Lost C2 Link Contingency Procedures for Seoul TMA and Assessment on Safety and Controller Workload

Hyeonwoong Lee, Seung-Hyun Park, and Hak-Tae Lee
Department of Aerospace Engineering
Inha University
Incheon, Republic of Korea
hyeonwoong.lee@inha.edu; parkseunghyun95@gmail.com; haktae.lee@inha.ac.kr

Bomi Park and Jae-Hyun Han
Department of Aviation Research
The Korea Transport Institute
Sejong, Republic of Korea
bomi.park@koti.re.kr; jhhan@koti.re.kr

***Abstract*—This paper describes the process of establishing lost C2 link contingency procedures in a busy terminal area and the assessment of the proposed procedures through Human-in-The-Loop simulations. Two contingency procedures, one for departure and the other for arrival, were developed based on existing procedures and historic traffic data analyses. A total of six 30-minute simulation sessions were performed with three controllers. By analyzing the safety using Detect and Avoid Well Clear metrics that are being developed for terminal areas, combined with two controller workload surveys, it was discovered that the lost C2 link situations with a single Remotely Piloted Aircraft were manageable without any noticeable safety or workload issues. The methodology of developing and assessing contingency procedures presented in this study will be useful for establishing such procedures in different areas to reflect their own traffic characteristics.**

***Index Terms*—Lost C2 Link, Contingency Procedures, Human-in-The-Loop (HiTL) Simulation, DAA Well Clear (DWC), Terminal Area, Controller Workload**

I. Introduction

Remotely Piloted Aircraft (RPA) is controlled by a Remote Pilot (RP) via Command and Control (C2) link. When the C2 link is lost, the RP loses control over the RPA and it will threaten the safety of other aircraft in the airspace. It is generally agreed upon that an RPA requires a pre-programmed contingency procedure that the behavior must be predictable when the C2 link is lost [1]. Similar to the loss of communication procedures of manned aircraft, the RPA that loses the C2 link during departure will first fly to a designated fix and be on a holding pattern to recover the C2 link. If the C2 link is not recovered within a pre-determined time, it will follow a designated standard arrival procedure back to the departure airport. The RPA that loses the C2 link during arrival will continue to the designated fix along with its arrival procedure and be on a holding pattern. If the C2 link is not recovered, the RPA will follow the designated standard approach procedure to the runway.

This paper describes designing specific contingency procedures for departure and arrival at Gimpo International Airport (GMP), which is one of the two busiest airports that serve the Seoul metropolitan area. First, two procedures are selected and modified from existing Standard Instrument Departures (SID) and Standard Arrival Routes (STAR) by analyzing their relative traffic levels using recorded traffic data of multiple high volume days. Then, the safety and controller workload of operations according to those procedures are assessed by Human-in-The-Loop (HiTL) simulations of representative scenarios.

With a total of six HiTL simulation sessions, it was concluded that the lost C2 link situations were manageable by all the participating controllers without raising any significant safety alerts or workload issues.

Section II describes the process of developing two contingency procedures for GMP. The simulation setup and the scenarios are presented in Section III. Section IV shows the results of the safety assessment using the Detect and Avoid (DAA) Well Clear (DWC) standards. Section V discusses the controller workload measured by two surveys. Comments from the participating controllers are presented in Section VI. Finally, Section VII concludes the paper.

II. Contingency Procedures

GMP is only 33 km away from Incheon International Airport (ICN) that some of the Class B airspaces of the two airports overlap. Traffic to and from both the airports are managed by the Seoul Approach. Both the airports have runways in northwesterly/southeasterly direction. However, since the airspace is blocked by the Pyongyang FIR to the

978-1-7281-9825-5/20/$31.00 ©2020 IEEE

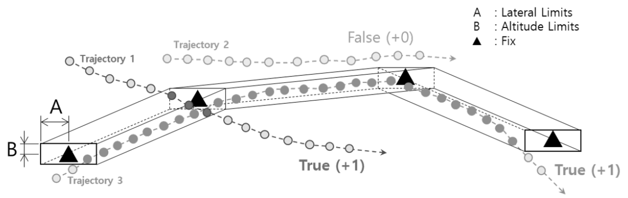


Fig. 1. Trajectory counting method for corresponding SIDs and STARs

TABLE I
LIST OF SIDS AND STARS AT GMP WITH THE AVERAGE NUMBER OF FLIGHTS PER DAY THAT ENTERS THE BOUNDARIES OF CORRESPONDING SIDS AND STARS

