in the deterministic capacity case but not in the general stochastic case with uncertainty in demand prediction. The paper proposed a new heuristic technique called "saturation technique" that can generate robust PAR policy with demand uncertainty. In O20, Zhu et al. (2019) proposed a multistage stochastic model based on ESOM and tested its performance on a realistic CTOP use case. This paper discussed the variance and risk issues in air traffic flow management applications and showed how to hedge system performance with variance or risk measures in the stochastic models.

- Relevance

Metron, in collaboration with Iowa State University, has explored improvements to demand and capacity modeling using various mathematical techniques. In setting capacity limits to airspace or airport constraints in CTOP and other TMIs, the demand and capacity predictions are very challenging due to the stochastic nature of their uncertainties. In these papers, Hoffman, Zhu, and their colleagues, developed and evaluated several different stochastic models for setting CTOP FCA rates in realistic CTOP use cases. The problem is difficult and more research is needed but developing new stochastic models for better demand predictions is important for more accurate rate settings that are vital to IDM and other future TMIs.