RPAS Integration in Non-segregated Airspace within Comparison between Radar Vectoring and Trajectory Based Operation Using a Real-Time ATC Simulation

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Abstract

As the demand for the RPAS (Remotely Piloted Aircraft System) in market is anticipated to grow in near future, the necessity of integrating its operation into non-segregated airspace has recently drawn much attention. The RPAS operation simultaneously with other manned aircraft is not currently permitted due to the lack of understanding on its safety aspects particularly related to the loss of communication link to the remoted pilot on the ground. The purpose of this paper is to analyze via human-in-the-loop (HiTL) simulations the impact caused by the delay or loss of the command and control (C2) link of RPAS in the two different air traffic management environments – conventional radar vectoring and Trajectory Based Operation (TBO). Simulation was performed by several trainee air traffic controller (ATC) with three scenarios, and the data was analyzed in three perspectives – the safety, the flight efficiency and the ATC workload by NASA Task Load Index and Instantaneous Self-Assessment (ISA).

Keywords

Remotely Piloted Aircraft Systems (RPAS), Human-in-the-Loop (HiTL) Simulation, Trajectory Based Operation (TBO), Command and Control (C2) Link

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I. Introduction

Recent technological advance in Remotely Piloted Aircraft System (RPAS) has brought new possibilities of using RPA and business models in various commercial markets. Since the RPAS operation has different aspects from those of manned aircraft, the RPAS integration into the non-segregated airspace would trigger the safety concerns in the aviation community. Compared with manned aircraft, the RPAS requires some unique features such as the Detect and Avoid (DAA) and Command and Control (C2) Link, and the possible degradation of those functions becomes the safety hazards that could result in the accident. To ensure these features not disrupting safety of other aircraft, various studies must be preceded to increase our understanding about the impact of RPAS integration into the non-segregated airspace.

One of the key features of RPAS is C2 link, which is the data link between the RPA and the remote pilot station for the purpose of managing the flight. The loss of C2 link in non-segregated airspace is critical to aviation safety, which possibly result in, without proper contingency procedure, catastrophic accidents. Another consideration is that, the communication link between pilots and air traffic controllers (ATCos) could also have potential risk of time lag, which is expected to increase pilots' reaction time and controllers' workload.

Recent studies have noticed potential risk from C2 and communication link (often refers to C3 link) delay and identified the impact of abnormal situation. Vu *et al*. suggested that ATCo rated RPA pilot verbal response latencies as acceptable when a 1.5 second delay was added to the RPA pilot response, but a 5 second delay was rated mostly unacceptable [1]. Similar study found that time lag between the ATCo instruction and the pilot response was negatively correlated with the ATC acceptability rating [2]. TEMPERIS project, the SESAR project on RPAS, concluded that the predictability of- the RPAS trajectory, runway capacity and ATCo workload has degraded from RPA operation [3]. These series of studies have a thread of connections of that C3 link delay and loss affected ATCo performance and workload which could be considered as potential hazard in aviation safety.

In previous research by H. Oh *et al.* with human-in-the-loop (HiTL) simulation, the result showed that 1 or 2 seconds of signal delay and 10 seconds of temporal loss in C2 link do not show definite trend in the safety metrics. However, the total flight time was increased by 15% and the workload was significantly increased, since RPA operations have triggered accumulation of traffic in airspace [4]. This paper extends the work of H. Oh by suggesting 4D Trajectory Based Operation (TBO) as the ATM concept that could relieve negative effects on air traffic flow and ATCo workload.

We investigate the impact of delay or loss of the C2 link in non-segregated airspace, using HiTL ATC simulation. The simulation is performed with three scenarios: a reference scenario without C2 link properties and two scenarios with three RPA with C2 link delay and loss. The result is analyzed into three perspective: safety, efficiency and ATCo workload. With 5 metrics, we compared two different ATM environments: conventional radar-vectoring ATC and 4D TBO operation to identify how much the impact of C2 link delay or loss has mitigated

Section Ⅱ discuss about operation concepts, and section Ⅲ describes the simulation system. Section Ⅳ explains simulation set ups such as performance metrics, scenarios, task and participants. The results are shown in Section Ⅴ. Finally, section Ⅵ concludes the study.

II. Operation Concept

(1) Principles of RPAS ATM Integration

The prerequisite condition for integration of RPAS in non-segregated airspace will be its ability to act and respond as manned aircraft does [5]. One example of systematic approach in implementing RPAS is International Civil Aviation Organization (ICAO) Aviation System Block Upgrade (ASBU). ASBU stated implementing RPA into non-segregated airspace with improvement of certification process, operational procedures, communication performance requirements, C2 link failure procedure and DAA technologies [6]. For example, in terms of communication, communications relay, transaction time, continuity of the link, and timeliness of response to ATC instruction must be considered as acceptable. To develop communication link performance requirements, understanding properties of RPAS communication link, assessing its impact on current system and establishing performance-based standard is needed.

Considering RPA integration in ATM, another condition is that RPA integration should not disrupt current ATM system. ICAO Manual on RPAS stated that *"When adding any new type of airspace user into the existing air navigation system, consideration must be given to minimizing risk to all airspace users... In order for RPA to be integrated into non-segregated controlled airspace, the RPA must be able to comply with existing ATM procedures… Any new ATM procedures should be kept as consistent as possible with those for manned flights to minimize disruption of the ATM system."* [7] Similarly, FAA UAS Roadmap also stated that UAS must be integrated into the NAS without reducing existing capacity, decreasing safety, negatively impacting current operators, or increasing the risk to airspace users or persons and property on the ground [8]. Hence, RPAS integration requires to be complied with current ATM systems and not to make negative influence in current system.

Furthermore, the RPA integration must be designed along with future concept of ATM technologies and systems. For instance, European RPAS roadmap has identified operational requirements and technological gaps along with ATM master plan [9]. Starting form short-term validation with current ATM environment, European RPAS roadmap also describes RPA integration in future ATM environment such as 4D mission trajectory based operation (TBO). Considering that RPA integration is long term process, reflecting the gradual development of ATM environment into RPAS integration is a pertinent suggestion.

(2) Command and Control (C2) Link

The C2 link is one of the critical issues in RPA operation. C2 link connects RPA and remoted pilot station (RPS) via wireless uplink and downlink data communication. C2 link latency or failure directly affects the aircraft controllability, ATC communication and DAA system. As mentioned above, RPA integration should not degrade safety or capacity of current ATM system. Thus, it must be ensured that C2 link is equivalent to the linkage of manned aircraft. However, it is difficult to determine C2 link requirements due to lack of quantitative and verifiable requirements yet [11].