Type	Name	Average Number of Flights / Day	Type	Name	Average Number of Flights / Day
SID	RNAV EGOBA 1R	24.2	STAR	RNAV GUKDO 1D	51.2
	RNAV NOPIK 1J	39.4		RNAV GUKDO 1B	21.8
	RNAV BULTI 1M	27.5		RNAV COWAY 1W	58.3
	RNAV BULTI 1J	29.8		RNAV WIKEN 2S	26.1
	RNAV EGOBA 1J	31.1		RNAV KARBU 1D	18.1
	RNAV OSPOT 1X	59.4		**RNAV OLMEN 1D**	**88.1**
	RNAV SOT 1J	28.0		RNAV KARBU 1B	9.8
	RNAV OSPOT 1R	43.5		RNAV OLMEN 1B	74.8
	RNAV OSPOT 1M	41.8		RNAV REBIT 1D	47.6
	RNAV BULTI 1X	56.7		RNAV COWAY 1F	38.4
	RNAV NOPIK 1R	27.1		RNAV WIKEN 2A	83.8
	RNAV BULTI 1R	**73.5**			

North, operations are restricted. On average, there are about 380 movements per day at GMP by 16 airlines [2].

GMP has twelve SIDs and eleven STARs. The number of aircraft that enter the boundaries of the SIDs and STARs are counted for the 24-hour period from midnight to midnight using recorded ADS-B trajectory data. As shown in Fig. 1, the boundary is defined by a box with a dimension of ± 1 nautical mile laterally and ± 1000 ft vertically from the route. The average number of flights per day for 100 high traffic volumes days selected from January 2017 to January 2020 are listed in Table I.

Two contingency procedures, one departure, and one arrival are developed based on the existing SIDs and STARs of GMP according to the concept presented in [1]. For the purpose of analysis, procedures with higher traffic volumes are selected. However, selecting procedures with lower traffic volume with subject matter expert reviews will be more appropriate when designing contingency procedures for the real operation.

If the C2 link is lost during departure, the RPA will fly to the newly created holding pattern at SS720 fix regardless of whether it has passed the fix or not. This location is selected to avoid existing SIDs and STARs. If the C2 link is not recovered until one round in the holding pattern, the RPA will fly to the GANJI fix to be on the OLMAN 1D arrival procedure as shown in Figure 2. As can be seen from Table I, OLMAN 1D is the busiest STAR. It was selected to test the worst-case scenario.

If the C2 link is lost during arrival, the RPA will continue its STAR towards the holding pattern at the DOKDO fix. If the C2 link is not recovered during two rounds in the holding pattern at an altitude of 4,000 ft and a speed of 200 kts, the RPA will follow the ILS approach procedure to runway 14R as shown in Fig. 4.

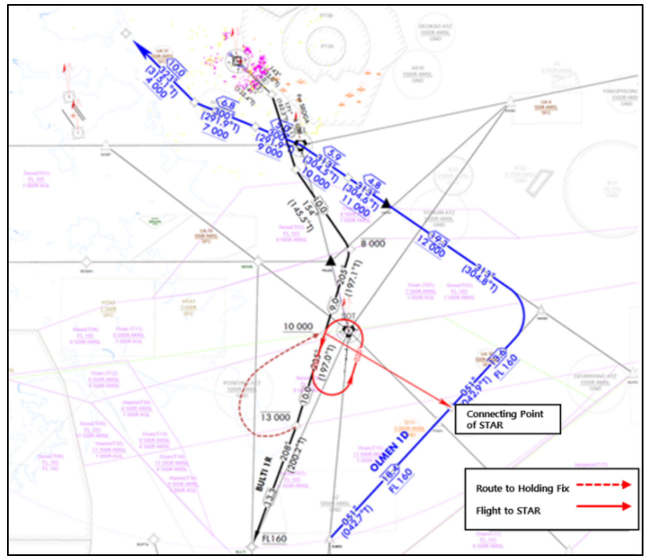


Fig. 2. Proposed contingency procedure for departure aircraft.

