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Downstream impact of flight rerouting

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ABSTRACT

In this paper, we estimate the impacts of post-departure flight rerouting on times of arrival at destination airports. There are mainly two types of post-departure reroutes – opportunistic reroutes (distance-saving reroutes) and reactive reroutes (distance-increasing reroutes). To the best of our knowledge, the downstream impact of rerouting has received little attention in the existing literature; however, the benefit/harm of both kinds of reroutes might be exaggerated if their system impact is not taken into account. Thus, we developed a framework for evaluating the net effect of applying a reroute at the system level by analyzing its impact on arrival times at the destination of the rerouted flight.

We focus on reroutes that affect en route flight time by 5 min or more. Adopting a "multiplier" concept that was proposed in previous research and making use of two-year (2013–2014) flight level data at the 34 main airports in the US, we analyze how the en route time change affects cumulative arrival throughput at the destination airport, and the associated time savings or time costs. We find that these impacts of reroutes differ remarkably at different airports, and identify airports where the arrival time impact is highly correlated with the en route time change as well as those for which this correlation is weak. In addition, we compare downstream impacts among different types of reroutes. Finally, we study cases with very high multipliers in detail in order to identify these circumstances under which they occur.

1. Introduction

It is common for flights to deviate from their initial planned routes. Such a change may be necessary if the original route traverses a region that should be avoided for some reason, such as poor weather conditions, sector congestion, or a potential conflict with another flight. Here we refer to such cases as reactive reroutes (RR). Alternatively, lower traffic than expected, improved weather conditions, and reduced uncertainty may enable a more direct path than the one defined in the flight plan, thereby saving flight time and fuel. We term these opportunistic reroutes (OR). The route may be changed prior to departure or after the flight is underway. The focus of this study is post-departure reroutes.

A number of research and development programs have been geared toward employing reroutes to increase efficiency. At NASA, Direct-to and Dynamic Weather Routes (DWR) programs use software that continually scans for opportunities to shorten flight paths by flying directly between waypoints. DWR can benefit flights with an initial planned route designed to avoid regions in which convective weather is forecasted but realized weather offers opportunities to shorten the planned route. As a pilot program, DWR has been implemented at American Airlines for flights going through the Dallas Air Route Traffic Control Center (ARTCC). A related

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program, known as the NAS Constraint Evaluation and Notification Tool (NASCENT), extends the DWR concept to the continental US. In general, DWR and NASCENT are intended to mitigate inefficiencies that result from initial conservative pre-departure flight plans made in the face of considerable uncertainty about convective weather.

Other programs, such as MITRE's En Route Flow Planning Tool (EFPT) and NASA's Advanced Airspace Concept (AAC), are designed to improve decision making when reroutes become necessary to avoid weather or congestion. EFPT is designed to help traffic managers identify flights and flows requiring rerouting within the next 15–90 min, devise and rank potential solutions, and execute the chosen reroutes. This helps avoid the high controller-pilot communications workload, traffic complexity, and unpredictability that often result from "just-in-time" route deviations initiated by pilots, which, by their nature, involve limited options and must be handled promptly. The AAC includes both strategic and tactical weather-avoidance capabilities as well as tactical conflict resolution functions. Strategic reroutes are initiated about 20 min prior to the predicted time of entry into the weather cell and re-evaluated every 15 min, whereas the tactical rerouting algorithm operates on a 1-min cycle.

To assess the benefits of these programs, most previous research has focused on the direct time savings of rerouted flights. Some studies consider only part of a route. For example, if a reroute allows a flight to fly directly from point A to point C in 20 min and the planned route included segments from A to B and from B to C with a total flight time of 25 min, then the direct timesaving would be 5 min. Using this approach, for example, McNally et al. estimated potential savings at about 10 min per flight rerouted using DWR and corrected potential savings, which account for route amendments to the same flights that are made currently without using DWR, of 6.6 min (McNally et al., 2015). Others consider the impact of rerouting on the entire flight route. For example, Refai and Windhorst used a fast-time simulation, Airspace Concept Evaluation System (ACES), to determine changes in delay, defined as the difference between actual and scheduled en route flight times, to rerouted flights (Refai and Windhorst, 2011).