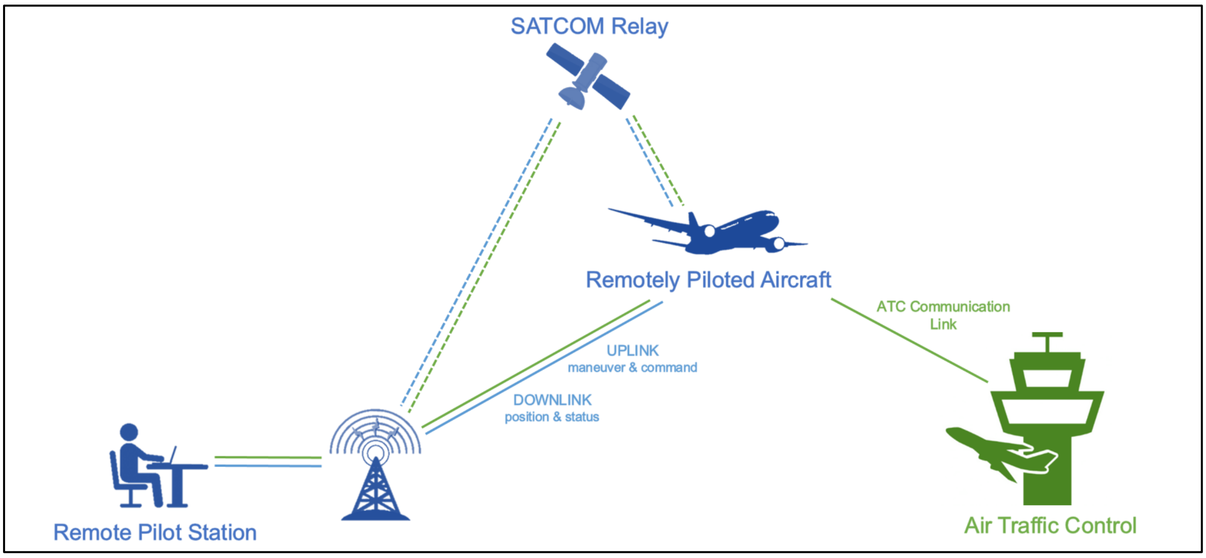

Figure 1. Example of C2 and ATC communication link architecture.

One of the biggest challenge in C2 link is the signal delay, particularly in long range BRLOS (beyond radio line of sight) operation due to communication relay. Since RPA and RPS are not directly linked, the signal latency of BRLOS operation is significantly longer than that of RLOS (Radio Line of Sight) operation. Signal relay poses a threat of degradation of communication performance and interference due to terrestrial or meteorological condition to C2 link.

The risk of C2 link delay has been recognized in several works. For RPA which requires direct manual control, even lag as brief as 50 milliseconds can produce noticeable degradation of performance and lead pilot induced oscillations. Thus, it is recommended that on-board flight control automation is required in certain level to ensure stability [12]. When it comes to RPAS with automated control, time lag did not affect stability of RPA, but triggered accumulation in air traffic that brought more radar vectors with higher ATCo workload [4].

Another concern in C2 link is signal loss. When the C2 link is lost, the RPS cannot maintain control of RPA, which leads to serious hazard to nearby aircraft. To mitigate the risk, contingency procedure for C2 link loss is required. There are some possible contingency procedures, for example: continue original flight plan; land at nearest appropriate designated landing site; direct return to departure aerodrome or departure site; flight termination; and climb to altitude to attempt to regain the C2 link [7].

(3) 4D Trajectory Based Operation (TBO)

4D Trajectory Based Operation was introduced to accommodate increasing air traffic demand by transforming current ATM system. With development of Flight Management System (FMS), CPDLC (Controller Pilot Data Link Communication), ADS-B (Automatic

Dependent Surveillance – Broadcast) and SWIM (System Wide Information Management), TBO means basically shifting clearance-based ATC to trajectory-based ATC. The 4D trajectory includes latitude, longitude, altitude and time of corresponding waypoints. By negotiation between airspace users and ANSPs (Air Navigation Service Provider), TBO enables users to fly as preferred trajectory with constraints issued for ATM purpose [14].

TBO can be performed by following procedures. First, based on airspace user's desired flight trajectory, ATCo issues CTA (Controlled Time of Arrival) or RTA (Required Time of Arrival) in specific waypoints, so that the aircraft crosses the waypoints within given time. After that airspace users and ANSP both agrees with the trajectory, the aircraft fly within the reference trajectory. Trajectory prediction and monitoring are constantly provided. The full 4D implementation is expected to enhance predictability and increase TMA capacity as a result of fewer tactical interventions [15].

Several researches on TBO are suggesting that implementation of TBO would benefit RPAS integration. Theunissen *et al.* noticed that 4D operations do not only benefit to manned aviation, but also to unmanned aircraft, and discussed connection of RPS into SWIM system [16]. Thomas *et al.* pointed out that when C2 link is lost, though alternate landing sites are pre-planned in advance, the exact profile the RPA will follow at the moment the failure is declared will not be known before that instant. Nevertheless, sharing even lately the 4D path the moment the event occurs is foreseen to facilitate the handling of the off-nominal situation [17].

In summary, for RPAS ATM integration, C2 link performance should be determined, with major challenges: C2 link latency, signal loss and degradation of ATC communication. It is recognized that assessing impact of abnormal C2 linkage in terms of ATM perspective is required. In previous research, we have found that signal delay and loss in C2 link negatively affected traffic flow [4]. In this paper, Trajectory Based Operation (TBO) is suggested as the solution expected to mitigate this impact. The TBO has been applied into the simulation and analyzed how well it reduced the negative effect of RPAS integration.

III. Air Traffic Control Simulation System

(1) Simulator System

The air traffic control simulation was developed with 5-DOF (degree-of-freedom) dynamic model and performance parameters from Eurocontrol BADA (Base of Aircraft Data) [18]. The simulator consists server, pilot stations and ATC stations. The server manages scenarios and data flow between the stations, processes flight states from pilot stations and send the processed positions and flight paths to ATC stations. Both pilot stations and ATC stations supports trajectory display, managing and sharing by CPDLC interfaces. Separation could be achieved by comparing trajectory of corresponding aircrafts and issuing proper altitude or RTA constraints for spacing.

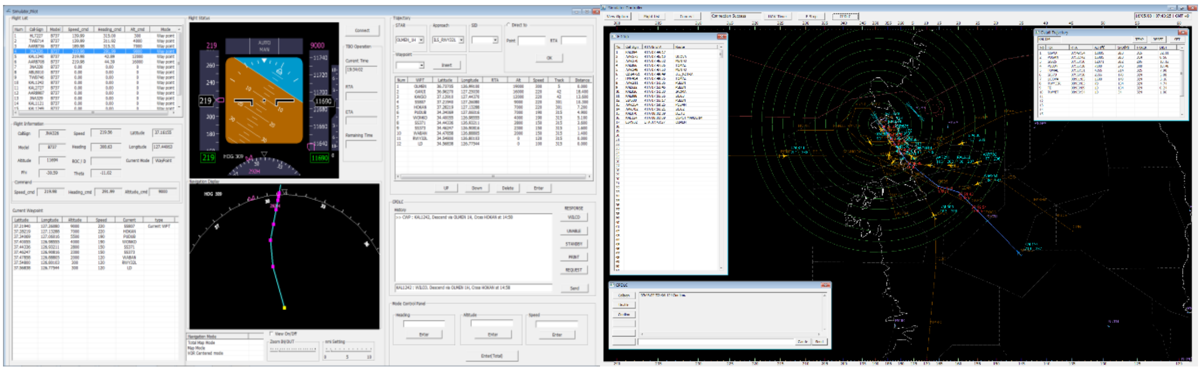

Figure 2. Pilot and ATC station interface.