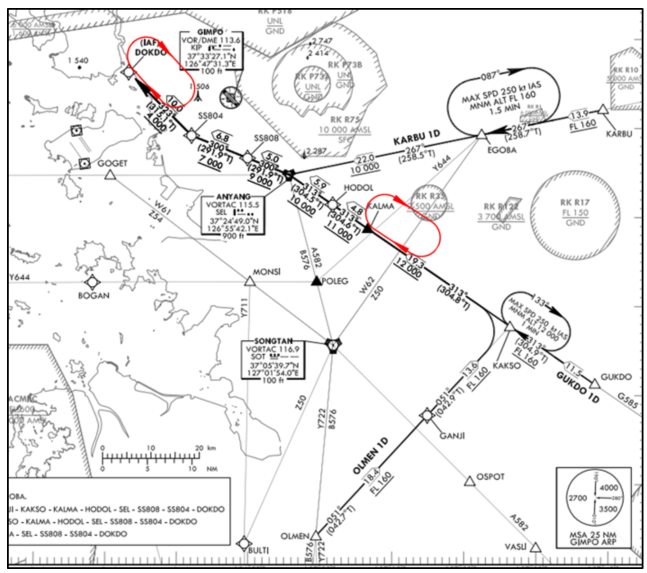


Fig. 3. Proposed contingency procedure for arrival aircraft.

For both the cases, the RPA will automatically switch the transponder code to 7400, and, if possible, the ADS-B message will show emergency status.

III. SIMULATION SETUP

The HiTL simulations were performed based on two scenarios generated using the recorded traffic data around the GMP on October 19th, 2019 from 11 am to 11:30 am. Flight plans of the background traffic were generated using the route finding algorithm developed in [3]. This algorithm removes the vectoring from the recorded trajectory as shown in Fig. 5 to make the scenario more realistic. To simplify the simulation,

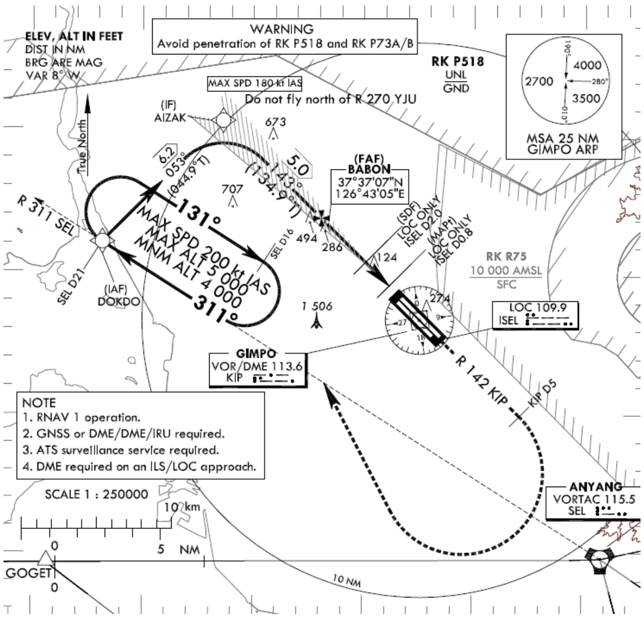


Fig. 4. GMP runway 14 approach procedure.

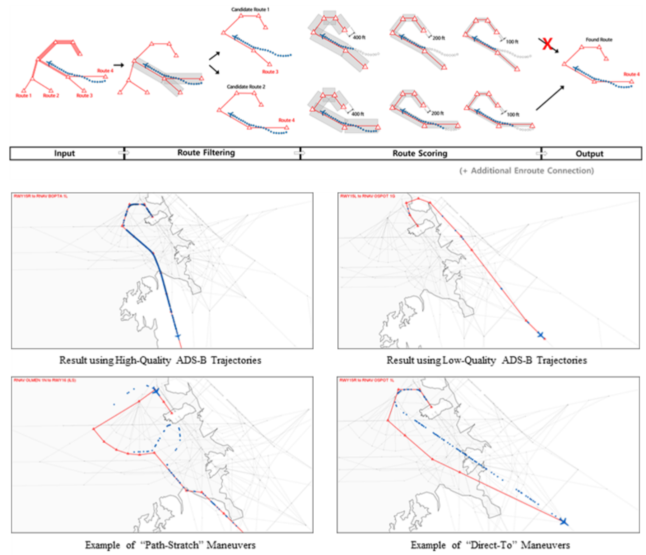


Fig. 5. Overview of the Route Finding Algorithm

only flights that depart or arrive at GMP or ICN are included excluding all the overflights.

