

Operationalization of Norms in Aircraft Approach/Departure Decision Support

Laura SAVIČIENĖ

Faculty of Mathematics and Informatics, Vilnius University, Lithuania

Abstract. This work is focused on norm operationalization in aviation domain. The investigated paradigm can be described as: from legal norms to technical rules in the artifact. Normative requirements (norms) for the aircraft trajectories are extracted from the flight rules and airport procedures, and operationalized in a decision support system (DSS). The decision support is based on evaluation of risk to violate the normative requirement. The following risks are modeled: trajectories' conformance with the flight rules, safe distance between aircraft, wake turbulence separation and avoidance of volcanic ash. The DSS is for the air traffic controller (not pilot) and must respond in real time. It provides surveillance, evaluates and recommends, whereas the human controller takes a decision.

Keywords. Air traffic control, instrument approach procedure, SKY-Scanner, real-time decision support, norm operationalization, risk model

Introduction

This research is focused on the operationalization of normative rules in aviation domain (air traffic control, ATC). A proposed paradigm can be called “from legal norms to technical rules in the artifact”. Normative requirements are extracted from the flight rules, maps and approach/departure procedure charts. An example of a normative rule is “Keep 3 degrees descent angle while landing and hold restrictions of the altitude and geography depicted in the aerodrome chart”.

Normative rules are modeled in order to provide decision support in terms of norm violation risk. A decision support system (DSS) provides surveillance, evaluates and recommends, whereas the human controller takes a decision. The final decision is done by human controller. This approach accords with SESAR (Single European Sky Air Traffic Management Research) target concept, which states that humans should constitute the core of the future air traffic management (ATM) operations [1].

The decision support is based on lidar (laser radar – LIght Detection And Ranging) and radar data fusion. It relies on the assumption that the precise aircraft position data (with error margin of meters, not hundreds of meters) from the lidar will facilitate detection of risks that are not possible to detect using only radar data.

The research goal is to develop a conception for operationalization of the aircraft approach/departure norms in a decision support system, taking into consideration the use of lidar for aircraft tracking. The goal is broken down into these tasks: (1) modeling norm violation risk in the airport traffic zone (ATZ), (2) modeling radar and lidar data fusion, and (3) development of a prototype decision support system.

1. Domain Analysis and Related Works

The norm operationalization is investigated in the context of the ATM paradigm developed in the EU FP6 SKY-Scanner project¹: expanding surveillance and the ATC control to the approach/departure phases by using radar and lidar data fusion and decision support in terms of norm violation risk. Only norms that can be checked using the lidar-radar fused data (position and speed) are examined and included in the operationalization conception.

The project was aimed at developing a laser system to detect and track aircraft up to at least 6 nautical miles (NM) from the aerodrome traffic zone (ATZ) barycenter [2]. The project objectives include aircraft collision probability model (ACPM) based on radar data and laser tracking data fusion and a prototype decision support system (Figure 1) for aircraft approach and departure [3]. The current research builds on the constraint models developed by the SKY-Scanner project, and aims to abstract them into a unified norm operationalization conception, also further refining the DSS prototype and visualization models.

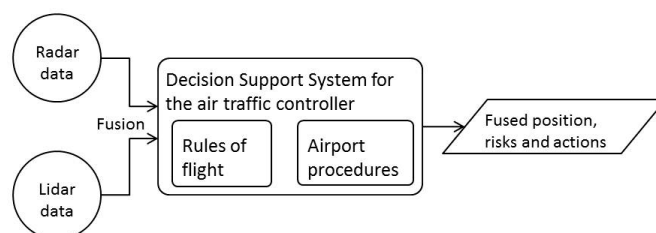


Figure 1. DSS for aircraft approach and departure

Several important assumptions stem from the SKY-Scanner project and thus form the boundaries of the current research:

1) ATC activities require a real-time response from the DSS. A study of time-critical decision support models provided in [4] concludes that the naturalistic decision support approach should be used and highlights the need to filter out the most important information for the user.

2) The emphasis is on informing the controller, who then makes a final decision on the actions. This accords with the results of studies of human-automation interaction: high levels of automation are not advisable in systems dealing with dynamic environments with many external and changing constraints [5].

