論 文 内 容 の 要 旨

博士論文題目　Air Traffic Control (ATC) Resilient Response Model Amid Automatic Dependent Surveillance-Broadcast (ADS-B) Ghost Aircraft Spoofing Cyberattack

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（論文内容の要旨）

As Automatic Dependent Surveillance-Broadcast (ADS-B) is being mandated by more Air Navigation Service Providers (ANSP) globally, the unchanging openness and unencrypted nature of the system pose a constant significant threat of cyberattack in the form of false message injection to the air traffic surveillance system. Among the attack types within the category of false message injection which is easy to launch and potentially causing high negative impact to Air Traffic Management (ATM), is the Ghost Aircraft Spoofing (GAS) attack that can be easily launched via a software-defined radio device targeting a ground station. It is considerably less complex and does not require a high level of skills for effective execution. This attack type aims to create confusion to the Air Traffic Controller (ATC) by exploiting the already degraded air traffic surveillance capability. The immediate impact of this attack is delayed aircraft arrivals and departures in the context of flight operations. This situation happens when legit real aircraft flying near the ghost aircraft will need to fly away or change its flightpath to avoid mid-air collision and other hazards. Changing flightpath or slowing down will certainly incur additional time to the flight, resulting in imminent delay. Moreover, prolonged attacks will cause greater impact, disrupting airport operations related to ground movement for taxiing-in and taxiing-out. ATC will suspend departures not just because of the posed risk and threat to climbing aircraft, but also to make way for landing aircraft. Uncertainties from GAS will make the departures continue to be suspended and the total number of aircraft affected on the airport ground will rise.

To mitigate this incident, this dissertation first, analyze the immediate impact to the arriving aircraft which are in descent phase, and later the cascading effects it brings to the departure operations and aircraft ground movement in quantitative terms of accumulation of delay time and number of affected aircraft. The methodology used for quantification is through statistical data from formation of First-In-First-Out (FIFO) queues representing pertinent queuing functions applied by the ATC in the entire Arrival-Ground Movement-Departure (AGMOD) dynamics. After the impact and cascading effects have been identified and proven, this dissertation proposes two types of mitigation plan based on possible ATC responses to reduce

the delay time for arriving and departing aircraft. The arriving aircraft will be guided with a tactical framework to continuously explore ideal deviational flight path that is shortest at that point of time and with less to no interference by other aircraft. The second proposed response plan focuses on the departure sequencing by countering uncertainties optimistically through synchronous aircraft movement for taxiing-out. The proposed approach records positive results with more aircraft at several designated taxiway zones close to the runway compared to conventional approaches which permit departures based on original schedule time prior the GAS attack or based on prioritization for aircraft closest to the runway to move ahead of others.

This dissertation demonstrates the advantages of the application of `best shortest path' theory in the arriving aircraft scenario and customized queueing engine to facilitate the taxiing-out movement. In both scenarios, delay time managed to be reduced compared to the conventional approaches that would be taken by the ATC. In overall, the proposed ATC response as elaborated by this dissertation promotes resilient ATM and in line with the main objective of the ATC, which is to facilitate safe and smooth movement of air traffic.

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（論文審査結果の要旨）

近年、航空管制においてレーダーを補完する航空機監視プロトコルとして ADS-B の導入が進んでいるが、その一方で、セキュリティへの懸念が全世界的な導入を阻んでいる。本論文では、ADS-B における問題発生時への効果的対処策を導出するため、離発着の系を待ち行列を用いてモデル化し、クアラルンプール国際空港の実データを用いて ADS-B 問題発生時の対処策の比較評価を行い、効果的対処策の導出に取り組んでいる。本論文の主な成果は、以下に要約される。

1. 理論的分析として、着陸-地上滑走-離陸の系全体のダイナミクスにおいて鍵となる箇所とフェーズを待ち行列を用いてモデル化し、ベースライン、低密度な攻撃、高密度な攻撃の3シナリオにおいてインパクト評価を実施している。
2. 実証的分析として、クアラルンプール国際空港の実データを用いて現地の航空管制専門家による知見を盛り込んだシナリオ設定ならびに評価を行い、航空交通管理に重大な影響を及ぼしうる事態に対する効果的対処策の導出につなげている。
3. 上記シナリオにおける到着遅延と離陸遅延の増大を緩和するアルゴリズムを提案し、実データと上記モデルを用いたシミュレーションにより先行研究と比較して到着遅延と離陸遅延の増大が抑えられることを示している。

以上のように、本論文は ADS-B を活用した航空管制におけるレジリエンス向上に資する理論的分析および実証的分析を実施し、待ち行列を用いたシミュレーションによる計装ならびに航空管制専門の知見に基づくシナリオ設定のもとで離発着の遅延が緩和されることを示すことでその有効性を検証している。それぞれの成果は1編の学術論文と3編の査読付き国際会議論文として発表されており、研究成果の有効性を見ることができる。よって本論文は、博士（工学）の学位論文としての価値があるものと認める。