For the loss of C2 link during departure, the RPA is assumed to be flying BULTI 1R SID. As shown in Table I, it was chosen because it is the busiest one among the twelve SIDs. The RPA loses the C2 link six minutes from the start of the simulation. When the C2 link is lost, the transponder code changes to 7400, and the target on the controller display changes its color to red. The controller is briefed about the contingency procedure described in II, but does not know when the C2 link will be lost. There are 178 manned aircraft and one RPA in the scenario. Regardless of the position of the RPA at the moment of lost C2 link, it will fly to SS720 fix to execute the designated procedure.

For the loss of C2 link during arrival, the RPA is assumed to be flying OLMEN 1D STAR. As shown in Table I, it was chosen because it is the busiest one among the eleven STARs. The RPA loses the C2 link 15.5 minutes from the start of the simulation. When the C2 link is lost, the transponder code changes to 7400, and the target on the controller display changes its color to red. The controller is briefed about the contingency procedure described in Section II, but does not know when the C2 link will be lost. There are 157 manned aircraft and one RPA in the scenario.

A total of three controllers participated in the HiTL simulations. Two controllers are active controllers at the Seoul Approach (Controllers 1 and 2). One retired controller (Controller 3) has previous experience working at the Seoul Approach. Controller 3 also participated in the development of the contingency procedures, so he was familiar with the situation.

The HiTL simulations consist of two 30-minute sessions, one departure and one arrival scenarios, for each controller. Before the start of the first scenario, each controller was briefed about the situation and given time to become familiar with the simulation system for fifteen minutes. After each simulation session, fifteen minutes were given to complete the NASA Task Load Index (TLX) [4] survey. Instantaneous Self Assessment (ISA) [5] scores were marked every two minutes during the simulation.

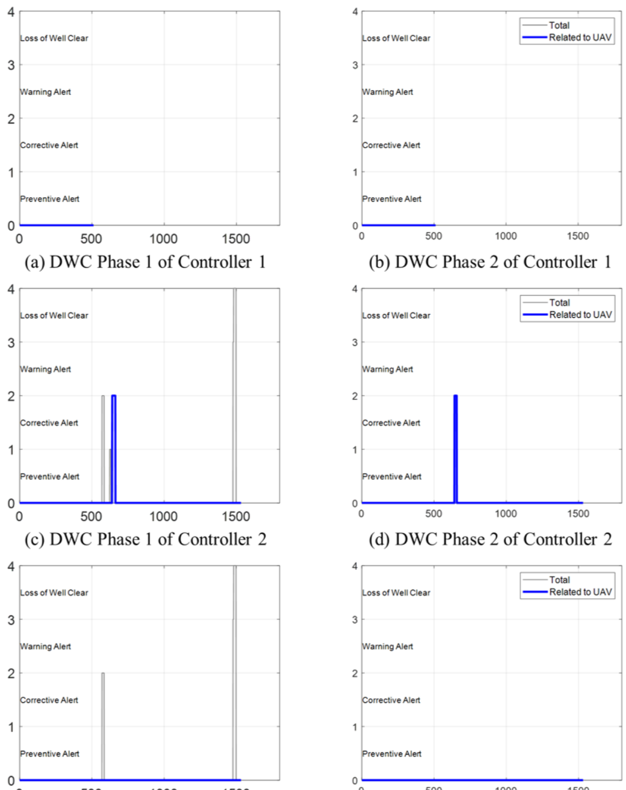
Among the six simulation sessions, the first scenario of controller 1 was stopped at about nine-minute mark due to a system issue. All the other sessions continued for the planned 30-minute duration.

IV. Safety Assessments

DWC is a metric devised to quantify the risk of RPA so that the DAA system of RPAS can provide alerts and suggest avoidance maneuver, which is specified in RTCA SC-228 MOPS [6]. DWC Phase 1 is the previously developed standards for en-route operations. Currently, DWC Phase 2 standards are being developed for terminal areas. For this paper, the latest values proposed by NASA [7], [8] are used to calculate the alerts.

