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Predictability impacts of airport surface automation

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ABSTRACT

Past evaluations of airport surface operations automation technologies have focused on capacity utilization, delay mitigation and fuel efficiency impacts. Predictability, while recognized as an important operational performance goal, has received little attention. One reason could be that applicable predictability metrics have not been developed in the context of airport surface operations management. This research fills the gap by proposing metrics for predictability performance evaluation. Using results from a SARDA human-in-the-loop simulation conducted at NASA Ames' Future Flight Central, we present a comprehensive assessment of the predictability impacts of airport surface automation. A wide range of the impacts is considered, which includes variability in taxi-out time, predictability of take-off time and take-off sequence, entropy of the airfield state, and perceived predictability from users.

1. Introduction

The Next Generation Air Transportation System (NextGen) is being enabled by a shift to smarter, satellite-based and digital technologies that, combined with new procedures, promise to make air travel more convenient, predictable and environmentally friendly (Medina et al., 2010; Federal Aviation Administration, 2013). Improving airport surface operations is recognized as a key element of NextGen because airfield resources are intensively utilized and ground operations play a fundamental role in implementing gate-to-gate trajectory management technologies. Recognizing the importance of airport surface operations, considerable research effort has been devoted to modernizing airfield operations under NextGen. One main cause of inefficiency in this domain is that, under high traffic conditions, multiple aircraft pushback at around the same time and contest for the runway. This leads to many aircraft taxiing to the runway simultaneously and long runway queues as well as congestion effects on taxiways. One means of addressing this problem that has received much attention in the literature is departure metering.

Multiple technologies have been proposed for departure metering (Malik et al., 2010; Brinton et al., 2011; Nakahara et al., 2011; Simaiakis et al., 2011; Simaiakis, 2013). One approach to departure metering is called N-control, which maintains efficient runway utilization while controlling the queue length by metering pushbacks from the gate (Simaiakis et al., 2011; Simaiakis, 2013). In this technology, the suggested pushback rates are only provided to ground controllers whose primary responsibility is to maintain separation and a smooth flow of aircraft on taxiways. Another method, called Collaborative Departure Queue Management (CDQM), manages the length of the runway queue by assigning flight operators taxiway entry

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slots according to ration-by-schedule principle (Brinton et al., 2011). A method similar to CDQM was developed and implemented at the John F. Kennedy International Airport in New York, and is currently under use (Nakahara et al., 2011). Both the N-control and CDQM methods manage runway queue length by controlling operations in the ramp only. Another surface traffic management system, known as the Spot And Runway Departure Advisor (SARDA), extends auto assistance to other areas: taxiway, queue area and runway. Specifically, SARDA provides advisories on actual pushback time, sequence and timing for spot release, sequence for take-offs, and sequence for active runway crossings (Jung et al., 2010; Malik et al., 2010; Gupta et al., 2012; Hoang et al., 2011). Moreover, the SARDA advisories are provided to both ground and local controllers, where the local controller is responsible for safe and efficient runway operations, including take-off, landing and runway crossings.

In the existing literature on performance evaluation of these automation technologies, attention has been focused on throughput increases, delay reductions, and fuel savings (Simaiakis et al., 2011; Nakahara and Reynolds, 2012; Gupta et al., 2013). Predictability, while recognized as an important performance goal by various stakeholders (ATSPFG, 1999; Bradford et al., 2000), has received little or no attention. In the context of airport surface operations, high predictability allows a multitude of direct benefits, such as reductions in communication and controller workload. Given that taxi-out time is the largest source of variability in total block time (Hao and Hansen, 2013), high predictability may help make a more accurate prediction on flight arrival time. Besides the operational benefits, high predictability may also deliver direct financial and environmental benefits by enabling greater use of single engine taxiing. If pilots know the departure clearance time in advance with certainty, they can use a single engine while taxiing until the time when they should start the second engine for take-off. With less predictability about departure clearance time, they must start the second engine earlier than necessary to make sure they are not caught short when cleared for departure, which consumes more fuel and generates more emissions. Given the importance of predictability and its potential benefits, it is desirable to understand how automation technologies affect operational predictability performance. However, the lack of predictability metrics hampers our ability to assess the predictability impact of automation tools.

To fill this gap and provide a new perspective on evaluating the impacts of automation technologies on airport surface operational performance, this study seeks to define and quantify predictability in the context of airport surface operation management. Using SARDA simulation data, we present a comprehensive assessment of the predictability impacts of airport surface automation. A wide range of such impacts is considered, which includes variability in taxi-out time, predictability of take-off time and take-off sequence, entropy of the airfield state, and perceived predictability from users. With the necessary data, the proposed predictability analysis could be repeated for other surface traffic automation tools and for other airports.

While this paper is mainly a scientific study based on the results of an automation tool simulation experiment, it is also an exploration of the meaning of "predictability" in the airport surface context, and more broadly in Air Traffic Management (ATM). There is wide consensus in the aviation community that predictability is an important performance goal for ATM (Bradford et al., 2000; Liu and Hansen, 2013). International Civil Aviation Organization (ICAO, 2005) emphasizes that predictability is essential to airspace users as they develop and operate their schedules. Service providers such as the Federal Aviation Administration (FAA) identify predictability as a key performance goal (Knorr et al., 2000; FAA, 2011). Anecdotally, flight operators respond very positively to the idea of improving predictability. However, the definition of predictability is elusive to the community. Thus, a contribution of this paper is to elucidate what predictability means, as well as how it might be measured, in the context of airport surface management. Moreover, through such efforts, claims of predictability improvements can become clear statements subject to rigorous analysis, rather than vague and unverifiable sentiments.

The remainder of the paper is organized as follows. In Section 2, the current related literature on predictability is summarized. In Section 3, the SARDA system and the experimental setup of the human-in-the-loop simulation are introduced, and the methods that are used to analyze SARDA predictability impacts are briefly discussed. In Sections 4–6, predictability performance is assessed and compared for the baseline case—without SARDA—and the advisory case—with SARDA—from multiple perspectives. Finally, the paper is concluded in Section 7.

2. Related literature on predictability

The majority of the literature on predictability in transportation assesses predictability by measuring variability in the 'travel time', which could be a road trip travel time, gate-to-gate time of a given flight, or taxi-out time of an aircraft on the airfield. There is a variety of variability measurements: difference between actual trip time and scheduled trip time (Kho et al., 2005), standard deviation of travel time distribution (Bates et al., 2001; Lomax et al., 2003; Ettema and Timmermans, 2006; Riikka and Paavilainen, 2010), standard deviation over the mean travel time (Taylor, 1982; Lomax et al., 2003), difference between travel time percentiles (Ettema and Timmermans, 2006; Gulding et al., 2009; Li and Rose, 2011) and difference in expected and actual travel delays (Cohen and Southworth, 1999; Liu and Hansen, 2014). In the context of advanced traveler information system, a few studies have examined the impact of intelligent transportation system on trip reliability, where similar predictability measures are used: standard deviation in travel time (Levinson, 2003) and difference between actual trip time and scheduled trip time (Kristof et al., 2005). None of these studies explicitly consider the temporal aspect of predictability. In contrast, Ball et al. (2000) find that error in predicting flight departure time decreases as the departure of a flight approaches. They proposed a metric termed integrated predictive error that takes this effect into account.