Normative rules for aircraft approach/departure from International Civil Aviation Organization (ICAO) flight rule documents [6, 7, 8, 9] are grouped into four categories: ATC separation rules, airport procedures, wake turbulence separation rules, and volcanic ash rules. Each airport has a different set of approach/departure procedures. Approach/departure procedure constitutes a complex object and contains a number of interrelated norms that define the ought-to-be trajectory with additional constraints.

Current aviation-related decision support systems do not model norms support systems comprehensively, but there is some research in that direction. One type of decision support – Conflict Detection and Resolution (CD&R) systems. The structure of the

¹ “Development of an Innovative LIDAR Technology for New Generation ATM Paradigms” (SKY-Scanner), 2007-2010, <http://www.sky-scanner.it/>

CD&R process [10] is designed for the aircraft separation conflicts, but can be expanded to cover other normative rules. Conformance alerting philosophy is suitable for the approach/departure norm supervising scenario: alert is issued when the aircraft is close to violating the norm.

2D visualizations in the ATM domain are no longer sufficient, and the modern 3D visualizations have drawbacks [3, 11]. By augmenting the 3D screens with auxiliary 2D elements it is possible to visualize the ought-to-be trajectory requirements: a relationship between horizontal position, distance and altitude.

2. Norm Conceptualization and Risk Modeling

The approach/departure decision support focuses on detecting violations of the flight rules for the aircraft. We conceptualize each norm as a triplet of a norm factor, norm pattern, and the expected value. Norm factor represents a quantitative trajectory attribute of one or several aircraft. Only factors that can be computed from the DSS input data are considered in this conception. Expected value, v_N , is the value defined in the text of the normative requirement. Norm pattern ($\leq v_N$, $\geq v_N$, or $=v_N$) explicates how to interpret the expected value. For example, norm pattern $\geq v_N$ means the actual value of the factor should be greater than the expected value.

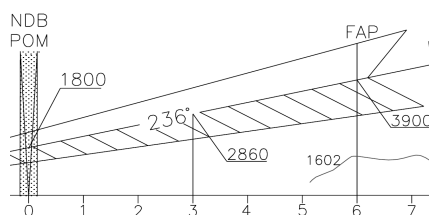


Figure 2. Examples of norms in the approach chart [12]

Patterns $\leq v_N$ and $\geq v_N$ constitute limit-based norms, and pattern $=v_N$ – deviation-based norms. Example of the limit-based norm (Figure 2): “height minimum is 3900 ft. at 6 nautical miles from distance measurement equipment (DME)”. An example of the deviation-based norm could be the track (the direction that the aircraft should follow), which is expressed in degrees from North, e.g. 236° [12].

The defined operationalization structure translates each norm into a risk definition in the DSS. The use of discrete risk levels abstracts from unnecessary details. In the DSS risk levels are defined based on the likelihood of violating the norm. A separate risk definition is formulated for each normative requirement. An individual risk evaluation maps the observed factor value to a discrete scale of risk levels.

The L-level risk concept is characterized by five elements (Figure 3): (1) risk factor (e.g. ‘altitude’ or ‘indicated airspeed’); (2) risk type (‘limit’ or ‘deviation’); (3) the norm pattern ($\geq v_N$, $\leq v_N$, $=v_N$); (4) expected value of the factor; (5) a set of thresholds for risk levels. If the risk type is ‘limit’, a set of thresholds consists of L-1 constants, defined in the terms of factor measurement units. If risk type is ‘deviation’, a set of thresholds consists of L-1 pairs of constants, defining allowable deviation levels.

For convenience of visual representation of the risk definition, a piece-wise linear risk-magnitude function is used, which maps the observed factor value to a number

from the interval [0, 1]. Zero means the lowest risk, 1 means the highest risk level, and values in the interval (0, 1) mean intermediate risk levels.

