Black Box Testing: Experiments with Runway Incursion Advisory Alerting System

Final Report

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Ravi Mukkamala

Department of Computer Science
Old Dominion University
Norfolk, VA 23529-0162
mukka@cs.odu.edu

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Abstract

This report summarizes our research findings on the Black box testing of Runway Incursion Advisory Alerting System (RIAAS) and Runway Safety Monitor (RSM) system. Developing automated testing software for such systems has been a problem because of the extensive information that has to be processed. Customized software solutions have been proposed. However, they are time consuming to develop. Here, we present a less expensive, and a more general test platform that is capable of performing complete black box testing. The technique is based on the classification of the anomalies that arise during Monte Carlo simulations. In addition, we also discuss a generalized testing tool (prototype) that we have developed.

1. Introduction

In order to get insight into the techniques for black box testing, we have adopted Runway Incursion Advisory Alerting System (RIAAS) developed by Rannoch Corporation and Runway Safety Monitor (RSM) system developed by NASA LaRC. Clearly, due to privacy and patent reasons, we were not given access to the source. The only thing that was available was executable code. So our task was to evaluate these two pieces of software and learn the effectiveness of our tools.

The simulator to test the systems was developed by Rannoch Corporation. It was primarily developed to test RIAAS software. However, we used the simulator to test the RSM simulator also. A schematic diagram of the simulator is shown in Figure 1.

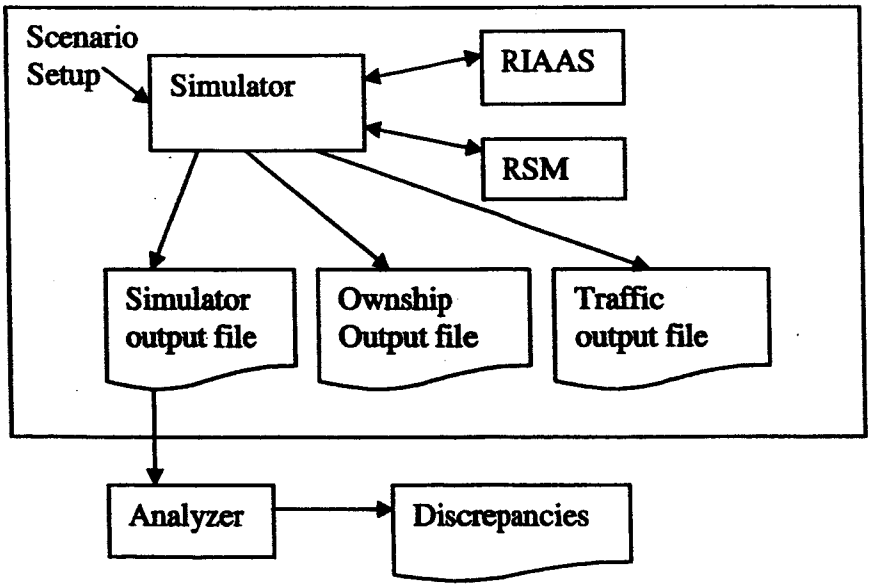

Figure 1. Schematic Diagram of the Test Architecture

To start the simulator, the user chooses the setup parameters. These include the airport and runway type, the orientation/position of the ownship (aircraft under study) and that of the traffic (the other aircraft), single or Monte Carlo simulation, etc. Once the parameters are set, the simulator starts running. During the execution, it has access to the airport data of the chosen airport.

The simulator generates an output containing the information with details of ownship and traffic. The details include (for every 0.5 seconds) the position information, whether or not an alert generated, if so when it was generated, etc. In a Monte Carlo situation, the one that we focused on, several runs (in our case 10,000 runs) are run for each setup. Thus, the details file contains details of the aircrafts for each of these runs at each 0.5 sec duration. The summary file contains a summary for each run. Details for each run include the positions of the two aircrafts and the time at which simulation started, whether or not an alert/warning was generated, and whether or not a collision (or near-collision) occurred during the run. In addition, at the end, it prints the number of collisions and near-collisions in the entire simulation (i.e., 10,000 runs).