(2) C2 link architecture and TBO procedures

In this paper, we assume that RPA and RPS are directly linked. The uplink information contains maneuver command, trajectory and constraints. The downlink information contains flight status and ETA for each waypoints. ATC instructions are given by CPDLC. Once RPA receives the uplink flow with trajectory and time constraints, FMS predicts minimum and maximum ETA for each. Then, FMS determine whether the waypoints are reachable or not by comparing min/max ETA with RTA. FMS computes parameters for aircraft control such as throttle, angle or speed vector to follow the reference trajectory. FMS consecutively monitors its trajectory with position data and modifies throttle or moments if necessary. Fig.3 shows the example of TBO operation with C2 link architecture which is used in the simulation

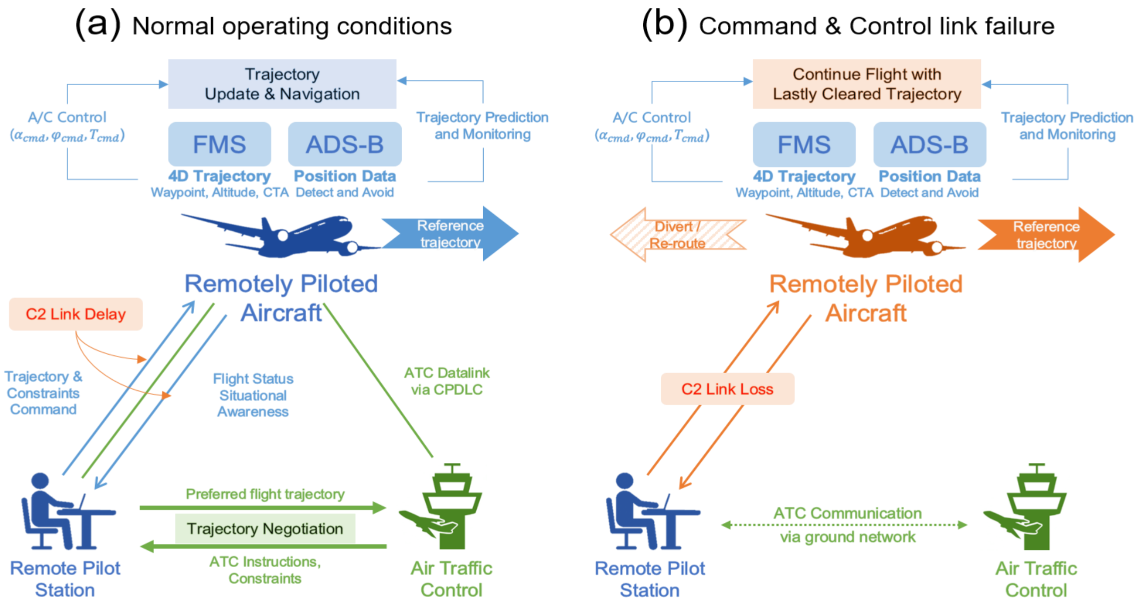

Figure.3. Schematics of Trajectory Based Operation with C2 link architecture. (a) C2 link delay affects both uplink (updating trajectory and constraints) & downlink (flight status). While ATC CPDLC message and the aircraft control does not directly influenced. (b) When C2 link fails, RPA continue flight with the lastly cleared trajectory till C2 link recovery.

In case of C2 link failure, ICAO RPAS manual recommended that RPA to return to origin or divert to alternative aerodrome as contingency procedure. However, if the aircraft beyond control suddenly changes its route without providing enough time for reaction, this might bring a chain reaction of convergences with nearby aircrafts. In contrast, with TBO, instead of dynamic re-routing, RPA would follow last cleared trajectory with its DAA function working on maintaining separation. Since the reference trajectory contains detailed flight profile, it is much more predictable than re-routing technique. Thus, in this simulation, when C2 link is lost, the RPA continues to follow reference trajectory.

IV. Simulation Set ups

(1) Scope

This paper only deals with RPAs which are large commercial aircrafts under IFR (Instrument Flight Rule) with waypoint based control. The term, 'Waypoint based control' indicates that the pilot sends trajectory instead of direct control of 'stick and rudder', while on-board FMS controls the aircraft. Also, RPAs were assumed to have same performance with manned aircraft except the C2 link feature.

The difference between previous researches is initial 4D TBO features: CPDLC, trajectory information sharing and ATC based on time difference by controlling RTA. Note that TBO was originally introduced to support better predictability and automation for optimized flight route. However, the purpose of this paper is to observe how trajectory based air traffic management systemically affected by C2 link architecture. Thus, only some basic components of 4D interface were introduced. Any submodules of air traffic flow management or other trajectory optimization methods are not introduced in this simulation.

(2) Performance Metrics

The performance metrics used in this paper is described in Table 1. Conflict intrusion parameter (CIP) and well clear (WC) is used to determine safety level. The total flight time is introduced for flight efficiency. NASA task load index (NASA TLX) and instantaneous self-assessment are used for assessing ATCo workload. Detailed descriptions of each metric are discussed in [4].

Table 1. Key performance areas and metrics

Performance Area	Metric	Description
Safety	Conflict Intrusion Parameter (CIP)	Quantitative measurement of separation between two aircrafts based on lateral separation (5NM) and vertical separation (1,000ft). Maximum CIP value, one means collision has occurred and zero means two aircrafts have been laterally or vertically separated [19].
	Well Clear (WC)	Proposed as a standard of airborne separation or self-separation for the DAA systems. Consists of lateral, vertical space and time parameter [20].

Efficiency	Total Flight Time	The sum of difference between inbound time and landing time. Inefficient flight trajectory or arrival delay leads to longer elapsed time.
Workload	NASA Task Load Index (NASA-TLX)	Designed to obtain workload by measuring six items by questionnaire: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort and Frustration. With weight derived from individual participant, the overall NASA-TLX score is the product of value and weight of each factors [21].
	Instantaneous Self-assessment (ISA)	Measure workload while performing the task. Participants self-rate their workloads every two minutes on a scale of 1 (low) to 5 (high) during the task [22]

(3) Scenario

The scenario is based on the actual flight plan of Incheon International Airport on October 10th, 2015, from 17:00 to 17:30 local time. 13 departures and 28 arrivals were scheduled during the time. As shown in table 2, case 1 represents RPA operation without any C2 link delay or loss, while case 2 & case 3 have three RPAs inbound with C2 link delay of 1 second, 2 seconds, and 10 seconds of temporal signal loss respectively.