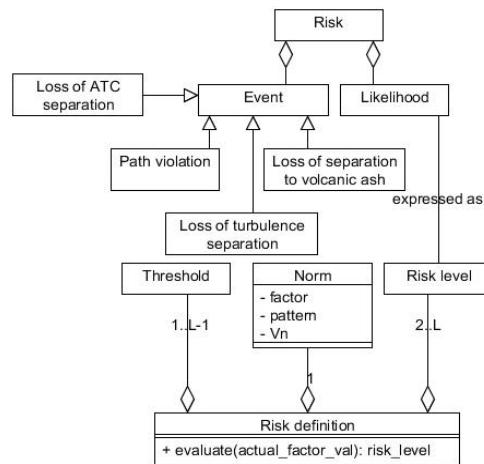


Figure 3. Risk definition

As an example we consider the norm “altitude 3900 ft at 6 DME” (Figure 2). In deviation-based risk evaluation we consider not the expected value itself, but the expected deviation ($d_N = 0$). There are 4 risk levels and 3 pairs of thresholds. The corresponding risk definition is: (1) factor: 'altitude'; (2) type: 'deviation'; (3) pattern: ‘= v_N ’; (4) expected value: 3900 ft at 6 DME (deviation 0); (5) thresholds: $d_{n0} = -0.5$, $d_{p0} = 2$, $d_{n1} = -1$, $d_{p1} = 3.5$, $d_{n2} = -1.5$, $d_{p2} = 5$; (see Figure 4) The threshold values in this example are chosen only for demonstration purposes.

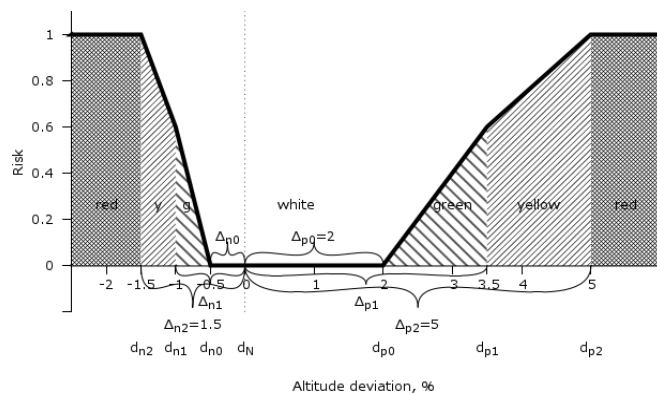


Figure 4. Altitude violation risk-magnitude function

Each risk is represented in a separate indicator on the DSS control panel (Figure 5). The risk level is shown with color and the number of colored slots on the indicator.



Figure 5. Risk indicators

3. DSS Prototype

The DSS prototype embodies the norm operationalization conception proposed in the previous chapter. It illustrates the modeling of several norms for the approaching aircraft, and provides a real-time simulation of the suggested decision support scenario.

Advanced ATC visualization ideas are adapted to context of approach/departure decision support. The DSS prototype provides a laboratory implementation, which advances technology readiness level (TRL [13]) 1-2 ideas to level 3. The aim was to visualize airport procedure requirements (the ought-to-be trajectory), so that the controller could visually estimate possible violation without looking at the control panel. Two visualizations are developed: 2D-in-3D prototype and pure-3D prototype. Both visualizations embed auxiliary 2D elements into the main 3D view of the observed airspace.

2D-in-3D prototype uses generalized terrain model and embeds 2D semi-transparent projection walls (Figure 6). Aircraft are represented with spheres. The ought-to-be trajectory is projected on the wall (white line), as well as the aircraft position (black dot). If the dot is not on the line, there is a path violation.

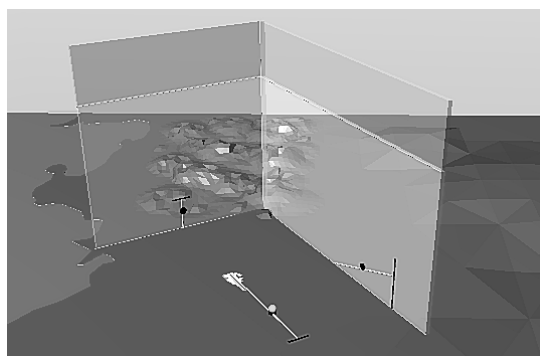


Figure 6. 2D-in-3D visualization

The pure-3D prototype uses photographic terrain (high resolution satellite images) and represent the aircraft as full 3D models (Figure 7). 2D rings enclose the ought-to-be trajectory (plus some allowable deviation). The violation is detected when the aircraft indicator is outside the rings. This approach is less strict than the 2D-in-3D.