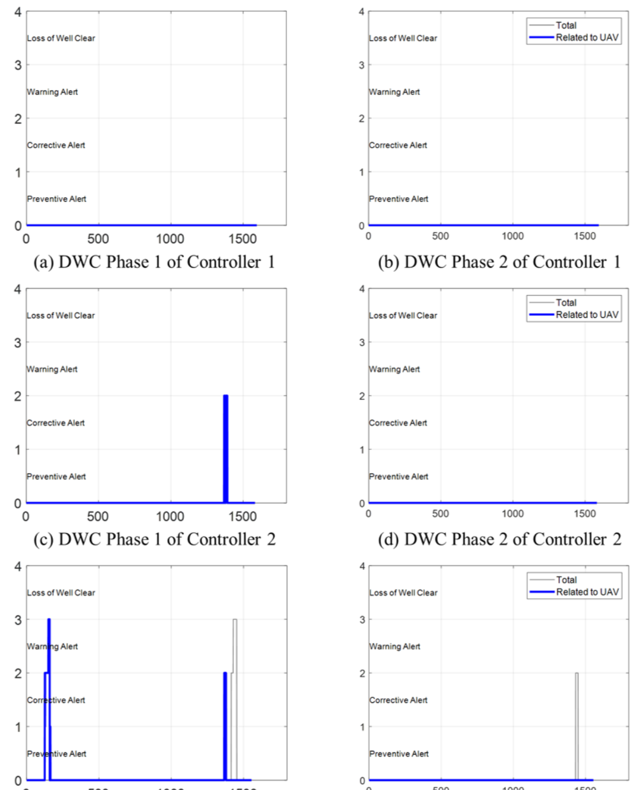
Fig. 6 shows the DWC alert levels for scenario 1 and three controllers using the DWC Phase 1 and 2 criteria. As can be seen, several alerts were issued between RPA and manned aircraft as wells as between manned aircraft with the DWC Phase 1 criteria. When the DWC Phase 2 criteria is used, only one corrective alert between the RPA and another manned aircraft was issued. Fig. 7 shows the same results as scenario 2. No alerts were issued with the DWC Phase 2 criteria. As the participating controllers commented that the situations were not particularly difficult to manage, and they did not feel safety was compromised, these results also suggest that the DWC Phase 2 criteria are better suited for the terminal area.

Fig. 8 shows the situation that raised the corrective alert with controller 2 and scenario 1 at around 635 seconds from the beginning of the simulation. Flight ESR211 and the RPA



(a) DWC Phase 1 of Controller 1 (b) DWC Phase 2 of Controller 1
(c) DWC Phase 1 of Controller 2 (d) DWC Phase 2 of Controller 2
(e) DWC Phase 1 of Controller 3 (f) DWC Phase 2 of Controller 3

Fig. 6. Results of DWC of Scenario 1



(a) DWC Phase 1 of Controller 1 (b) DWC Phase 2 of Controller 1
(c) DWC Phase 1 of Controller 2 (d) DWC Phase 2 of Controller 2
(e) DWC Phase 1 of Controller 3 (f) DWC Phase 2 of Controller 3

Fig. 7. Results of DWC of Scenario 2

were in a converging path. Although ESR211 was climbing, the target altitude of 12,000 ft was 1,000 ft lower than the altitude of the RPA, which will ensure safe separation.

Fig. 9 shows the situation that raised the corrective alert with controller 2 and scenario 2 at around 1384 seconds from the beginning of the simulation. As can be seen, the alert was raised only when the DWC Phase 1 criteria was applied. Similar to Fig. 8, COY201 and the RPA were in a converging path while COY201 was descending. RPA was maintaining 4,000 ft, and the target altitude of COY201 was 5,000 ft, which will ensure safe separation.

Table II summarizes the numbers and levels of the DWC alerts. The analyses show that there was only one case of corrective alert with the DWC Phase 2 criteria and that the single case was not a real risk but rather caused by the fact that the DWC alerts not considering the target altitude or other maneuvers. Moreover, with the corrective alert, the RPA pilot is considered to have enough time to coordinate the avoidance maneuver with the controller.

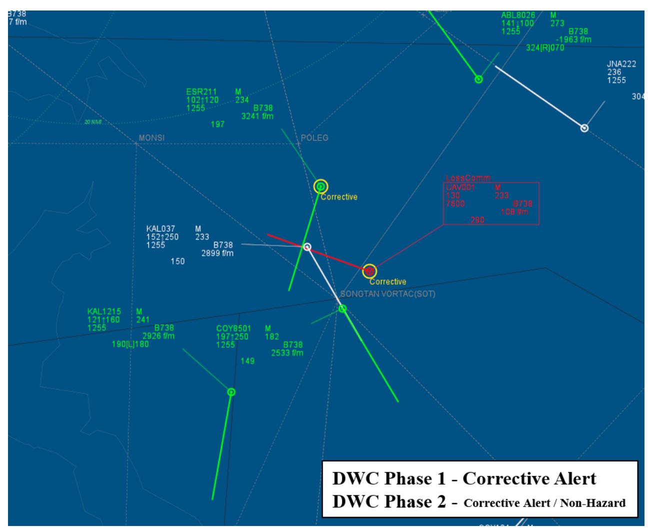


Fig. 8. Controller display in DAA Well Clear Alerts (Scenario 1 at 635 sec)