Although simple and straightforward, the direct timesaving approach may not accurately reflect the impact of the rerouting on arrival times at destination airports, since it does not consider how the change en route time may affect when that flight can actually land, or the landing times of other flights bound for the same destination. For instance, due to airport congestion, the direct timesaving of a reroute may result in the flight taking a longer delay when it reaches the destination terminal area if the destination airport is operating at capacity – the so-called "hurry up and wait" phenomenon. In addition, adding one more flight (the rerouted flight) into the arrival queue of the destination airport earlier may delay the flights behind it. Such increased delay due to the rerouted flight may partly or completely offset the direct timesaving. In contrast, it is also possible, as explained below, for the direct timesaving from a reroute to lead to an even greater timesaving if one considers all the arriving flights instead of just the rerouted one. For brevity, we will refer to the impact of a reroute to a given flight bound for airport A on the arrival times of all flights to A as the *system impact* of the reroute. To properly assess the value of the aforementioned programs for guiding and executing rerouting, and guide the development for other rerouting tools in the future, the system impact of reroutes must be taken into account.

In this study, we develop a methodology for estimating the system impact of rerouted flights. We apply this methodology to an extensive data set of US flights and studied the relationship between the direct impact of a reroute – i.e. the change in en route time of the rerouted flight–and the system impact, in the sense defined in the previous paragraph.

After a brief review of relevant literature in the next section, we present our methodology in Section 3. Section 4 introduces the data set and summarizes what it reveals about flight distance changes that result from reroutes. Section 5 presents the results of applying the methodology to the data set, followed by conclusions in Section 6.

2. Literature review

Much research attention, at both the local (i.e., individual flight) and system (impact on NAS) scales, has been devoted to the study of delay propagation. Many studies define multipliers for quantifying the downstream impact of flight delay or airport-level delay. Based on actual delay statistics, Boswell and Evans developed an analytical model to estimate the delays to successive flight legs when a multi-leg flight encountered an initial delay in a daily itinerary (Boswell and Evans, 1997). In their study, a downstream multiplier is defined as the ratio between seed delay and its total downstream impact. This study provides an omnibus multiplier that can be applied at all sites and in all traffic conditions; however, this multiplier is computed only for the winter season due to data limitations. It reveals that, on average, 2.5 downstream legs are impacted by a seed delay, and 1 min of seed delay engenders 0.8 min of parallel carryover delay in subsequent flight legs in winter weather. Kondo adopted a similar omnibus multiplier idea and compared the difference of flight delay propagation between point-to-point carriers and network carriers (Kondo, 2011). Welman et al. looked into airport delay propagation for other airports in the NAS. They used an "aircraft-operational day" as the study unit and developed arrival delay propagation multipliers for both individual and multiple airports in metroplexes in airport cost-benefit studies by mapping original and propagated delay across the NAS (Welman et al., 2010). The authors discovered the variation of the multipliers at different sites, reflecting that delay propagation is a network phenomenon and is influenced by a mixture of factors across the network. Other tools, such as techniques from complex network and econometrics analysis, also have been adopted in studying delay propagation. Laskey et al. applied Bayesian networks (BN) in a stochastic model to model the relationships among different components of aircraft delay (Laskey et al., 2006). Propagated delay, in the study, is defined as delays resulting from previous flight phases. The study developed regression models to investigate the causal factors contributing to delay in each flight phase and the impact of delay in each phase to the final arrival delay. Using a case study from ORD to ALT during summer 2004, the study identified departure delay as the major factor driving final arrival delay at the destination airport and weather affects delay in all flight phases.

Fleurquin et al. introduced an agent-based model to study observed delay propagation in 305 US airports (Fleurquin et al., 2013). The authors defined the category of "congested airports" and studied how such airports form connected clusters in the network.