Table 2. Simulation Scenarios

	Description	RPA870	RPA622	RPA124
Case 1	3 RPAs without any C2 link delay or loss (Reference scenario)	0 second	0 second	0 second
Case 2	2 RPAs with C2 link delay and last RPA under temporal signal loss (10 second)	1 second	2 second	10 second
Case 3	2 RPAs with C2 link delay and 1 RPA under temporal signal loss (10 second)	2 second	10 second	1 second

(4) Participants and Tasks

The participants were one ATCo and two pseudo pilots. Before the experiment, briefing about procedure and purpose of the simulation was given. To ensure realistic progress of the simulation, flight schedule and relevant information was given to ATCo except for the C2 link delay or loss.

ATCo performed approach control in Seoul Terminal Maneuvering Area (TMA). The traffics arrive in 5 waypoints, and controllers guided aircraft to Initial Approach Fix (IAF) of runways 34 and 33R of Incheon International Airport (RKSI) with standard approach procedures. ATCo managed aircraft with 4D trajectory such as waypoints, altitude and required time of arrival (RTA). During the simulation, ATCo was asked to fill out the ISA questionnaires each 2 minutes. After finishing the whole simulation, NASA-TLX interview was performed.

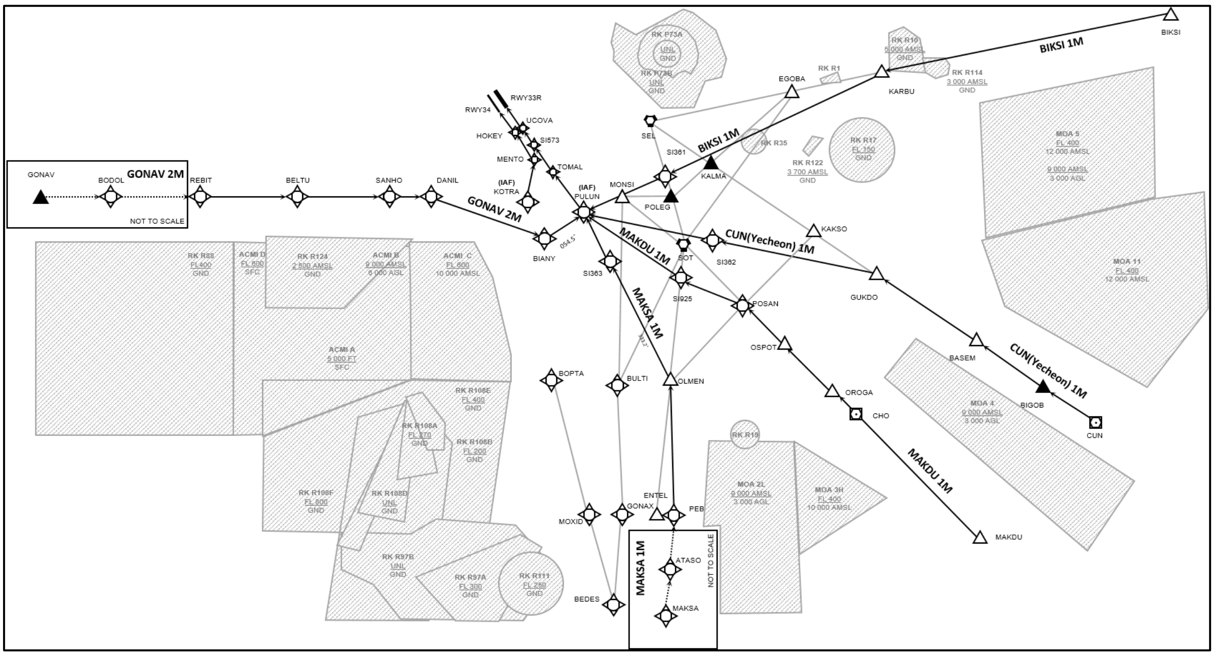

Figure 4. Incheon airport (RKSI) RWY33R & RWY34 arrival routes in Seoul TMA. Total five STAR and two GNSS approach procedures were used. RWY 33R and RWY 34 are independent runways with separated Initial Approach Fix.

V. Results

(1) Conflict Intrusion Parameter (CIP)

In order to examine the impact of C2 link with regard to the safety measurement, Conflict Intrusion Parameter (CIP) and Well Clear Score (WCS) were measured. As presented in Fig.5, the CIP measured in Case 2 and Case 3 (RPA with C2 link delay and loss) was higher than that in Case 1 (no C2 link delay or loss). This implies that RPA operations with C2 link delay or loss were more likely to induce Loss of Separation (LOS). (Note that the CIP value other than 0 implies that there was at least one of horizontal or vertical separation violated.)

Another remarkable observation is that the total CIP measured in TBO was higher than that in radar vectoring ATC environment. However, examining CIP between only inter-arrivals (excluding departure traffic), there were some CIP detectable in radar vectoring ATC environment were not observed in TBO (red solid circle) or vice versa (green dotted circle) (Fig.6 and Fig.7). Since the red circle appears more than the opposite one, we inference that CIP in TBO was mainly caused by inter-departure traffics or between departure traffic and arrival traffic. Since we only observed approach controller, we cannot clearly conclude the TBO resulted more frequent occurrences of LOS. Though it is hard to find the reason why TBO generated more CIP in departure traffic, we suppose that the participants were not accustomed to TBO environment enough to take departure traffic into account.