V. Workload Assessments

Controller workload metrics are measured using the NASA TLX survey and ISA. Controllers complete the NASA TLX survey after the simulation. It consists of six categories and the scores are from 0 to 100. TLX score of 50 generally means a normal workload. ISA scores are recorded during the simulation every two minutes. It ranges from one to five and represents the overall workload at that moment.

Table III summarizes the NASA TLX scores for the three controllers. The average scores are basically below 50 for all categories for both the scenarios. Only the ‘effort’ category of scenario 1, the departure case, is slightly over 50. Two large scores of 95 and 85 are in the ‘frustration’ category.

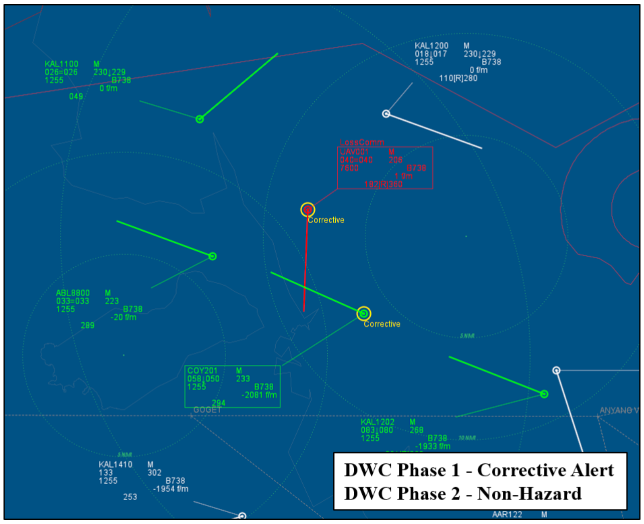


Fig. 9. Controller display in DAA Alerts (Scenario 2 at 1,384 sec)

TABLE II
THE NUMBER OF DWC ALERTS AND HIGHEST ALERT LEVELS.

			Scenario 1	Scenario 2
Controller1	DWC Phase 1	Number of Alerts	0	0
		Highest Alert Level	-	-
	DWC Phase 2	Number of Alerts	0	0
		Highest Alert Level	-	-
Controller2	DWC Phase 1	Number of Alerts	1	1
		Highest Alert Level	Corrective Alert	Corrective Alert
	DWC Phase 2	Number of Alerts	1	0
		Highest Alert Level	Corrective Alert	-
Controller3	DWC Phase 1	Number of Alerts	0	2
		Highest Alert Level	-	Warning Alert
	DWC Phase 2	Number of Alerts	0	0
		Highest Alert Level	-	-

The major cause of this high frustration score is mostly due to the controller user interface not being exactly the same as the one that is currently used at the Seoul Approach. The current simulation system was developed based on the user interfaces of the Incheon Area Control Center, and modified to suit the needs of the Seoul Approach based on the feedback of Controller 3.

TABLE III
NASA TLX SURVEY RESULTS.

Subject	Scenario 1				Scenario 2			
	Controller 1	Controller 2	Controller 3	Average	Controller 1	Controller 2	Controller 3	Average
Mental Demand	75	25	5	**35.0**	20	40	15	**25.0**
Physical Demand	50	15	5	**23.3**	5	50	15	**23.3**
Temporal Demand	50	25	5	**26.7**	5	50	15	**23.3**
Performance	50	45	50	**48.3**	75	30	15	**40.0**
Effort	50	50	55	**51.7**	50	75	15	**46.7**
Frustration	85	20	25	**43.3**	15	95	10	**40.0**

TABLE IV
ISA RESULTS.

	Scenario 1			Scenario 2		
	Controller 1	Controller 2	Controller 3	Controller 1	Controller 2	Controller 3
Average ISA	2.5	1.0	1.3	2.2	1.0	1.1
Maximum ISA	4	1	2	4	1	2

Table IV shows the average and the maximum ISA during the simulations. The average ISAs are below three for all the controllers for both the scenarios. Controller 1 reported the maximum ISA of four, which is consistent with his relatively higher NASA TLX scores.