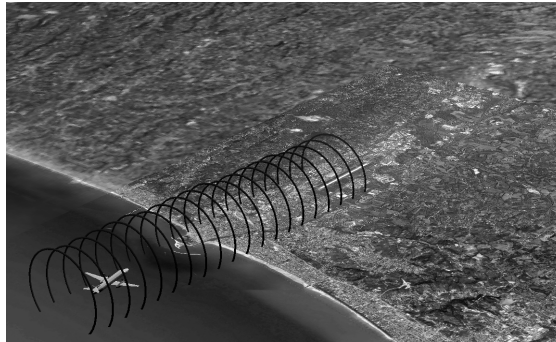


Figure 7. Pure-3D visualization

Human operator needs are satisfied in the following way: 3D display improves situation awareness as the airport environment is depicted with essential terrain obstacles; 2D elements (walls, ring) that relate the aircraft position to the airport procedures reduce cognitive workload.

4. Conclusions

The following conclusions are drawn:

1. The proposed norm operationalization conception enables to represent a subset of aircraft approach/departure normative rules in a decision support system for the air traffic controller. The referred subset is defined as the norms concerning aircraft trajectories, or simply, geometrical norms.
2. The prototype decision support system provides an integrated solution to facilitating the controller: risk indicators automate detection of the possible norm violations, 2D-in-3D visualizations help comprehend conformance to the approach/departure procedure. The controller's work improvement is not quantifiable because the research addresses the needs that will only become relevant in the future.
3. Analysis of the prototype development process demonstrates that the following steps are needed to operationalize a norm: (a) setting up risk levels and colors, (b) creating risk definitions (consisting of norm factor, expected value, type, pattern and a set of thresholds), and (c) setting up risk indicators. The process cannot be fully automated, as each norm factor is unique, and analysis has to be performed for each new kind of norm to be operationalized.

References

- [1] *The ATM Target Concept*, SESAR Consortium, Toulouse, France, Sept. 2007.
- [2] M. Salerno, D. Rondinella, M. V. Crispino, G. Costantini, M. Carota, and D. Casali, SKY-Scanner: a new paradigm for air traffic management, *International Journal Of Circuits, Systems And Signal Processing* 2(2) (2008), 131-139.
- [3] S. Rozzi, A. Boccalatte, P. Amaldi, B. Fields, M. Loomes, and W. Wong, *Innovation and Consolidation Report*, Middlesex University, London, UK, 2007.
- [4] K. Lapin, SKY-Scanner: time-critical decision support system surveilling aircraft landing and take-off. In: *Proceedings of 9th Innovative Research Workshop & Exhibition*, Brétigny-sur-Orge, France, 2010, 19-26.

- [5] R. Parasuraman and C. D. Wickens, Humans: still vital after all these years of automation. *Human Factors* **50**(3) (2008), 511-520.
- [6] *Procedures for Air Navigation Services - Air Traffic Management*. Fifteenth ed. International Civil Aviation Organization, ICAO, 2007.
- [7] *Aeronautical Charts. Annex 4 to the Convention on International Civil Aviation*. 11th ed. International Civil Aviation Organization, ICAO, 2009.
- [8] *Procedures for Air Navigation Services – Aircraft Operations*, vol. 1 and 2. International Civil Aviation Organization, ICAO, 2006.
- [9] *Manual on Volcanic Ash, Radioactive Material and Toxic Chemical Clouds*. Second ed. International Civil Aviation Organization, ICAO, 2007.
- [10] J. K. Kuchar and L. C. Yang, A review of conflict detection and resolution modeling methods, *IEEE Transactions on Intelligent Transportation Systems* **1**(4) (2000), 179-189.
- [11] W. B. Wong, S. Rozzi, A. Boccalatte, S. Gaukrodger, P. Amaldi, B. Fields, M. Loomes, and P. Martin, 3D-in-2D displays for ATC. In: *6th EUROCONTROL Innovative Research Workshop*, Bretigny, France, 2007, 47-62.
- [12] *Vatla Dispatching*, IAC No. 350, Instrument Approach Chart, 2003.
- [13] J. C. Mankins, *Technology Readiness Levels*, NASA, Office of Space Access and Technology, Advanced Concepts Office, April 1995.