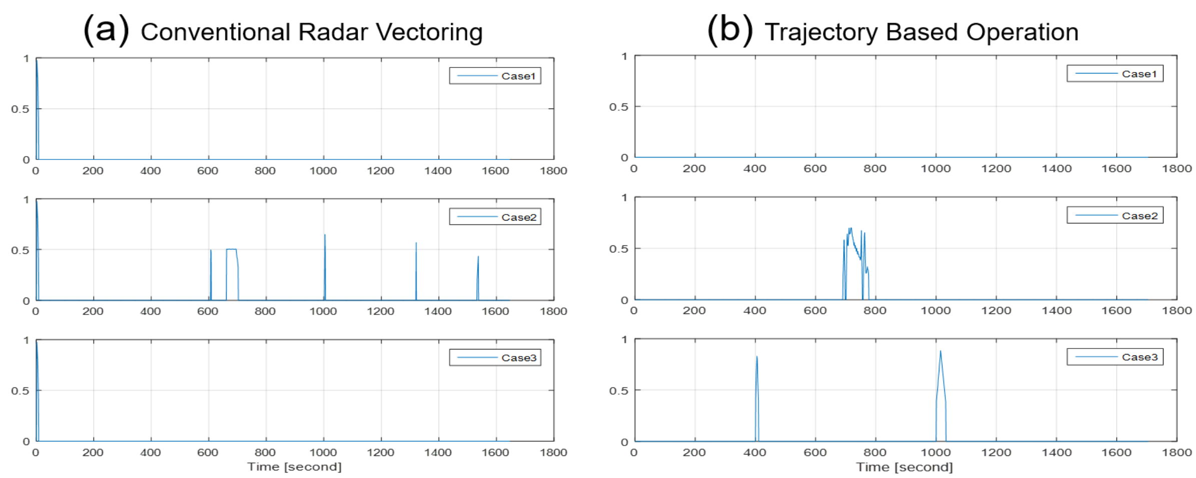

Figure 5. Measured total CIP (Loss-of-separation) of all aircrafts over time

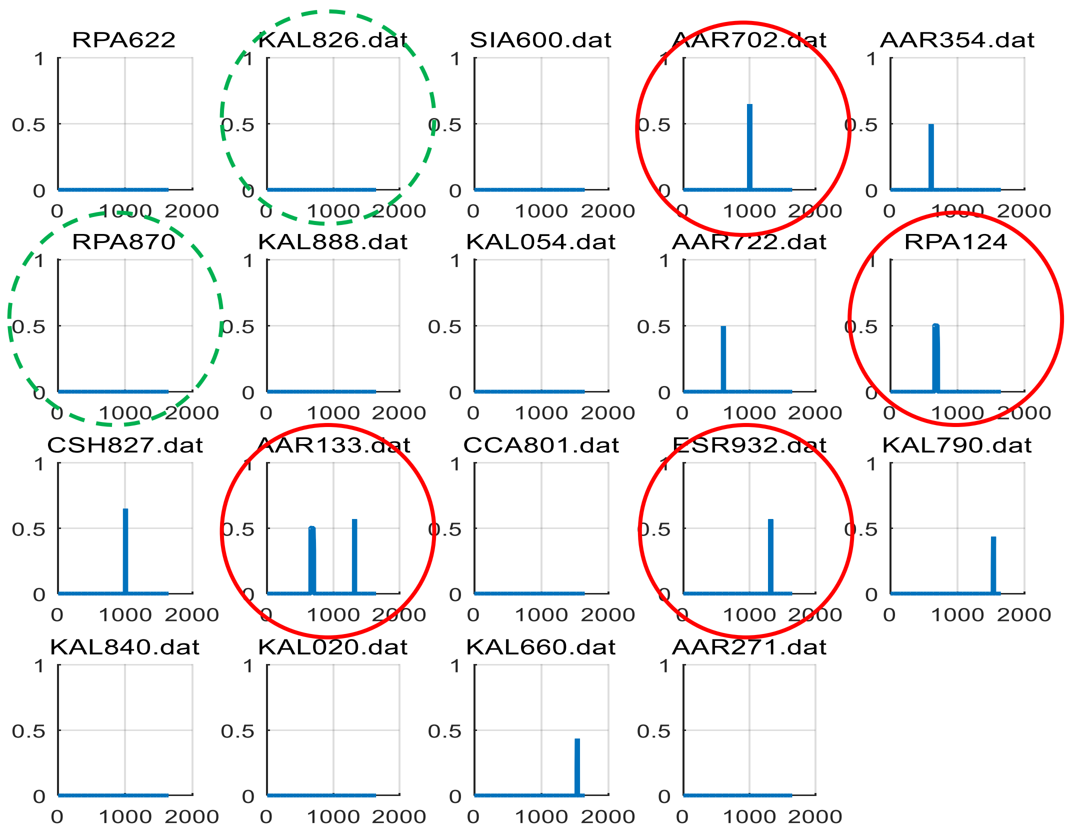

Figure 6. CIP of each arrival in radar vectoring ATC environment

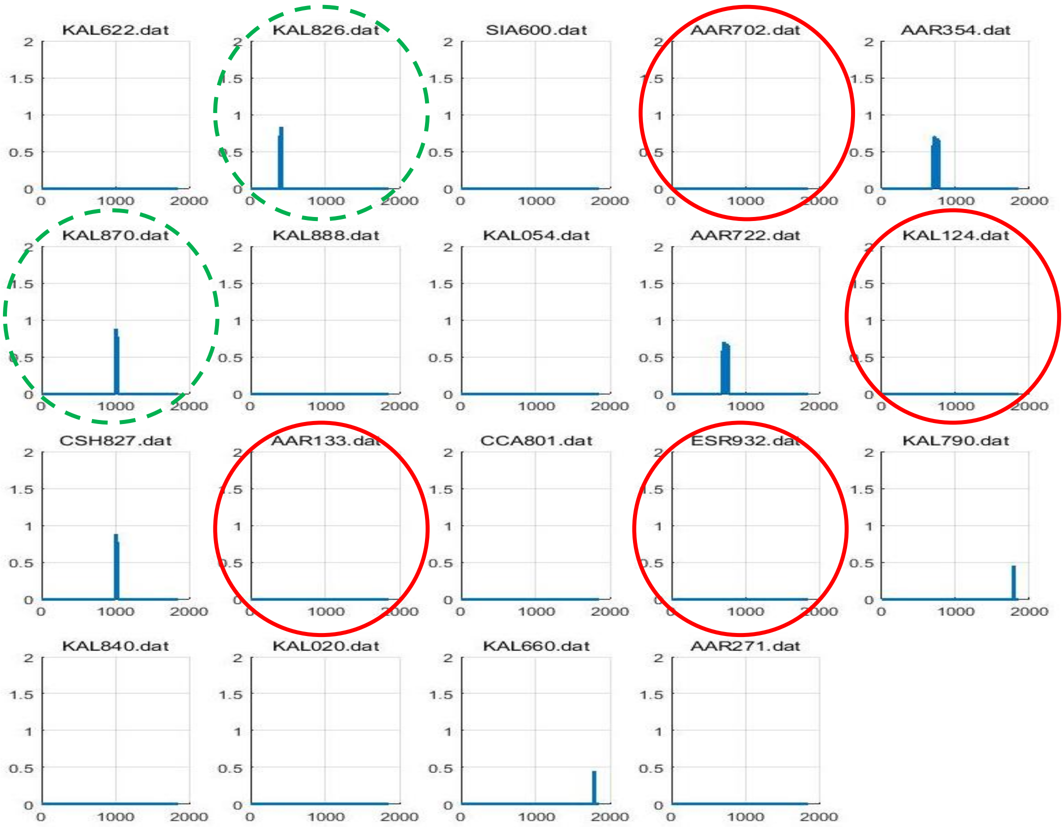

Figure 7. CIP of each arrival in TBO environment

(2) Well Clear (WC)

Well Clear score (WCS) was analyzed in order to measure proximity between aircrafts within 5 stages [20]. Fig.8 shows the overall WCS of each case and environment. In radar vectoring, distinct fluctuations of total WCS (red lines) can be observed between cases. In comparison, total WCS are less likely to vary over cases in TBO. Through Fig.9 to Fig.11, the WCS of each RPA (RPA870, RPA622 and RPA124) are presented. Decrease in maximum value and average of WCS were recognized for all RPAs.