In order to compare the performance of RIAAS and RSM, we have run both RIAAS and RSM with simulator input. In order to do further analysis on the ownship and traffic data, we have developed an analyzer program. The program looks at the summary output file, and categorizes each run into one of several classes as described in the next section. The results from the analyzer are summarized in this report. In consultations with NASA, we have identified 24 scenarios that need to be tested. In addition, several other simulations were carried out to test the two software packages. During the testing, we identified several anomalies with the behavior of the simulator. While these are not reflective of the errors in the RIAAS and RSM software, it did cause some problems in our testing and in distinguishing between simulator errors versus the test software errors.

In this report, we first describe a classification of the simulation runs. We then describe the results of our analysis of the selected scenarios. Each scenario has been tested with 10,000 runs.

2. Classification of Monte Carlo Runs

The first step of a black box testing software is to classify the inputs into different types. In the system under consideration (RIAAS/RSM), where input is generated randomly using Monte Carlo generator, we classified inputs into three categories. Figure 2 shows our classification. It is also schematically shown in Table 1.

Collisions: An event is defined as *collision* if the separation distance between ownship and traffic is less than 200 ft.

Near-collision: An event is defined as *near-collision* if the separation distance between ownship and traffic is within 200-300 ft.

Safe or No-collision: An event is defined as *safe* if the separation distance between ownship and traffic is greater than 300 ft.

Ideally, the software under test (SUT) should be able to correctly identify each case (i.e., scenario). However, ineffective software may categorize collisions as non-collisions (namely, *missed alerts*) and non-collisions as collisions. (namely, *false alerts*). We measure the effectiveness of the SUT (RIAAS/RSM) based on the classification in Figure 2. For example, the most effective software would have zero percent *false alerts*, and zero percent of *avoid possible* cases. The *avoid impossible* cases are those where it is impossible to alert collision (or near-collision) by any such software, under the given assumptions.

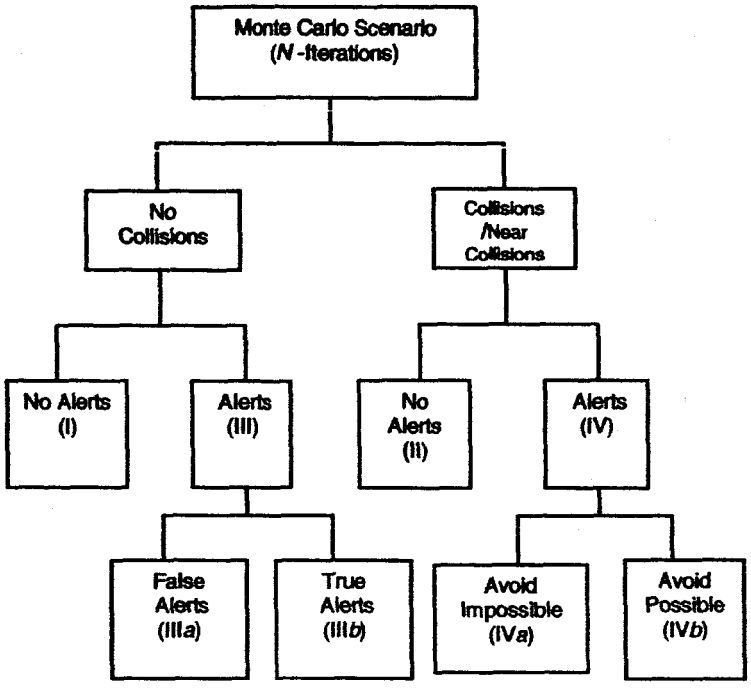

Figure 2. Classification of Monte Carlo Scenario

Category	Result of run	Action
Class I	No collisions or near collisions	Alerts not generated
Class II	Collisions or near collisions	Alerts not generated **(Missed alerts)**
Class III	No collisions or near collisions	Alerts generated
Class IV	Collisions or near collisions	Alerts generated
Class IIIa	No collisions or near collisions	False alerts generated **(there was never a danger of collision)**
Class IIIb	No collisions or near collisions	True alerts generated **(danger was averted due to alerts)**
Class IVa	Collisions or near collisions	Alerts were correctly generated and collision **could not** have been avoided
Class IVb	Collisions or near collisions	Alerts were correctly generated, and collision **could have** been avoided

Table 1. Classification of Monte Carlo Runs

3. Analysis of the Software Under Test (SUT)

In this section, we describe the way we tested the black box software (RIAAS and RSM), and the findings from the analysis.

