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Estimating fuel burn impacts of taxi-out delay with implications for gate-hold benefits

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A B S T R A C T

The aviation community is actively investigating initiatives to reduce aircraft fuel consumption from surface operations, as surface management strategies may face fewer implementation barriers compared with en route strategies. One fuel-saving initiative for the air transportation system is the possibility of holding aircraft at the gate, or the spot, until the point at which they can taxi unimpeded to the departure runway. The extent to which gate holding strategies have financial and environmental benefits hinges on the quantity of fuel that is consumed during surface operations. A pilot of an aircraft may execute the taxi procedure on a single engine or utilize different engine thrust rates during taxi because of a delay. In the following study, we use airline fuel consumption data to estimate aircraft taxi fuel consumption rates during the "unimpeded" and "delayed" portions of taxi time. We find that the fuel consumption attributed to a minute of taxi-out delay is less than that attributed to minute of unimpeded taxi time; for some aircraft types, the fuel consumption rate for a minute of taxi delay is half of that for unimpeded taxi. It is therefore not appropriate, even for rough calculations, to apply nominal taxi fuel consumption rates to convert delayed taxi-out time into fuel burn. On average we find that eliminating taxi delay would reduce overall flight fuel consumption by about 1%. When we consider the savings on an airport-by-airport basis, we find that for some airports the potential reduction from reducing taxi delay is as much as 2%.

1. Introduction

Reducing fuel consumption is a unifying goal across the aviation industry. Airlines can save cost and reduce their environmental impact by reducing their fuel consumption and also manage the risks related to fuel price fluctuations and uncertainty surrounding future environmental policy. The aviation community is considering many initiatives in the form of policy, operational changes, and technology deployment. One fuel-saving initiative for the air transportation system is the possibility of holding aircraft at the gate, or the spot, until they can taxi virtually unimpeded to the departure runway. The extent to which gate holding strategies have financial and environmental benefits hinges on the quantity of fuel that is consumed during surface operations. Estimating the possible fuel savings from gate holding is, however, a challenging task as the rate at which aircraft consume fuel in taxi is not well understood. Aircraft may execute all or a portion of the taxi procedure on a single engine or utilize different engine thrust settings; these fuel saving strategies might be employed generally

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during taxi or employed during a taxi delay. In the following study, we utilize airline fuel consumption data to estimate the relationship between taxi fuel consumption and taxi time for different aircraft types. This enables us to estimate the reduction in fuel consumption from adopting gate holding at airports throughout the National Airspace System (NAS), by assuming that this would essentially eliminate taxi delay.

Delays on the ground are growing as a function of rising airport demands and airline mergers (Balakrishna et al., 2008; Ryerson and Kim, 2013); as a result, fuel consumed from aircraft surface operations is growing. Saving fuel can improve the financial health of airlines, as fuel costs grew from 14% of operating costs to 33% of operating costs from 2003 to 2012 (International Air Transport Association, 2012). Reducing fuel consumption also provides airlines with financial stability, as airlines are better able to plan for the future when their dependency on a resource with a wildly fluctuating price is reduced (Ryerson and Hansen, 2010). Finally, reducing fuel consumption has significant environmental benefits, as ground-based environmental emissions can be particularly harmful. While greenhouse gas emissions have an increased warming effect when emitted at altitude, local pollutants such as CO, NOx, and PM have their strongest impact on human health when emitted on the ground (Chester and Horvath, 2009; Williams et al., 2002). The cost of the human health and agricultural impact for a single flight on a large aircraft at an airport in a major city like Los Angeles, New York, or Chicago has been estimated to be $2500 or higher (Nahlik et al., 2016). The work of Schlenker and Walker (2011) links daily variations airport taxi time to contemporaneous health outcomes in the region surrounding the airport.

The cost and environmental impacts of taxi fuel consumption, along with the relative simplicity of ground-based versus air-based initiatives, render advancements in efficient surface operations attractive for both airlines and Air Navigation Service Providers. However, there is considerable uncertainty regarding the quantity of fuel that airlines consume during taxi. Uncertainty regarding taxi fuel consumption rates could lead to inaccurate fuel savings benefit pool estimates for ground-based initiatives, causing airports, governments, and Air Navigation Service Providers (ANSPs) (such as the Federal Aviation Administration (FAA)) to make suboptimal investments. To address this problem, we use airline fuel consumption data to estimate the different taxi fuel consumption rates for unimpeded taxi time and taxi delay for different aircraft types. We develop statistical models of fuel consumption based on actual airline data to isolate the effects of both categories of taxi time on fuel burn. We find that the taxi fuel consumption rate during delay is smaller – sometimes significantly smaller – than the rate for unimpeded taxi. We then employ our model to estimate a benefit pool for the reductions of taxi delay that would result from implementing gate holding, on a per flight and a per airport basis.

2. Background on surface operations and fuel consumption

There is a growing body of research on procedures and technologies to reduce the time aircraft spend in surface operations and to reduce the fuel consumed during this time. Jung et al. (2011) investigate the potential of a surface management strategy which provides times and sequences for flights being released into the aircraft movement area. The study finds that, during periods of high traffic, taxi fuel consumption from decreased movement and time was reduced up to 38%. Simaiakis et al. (2014) investigate the potential of metering gate pushbacks to prevent aircraft from queuing on the taxiways. In a field test at Boston Logan International Airport, the authors found that they were able to reduce fuel consumption from surface operations significantly. In estimating the fuel benefit of surface management strategies, both studies utilize the International Civil Aviation Organization (ICAO) Emissions Databank, a database capturing fuel flow rates for all engine types at different thrust settings, to calculate the taxi fuel consumption and savings. Simaiakis et al. (2014) assume each aircraft uses two engines at a constant thrust during taxi to calculate fuel consumption during taxi. Jung et al. (2011), employing a model built by Nikoleris et al. (2011), assume each aircraft runs two engines during taxi at a thrust setting that varies with aircraft movement states (stopping, turning, accelerating, moving forward at a constant speed, or braking). This research on surface management strategies showcases how gate holding could reduce fuel consumption.

There is a growing movement among flight operators to employ fuel-saving strategies on the surface. One such practice is aircraft taxiing on a single engine. A report from ICAO (2012) noted that the single engine taxi procedure should be used whenever possible, because of the large potential for fuel savings (Sowden, 2002). The American Airlines (AA) FUEL SMART program suggests a company guideline of using one engine during taxi when safe and operationally feasible. American Airlines claims that the procedure saves more than two million gallons of jet fuel and eliminates about 42 million pounds of CO_2 emissions annually (American Airlines, 2014). Similar results are found in a study by Spanair which quantified the effects of single engine taxi on carbon dioxide (CO_2) emissions by comparing it with two-engine taxi (Enviro.aero., 2008).

Despite the fuel savings potential of taxiing on a single engine, such a procedure cannot always be executed as it is sensitive to numerous factors. Larger aircraft types, and aircraft with greater take-off weights, may have more difficulties taxiing on one engine because additional thrust may be necessary to propel the aircraft. The blast from turning on an engine can also be significant, and a larger aircraft must take precautions to avoid harming the trailing aircraft when starting up an engine on the taxiway (Guo et al., 2014). Because the incidence of single engine taxi is unknown, benefit pools from gate holding are not completely understood. In the absence of understanding the incidence of single engine taxi, researchers have considered the incidence of single engine taxi parametrically or avoided the topic all together. For example, Kumar et al. (2008) compare single engine taxi procedures to procedures with both engines running at two case study airports to compute upper and lower bounds of taxi fuel consumption. Citing uncertainty about single engine taxi procedures and the absence of airline data