Table 3 presents total, mean, maximum value and occurrence of WCS more than 10. In previous research, the total WCS were 37,888, 41,552 and 42,846 respectively. Compared to reference scenario, each case with C2 link delay has increased 9.67% (case 2) and 13.08% (case 3). However, in TBO environment, there was no prominent differences between each cases. This indicates that the correlation between C2 link delay and WCS were more significant in radar vectoring, than in TBO environment. Also, there were great decreases in occurrence of WCS over 10 between radar vectoring and TBO: from 2,535 to 715 in average. This indicates that the complex and hazardous situations were less likely to occur in TBO environment. With TBO, ATCos are supported better predictability which facilitated predicting conflict, and TBO allowed enough time to ATCos to handle traffics against their intentions. Thus, the WCS result indicates that introducing TBO countervailed the risk from C2 link delay and failure.

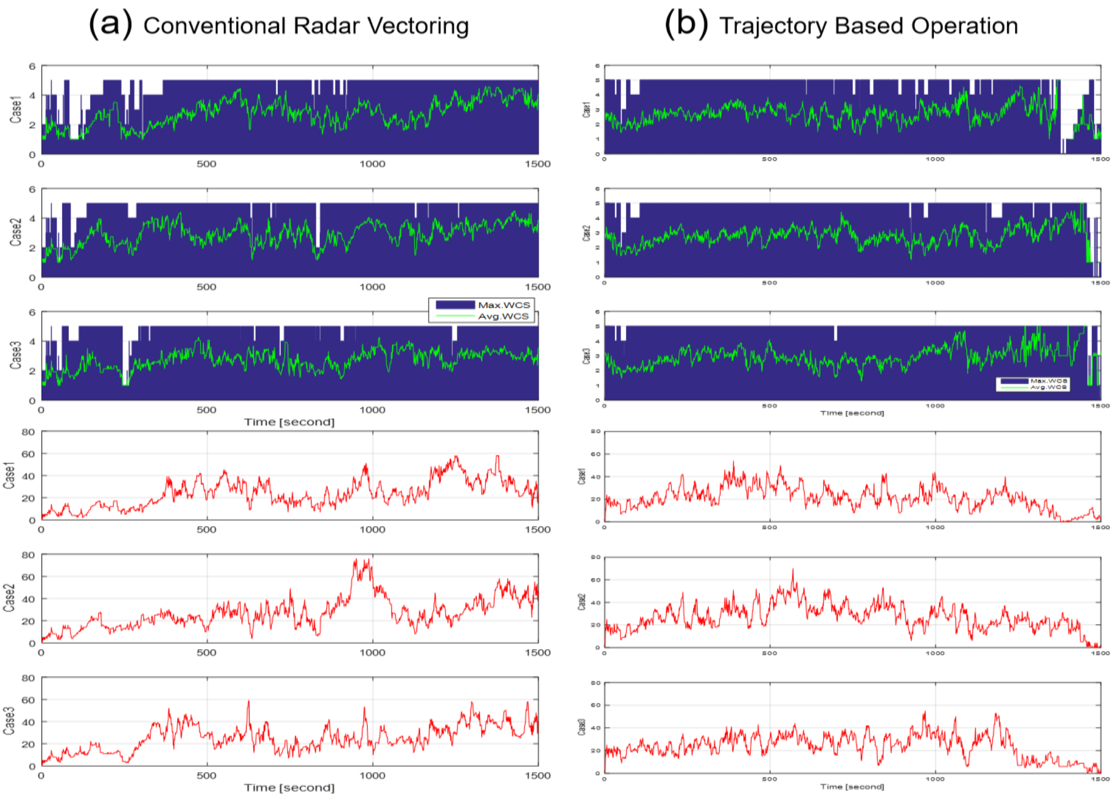

Figure 8. Maximum and average WC score (green lines & blue areas), Total WC score (red lines)

Table 3. Result of overall WC score

		All aircrafts			RPAs			Manned aircrafts		
		Case 1	Case 2	Case 3	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Radar Vectoring	total	37,888	41,552	42,846	7,255	7,949	8,683	30,633	33,603	34,266
	mean	23	25	26	1	2	2	1	1	1
	max	58	76	68	15	17	21	12	4	13
	over 10	1,443	4,446	1,716	274	198	309	1,252	1,503	1,400
Trajectory Based Operation	total	32,489	40,859	36,164	3,976	5,554	5,032	30,756	35,167	29,099
	mean	19	24	21	1	1	1	1	1	1
	max	54	70	55	9	11	11	5	5	5
	over 10	78	1,638	429	0	19	30	739	1,194	812

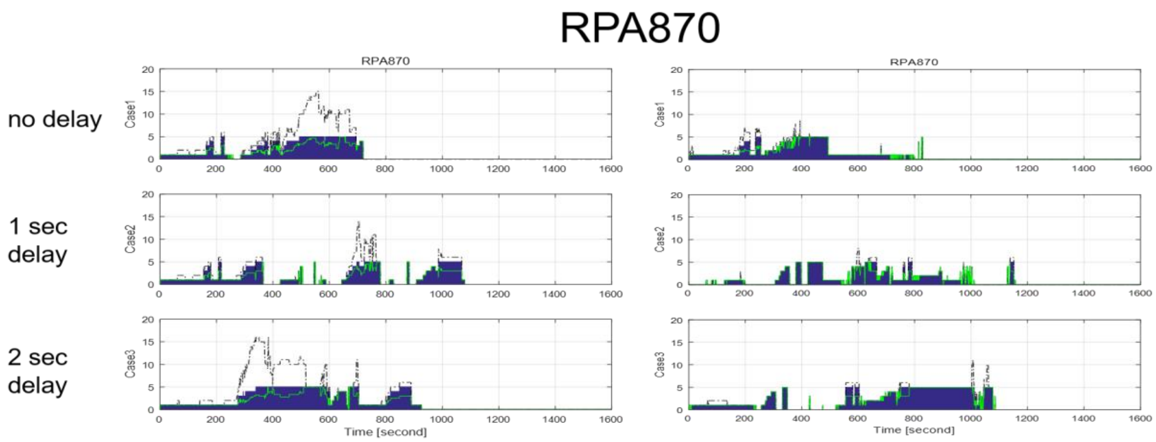

Figure 9. WCS of RPA870 in radar vectoring (left) and TBO (right)

