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Detecting flight trajectory anomalies and predicting diversions in freight transportation

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ABSTRACT

Timely identifying flight diversions is a crucial aspect of efficient multi-modal transportation. When an airplane diverts, logistics providers must promptly adapt their transportation plans in order to ensure proper delivery despite such an unexpected event. In practice, the different parties in a logistics chain do not exchange real-time information related to flights. This calls for a means to detect diversions that just requires publicly available data, thus being independent of the communication between different parties.
The dependence on public data results in a challenge to detect anomalous behavior without knowing the planned flight trajectory.
Our work addresses this challenge by introducing a prediction model that just requires information on an airplane's position, velocity, and intended destination. This information is used to distinguish between regular and anomalous behavior.
When an airplane displays anomalous behavior for an extended period of time, the model predicts a diversion. A quantitative evaluation shows that this approach is able to detect diverting airplanes with excellent precision and recall even without knowing planned trajectories as required by related research. By utilizing the proposed prediction model, logistics companies gain a significant amount of response time for these cases.

1. Introduction

The growth of inter-continental trade has led to a notable increase in multi-modal transport. Multi-modal transport involves at least two modes of transportation on two consecutive transportation legs, which have to be synchronized. This is, for instance, the case when air freight cargo is unloaded at airports in order to be distributed into the hinterland by trucks, or sea ship cargo being redistributed at sea ports.

Because multi-modal transport faces increasing challenges in terms of efficiency, describing and planning such sequential dependencies is a common concern [1].

The desire for efficiency is on the one hand driven by lean or just-in-time production systems, which require timely delivery. On the other hand, efficiency is demanded from an environmental perspective in order to avoid unnecessary CO_2 emissions. A crucial problem in this context is that different parties involved in a transportation chain hardly exchange real-time information related to individual deliveries [2]. This makes it difficult for a receiving party to respond in a timely way to unexpected events that occur earlier on in the transportation.

The impact of such unexpected events is especially prominent in supply chains that involve cargo airplanes. In case an airplane has to land in an airport that is not the intended destination (i.e. the flight is diverted), re-planning and adaptation mechanisms must be triggered so that other parties involved in the chain can continue with the delivery of the cargo. For instance, it may be required to cancel the transport orders for the planned airport and to provide transport capacities at the diverted airport. The resultant impact on a company's ability to deliver goods in time, the utilization of trucks, and the additional costs it incurs, can be mitigated by timely responding to diversions. To enable parties to do so, diversions need to be detected as early as possible.

Although there exist approaches that achieve this (e.g. [3, 4]), these typically depend on information about the planned flight trajectory in order to detect a diversion. However, such information is often not readily available in practice [2], especially for logistics service providers.

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Therefore, it is desirable to identify anomalous flight behavior without depending on such information completeness.

In this paper, we address the problem of alerting receiving parties, e.g. trucking companies, in case a delivering airplane is diverted. Based on real scenarios and hence, keeping the decision making problem as realistic as possible as suggested in [5] from the standpoint of logistics service providers, we make use of event data that is semi-publicly available. More specifically, our contribution is a prediction model that detects flight trajectory anomalies based on minimal input data. We implemented the model as a prototype and tested it on a sample of flights yielding a high predictive accuracy. The prediction model provides considerable gains in response time. It is therefore suited to be integrated in decision systems that support operations of logistics service providers, in contrast to traditional model-based decision support [6].

The remainder of the paper is structured as follows. Section 2 discusses the background of our research by describing a real-world scenario and by considering related work.

Section 3 defines our prediction model, which builds on feature extraction and the classification of regular and anomalous airplane behavior. Section 4 presents the evaluation of this framework with a focus on effectiveness and response time gain. Finally, Section 5 presents the conclusions of this work.

2. Background

Our research is motivated by the need to monitor air transportation in scenarios where only a limited amount of flight information is available and by the lack of support for detecting en-route diversions under these circumstances. In this section, we first describe a freight transportation scenario from the EU-FP7 GET Service project[1] to motivate the problem we tackle. Subsequently, we identify the research gap by considering existing work related to the problem.