VI. Controller Comments

Selected comments from the participating controllers are listed in this section. They provide several points that have to be addressed in the future and will be useful for designing the next HiTL simulations to investigate the contingency procedures.

- *Controller 1*
  - It would be helpful if he can still communicate with the RP even though the RP cannot control the RPA.
  - More HiTL simulations with various scenarios will be helpful.
- *Controller 2*
  - Due to the difference in the user interface, there was a learning curve at the beginning of the simulation.
  - Due to the mostly homogeneous wake turbulence category (WTC) of the scenario, managing the separation at the final approach was not difficult. It will be helpful to perform more simulations with a more diverse mix of WTC.
  - For scenario 2, because the RPA was in a holding pattern at 4,000 ft, all the other aircraft had to be vectored, which was a little stressful.
- *Controller 3*
  - For scenario 1, if the RPA maintained the originally planned contingency procedure altitude of 13,000 ft, extra coordination with other aircraft would not be necessary. However, since the RPA was maneuvered to FL160 before the C2 link was lost and maintained FL160 after the loss of C2 link, extra coordination was necessary.
  - It might be better to have a separate sector or communication frequency in case of loss C2 link depending on the controller workload.

VII. Conclusions

This paper proposes steps for developing lost C2 link contingency procedures. First, the existing standard procedures should be evaluated for the traffic volume using historic data. Second, based on the results from the first step, appropriate procedures should be selected and modified if necessary. Third, selected procedures should be evaluated through HiTL simulations with a diverse set of scenarios.

In this study of Seoul TMA, even though controllers do not have experiences with aircraft with such an extended period loss of communication, they reported that the situations were manageable, especially considering the fact that the scenarios were chosen along with the SID and STAR with the highest traffic volumes. The safety and workload analyses also support the controller remarks with no real safety issues with a moderate workload.

Some issues still remain to be addressed. One issue is whether to designate altitude at the holding pattern so that an RPA with lost C2 link will not only fly towards the pre-programmed fix but also will climb or descend to the designated altitude. Another issue is the runway configuration. If the runway direction changes after the departure and the C2 link is lost, especially due to the change in wind direction, it may not be feasible for the RPA to land.

ACKNOWLEDGMENT

This work was supported by the Flight Safety Regulation Development and Integrated Operation Demonstration for Civil UAS (No. 20ATRP-C108186-06) Project under the Aviation Safety Technology Development Program funded by the Ministry of Land, Infrastructure, and Transport (MOLIT), Republic of Korea.

REFERENCES

[1] ICAO RPASP/6-WP/6, RPAS PanelWorking Group 6 (ATM), "Contingency procedures for c2 link loss," 2016.

[2] Korea Airports Corporation. (2020) Flight statistics. [Online]. Available: https://www.airport.co.kr/www/extra/stats/airportStats/layOut.do?cid=2015102917501542253&menuId=397

[3] H. Lee, B.-S. Park, and H.-T. Lee, "Analysis of alerting criteria and daa sensor requirements in terminal area," in *2019 IEEE/AIAA 38th Digital Avionics Systems Conference (DASC)*. IEEE, 2019, pp. 1–9.

[4] S. G. Hart, "Nasa-task load index (nasa-tlx); 20 years later," in *Proceedings of the human factors and ergonomics society annual meeting*, vol. 50, no. 9. Sage publications Sage CA: Los Angeles, CA, 2006, pp. 904–908.

[5] A. J. Tattersall and P. S. Foord, "An experimental evaluation of instantaneous self-assessment as a measure of workload," *Ergonomics*, vol. 39, no. 5, pp. 740–748, 1996.

[6] *DO-365: Minimum Operational Performance Standards for Unmanned Aerial Systems*, RTCA Special Committee 228, 2017.

[7] M. Vincent and D. Jack, "An evaluation of alert thresholds for detect and avoid in terminal operations," in *2018 IEEE/AIAA 37th Digital Avionics Systems Conference (DASC)*. IEEE, 2018, pp. 1–5.

[8] M. J. Vincent, A. Trujillo, D. P. Jack, K. D. Hoffler, and D. Tsakpinis, "A recommended daa well-clear definition for the terminal environment," in *2018 Aviation Technology, Integration, and Operations Conference*, 2018, p. 2873.