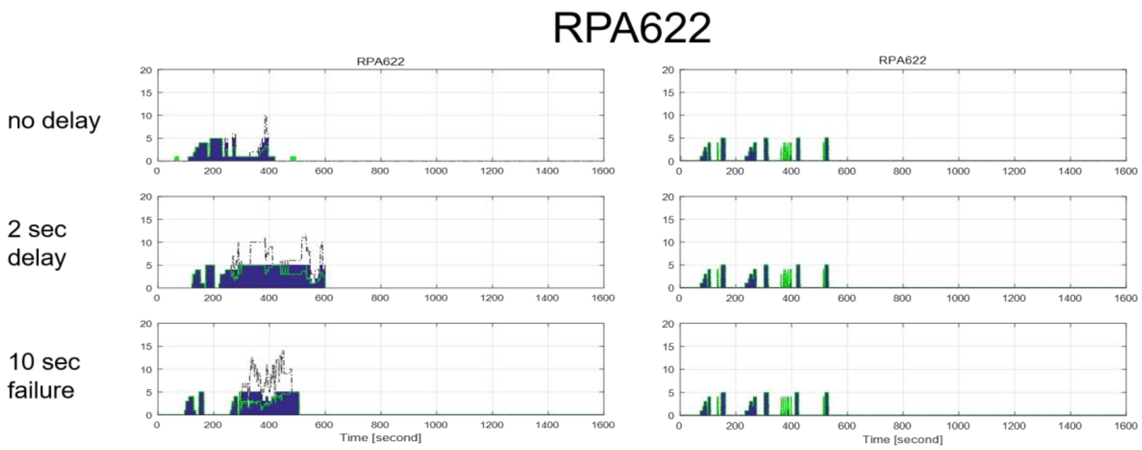

Figure 10. WCS of RPA870 in radar vectoring (left) and TBO (right)

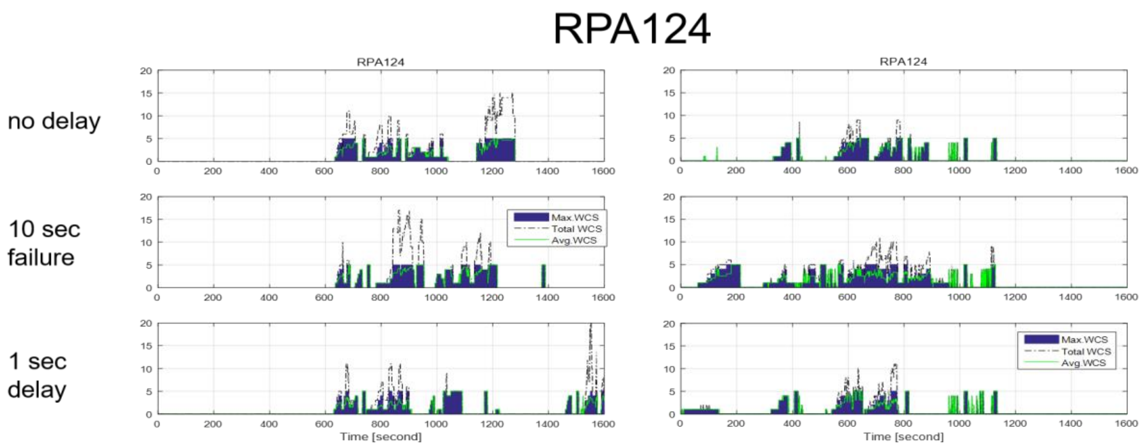

Figure 11. WCS of RPA870 in radar vectoring (left) and TBO (right)

(3) Total Flight Time

For the efficiency of flight, the total elapsed time before landing was measured. As presented in Table 4, in radar vectoring, the sum of flight time was 17,250, 19,780 and 19,865 seconds respectively. The total flight time in case 2 and case 3 were 14.67% and 15.16% longer than that of case 1. In case 2 and case 3, due to C2 link delay and loss, ATCo interventions were occurred, so that each flight route has been indirect which brought arrival delay eventually. In comparison, the total flight time was measured as 13,972, 14,477 and 14,327 seconds in TBO. C2 link delay and loss provoked 3.61% (case 2) and 2.54% (case 3) longer flight time.

Note that TBO reduced the overall flight time even in no RPA case. Fig.13 and Fig.14 indicates that TBO had a powerful impact; it not only reduced elapsed time, but even changed the sequences of landing. Thus, comparing the rate of increase rather than absolute value is considered appropriate.

Also, Fig.12 shows that the maintaining separation with conventional radar vectoring results significant arrival delay within arrivals due to C2 link delay (yellow and orange color). However, with implementing TBO operation, the delay has been mitigated.

Table 4. Comparison of total flight time

	Case 1 reference scenario	**Case 2**		**Case 3**	
		sum	growth	sum	growth
Radar Vectoring	17,250	19,780	+14.67%	19,865	+15.16%
Trajectory Based Operation	13,972	14,477	+3.61%	14,327	+2.54%

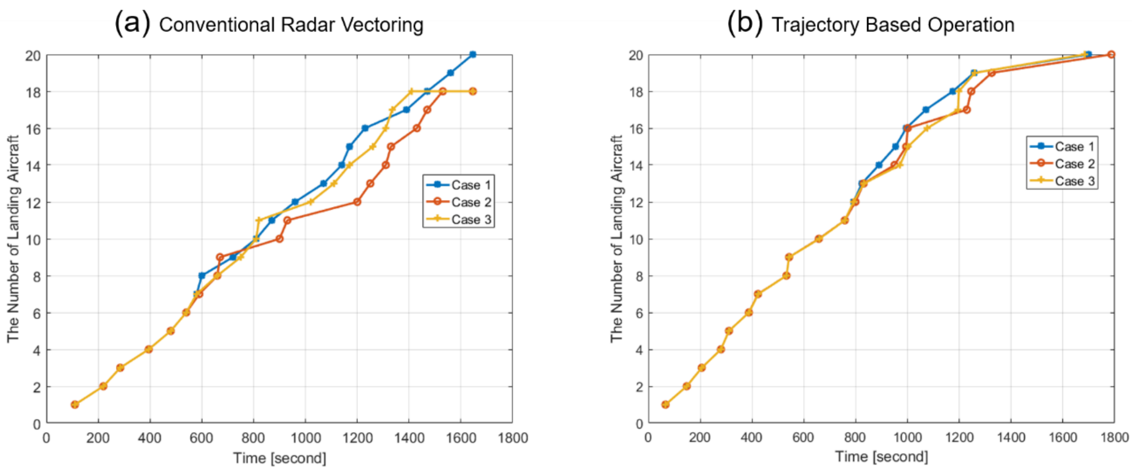

Figure 12. The number of landed aircraft over time.