2.1. Scenario

This section describes a real-world transport scenario that demonstrates the importance of prompt and accurate prediction of diverting airplanes. In this multi-modal transport scenario, goods are transported from John F. Kennedy International airport (New York, USA) to a plant located in Utrecht (The Netherlands) [2]. It consists of two transportation legs. The first leg comprises air transportation from New York to Amsterdam Airport Schiphol . At the airport, the goods are transferred to trucks that have been sent by a logistics service provider to pick up the cargo. In the second leg, the trucks transport the goods to the destination plant in Utrecht.

In this scenario, the goal of the logistics service provider is to deliver the goods on time to Utrecht, i.e. in conformance with service level objectives that have been agreed upon with the client [7]. A crucial factor impacting a logistics provider's ability to meet its service level objectives is whether or not an airplane arrives on time at its connection point. However, it is possible that this does not happen, because the airplane has to divert and land at a different airport.

Such diversions can occur, for instance, due to adverse weather conditions or technical difficulties. In order to be able to still meet its service level objectives, a logistics service provider must respond in a timely and efficient manner to such events.

Although diversions are relatively rare, their impact on the logistic chain is significant. To recognize the impact of a diversion on costs and CO_2 emissions, it must be considered that the freight of an airplane is, on average, loaded onto 30 trucks.[2] If the airplane diverts to a different destination airport, the logistics service provider has to cancel (or reroute) the trucks that have been sent to the Schiphol airport, and in parallel arrange for new transportation means to pick up the cargo in Eindhoven . Therefore, this requires a rerouting of up to 60 trucks for a single airplane. Optimization of scheduling around such unexpected events is therefore recognized as one of the most important fleet management decisions [8]. In order for these corrective actions to be effective, it is crucial that the logistics service provider becomes aware of the airplane diversion as soon as possible [9]. Unfortunately, the communication between logistics service providers and cargo airlines is in practice not as prompt as required [2]. In fact, logistics service providers do not receive real-time information and are generally even only notified once an airplane has already landed at another airport.

These delayed diversion notifications threaten the ability of logistics service providers to meet their service objectives.

In order to reduce the impact of diversions in practical settings, we thus face the challenge to automatically detect flight diversions by only making use of data from public data services. As such, logistics service providers can respond to diversion in a timely manner, independent of the quality of communication with other parties involved in the logistics chain.

2.2. Related work

In order to address the aforementioned challenges we are especially interested in prior research that relates to flight monitoring for anomalous trajectory detection. To the best of our knowledge, our research work is the first that addresses the issue of predicting the diversions of flights. We also remark here that our approach operates under the requirements that trajectories are not known a priori, and that there is no limited geographical area that is specifically meant to be put under analysis. Previous techniques have challenged related issues in the area of monitoring aircraft routes based on flight data. The approaches in this context differ in the goal they pursue, which is different to ours. Their operating conditions also change in terms of information they require about planned flight trajectories, the circumscription of the geographical area in scope, and the number of factors used to detect anomalous behavior. Nevertheless, they provide useful insight in the general scope of the automated detection of anomalies in flight transportation data.

The techniques that consider the expected flight routes typically represent such information by means of waypoints, namely sets of coordinates through which airplanes pass as intermediate junction points of a segmented trajectory.

For example, Krozel [3] describes a set of methods to detect and measure to which extent the actual route differs from the filed flight plan assuming that information about the due waypoints is available, and reasons about the causes of such discrepancies. Periodic updates of the position of the aircraft including its location, altitude, and speed are analyzed to such extent. In our approach, we aim at predicting diversions, rather than signaling aircrafts that are not within normal navigation performance error limits. Nevertheless, we also make use of location, altitude, and speed values as representative quantities to be monitored. Reynolds and Hansman [4] introduce a model-based framework for flight conformance monitoring based on Fault Detection and Isolation techniques. To do so, the flight data are compared with a model consisting of aircraft positions, velocity, and acceleration, supplemented with future conditions to be compliant with, in terms of planned trajectory, destination and target states toward the next waypoint. They validate their model-based conformance checking with simulated flight tracks.

Although we do not assume to have any predefined flight model at hand, we also propose a technique that does not analyze the registered values singularly, but rather considers their difference-based evolution over the time.

[1] http://getservice-project.eu/.
[2] According to a major logistics service provider that we have collaborated with in this research project.