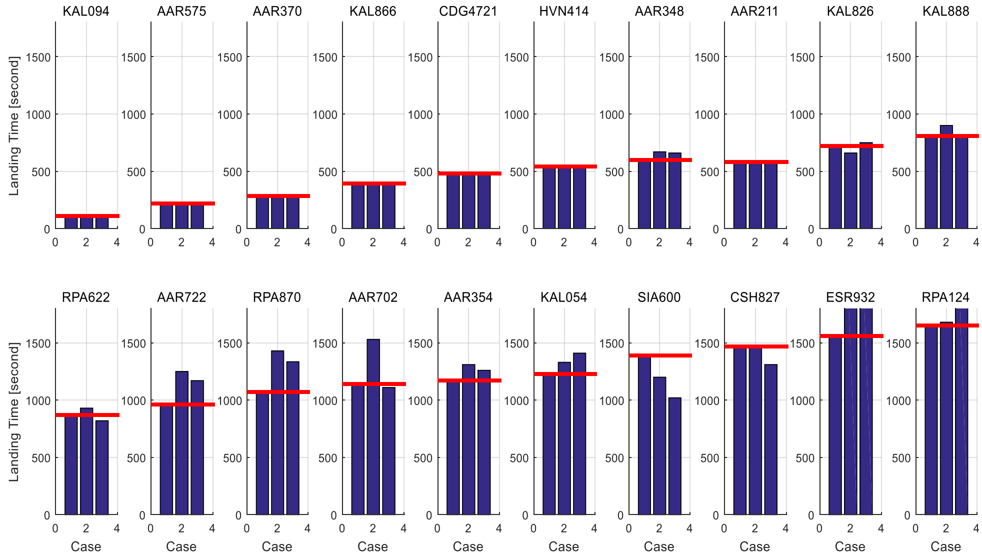

Figure 13. Arrival time in radar-vectoring environment

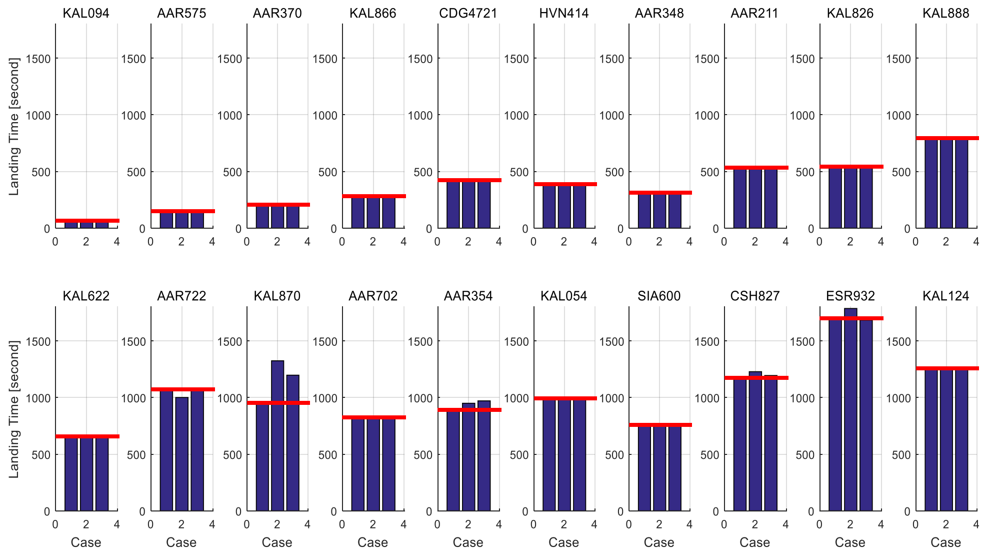

Figure 14. Arrival time in TBO environment

(4) NASA Task Load Index (NASA-TLX)

As presented in Table 5, the NASA TLX scores show that C2 link delay and loss triggered higher ATCo workload both in radar vectoring and TBO. Also, the NASA-TLX score was lowered with TBO in every case. The participated ATCo stated that higher predictability of incoming traffic was useful to manage time separation between aircrafts in merging point. Thus, introducing TBO will support ATCos by providing the detailed trajectory information, and improve predictability. However, it is hard to distinguish that the decrement of NASA-TLX score were resulted from the nature of TBO itself or from the interaction between C2 link architecture and TBO.

Table 5. Comparison of NASA-TLX score

	Case 1	Case 2		Case 3	
	Score	Score	Comparison w/ case 1	Score	Comparison w/ case 1
Radar Vectoring	47.00	66.00	+13.0 (+40.43%)	78.67	+31.67 (+67.38%)
Trajectory Based Operation	31.33	53.65	+22.32 (+71.24%)	52.99	+21.66 (+69.14%)
Decrement (vectoring vs TBO)	-15.67 (-33.34%)	-12.35 (-18.71%)		-25.68 (-32.64%)	

(5) Instantaneous Self-assessment (ISA)

Table 6 shows the result of ISA score. As described in total flight time, there was less traffic congestion in TBO than in radar vectoring environment. If there are less traffic in the air, the workload of ATCo would be lower. This indicates that the lower ISA score represents less congestion. This trend was notable in latter half of the simulation. High ISA scores of latter half in radar vectoring environment are mainly due to accumulation in arrival traffics, while traffic accumulation was significantly mitigated in TBO scenario.

Table 6. Comparison of average ISA score

	Case 1			Case 2			Case 3		
	Total	1st half	2nd half	Total	1st half	2nd half	Total	1st half	2nd half
Radar Vectoring	2.4	2.7	2.2	3.9	3.8	4.0	4.0	3.8	4.2
Trajectory Based Operation	2.1	2.7	1.5	2.7	3.2	2.2	2.8	3.3	2.3
Decrement	-13.8%	-0.0%	-31.8%	-31.9%	-15.8%	-45.0%	-29.2%	-13.2%	-45.2%

VI. Conclusion

Recently, the integration of RPAS into the non-segregated airspace becomes a major issue in aviation industry. Despite various commercial benefits of RPAS, it is not allowed to fly together with manned aircraft, because the safety aspects of RPAS integration have not been fully validated. One of the key features of RPAS is C2 link, and the signal delay or failure of C2 link poses a significant risk in safety. Therefore, the intrinsic characteristics of C2 link with respect to traffic management must be properly understood.

Our last study found that C2 link delay and failure has negative impact on air traffic flow and ATCo workload. The main hypothesis of this paper is that TBO can be a solution to mitigate such impact. To test our hypothesis, HiTL simulation was performed with RPAS with C2 link delay and failure in two different ATM environments: ATC with conventional radar vectoring and Trajectory Based Operation. The simulation results are analyzed in terms of various metrics related with safety, efficiency and ATCo workload.

The results show that the introduction of TBO has improved overall performances. WCS indicates that the risk from C2 link delay and loss was dramatically reduced, and the flight time as well as NASA-TLX and ISA scores were also improved by TBO. Although it is not clearly distinguishable that the performance improvement comes from either by the introduction of TBO itself or by the interaction between TBO and C2 link architecture. TBO is beneficial not only to manned aircraft, but also to RPAS.

This study focuses on the impact of C2 link delay or loss, and work remains to be done to identify other aspects of RPAS such as airworthiness and DAA. More realistic simulation environment with RPAS with various sizes, types and missions must be incorporated in future research, while RPAs in the current simulation were assumed to be as large as IFR aircraft, flying in high density aircraft. In addition, the experiments with more experienced ATCos must be done in future study to improve reliability of the results. Analyses on different traffic configuration are also left for future work.

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