3.1 Generation of input.

One of the primary considerations in conducting blackbox testing is choosing the right type of test cases that can ensure coverage of all aspects of the software under test (i.e., RIAAS and RSM). Due to the nature of the software and the environment in which it is supposed to run, we have resorted to domain expert knowledge. In particular, we have chosen the scenarios summarized in Tables 2 and 3. Table 2 describes scenarios used for Crossing runway situation and Table 3 for Single runway situation. For each scenario in these tables, 10,000 random input cases were generated and the results categorized into Classes I-IV as described above. Each input consists of starting the ownship and the traffic at certain positions, either in taxiing, arrival, or departure operations. The position of the aircrafts is supplied to the software at frequent intervals, until the designated time elapses. This si repeated for each run.

3.2 Output Analysis

The SUTs (RIAAS and RSM), when subjected to different input scenarios generated by the data generator, make decisions as to whether or not to generate an alert, and when to generate it. During the run, the simulator (same as the data generator) keeps track of the position of the aircrafts as well as the action taken by the software. It also prepares statistics such as the number of collisions, near collisions, missed detections and other supplementary information. This information is analyzed by an analysis program that we developed. The analyzer checks whether or not the software's behavior is as expected. The program also classifies each experiment into one of the types that we described in Figure 2 and Table 1. For example, a near collision event is identified if the closest distance between the ownship and traffic is between 200 and 300ft; the alert flag information is used to identify whether or not alerts were generated. Upon classification of the samples, the analyzer statistics are independently evaluated and compared with the statistics given by the simulator output to check for inconsistencies.

4. Detected anomalies

During our analysis of the software, we identified several anomalies. Some of them are manifestations of the simulator (developed by Rannoch corporation) and others may be limitations of the software (RIAAS and RSM). Below, we demonstrate the application of testing program with some examples.

4.1 Anomaly 1: Collisions and Near Collisions occur without alerts.

This is a serious problem and a weakness of the software. For example:

Consider a near collision case of RIAAS in a single runway scenario where the Owship state is in arrival and traffic state is in taxi. Assuming the type of evasive action taken on

Ownship is RCA and none for traffic, we have the following output for the simulator (verbatim).

Note: The description of examples given below is as follows.

Description	Example
Summary	201
Run number	15.0
Ownship start time	0
Traffic start time	984.3
Distance from traffic to threshold	8202.5
Distance from ownship to threshold	0
The time delay at which pilot receiving RTA	0.0
The time delay at which pilot receiving RCA	0.0
The time at which both ownship and traffic are 3d closest	55.0
The distance at which both ownship and traffic are 3d closest	**262**
The altitude which both ownship and traffic are 3d closest	**0**
The time at which both ownship and traffic are 2d closest	55.0
The distance at which both ownship and traffic are 2d closest	262
The altitude which both ownship and traffic are 2d closest	0
Evasive action taken for both ownship and traffic	N/A
Ownship evasive maneuver	None
The speed of ownship at which evasive action is taken	0.0
The speed of traffic at which evasive action is taken	0.0
Distance from ownship to threshold	0.0
Speed of ownship at which ownship and traffic both are 3d closest	135.0
Speed of traffic at which ownship and traffic both are 3d closest	16.6
Speed of ownship at which both ownship and traffic are 2d closest	135.0
Speed of traffic at which both ownship and traffic are 2d closest	16.6
Ownship x position at which both ownship and traffic are 3d closest	0.0
Ownship y position at which both ownship and traffic are 3d closest	1026.1
Traffic x position at which both ownship and traffic are 3d closest	258.3
Traffic y position at which both ownship and traffic are 3d closest	983.8
RTA number	None
RCA number	None
Time at which traffic has taken evasive action	N/A
Traffic evasive maneuver	None

Table 2. Explanation for the Summary Output

Summary	201	15.0	0	984.3	8202.5	0	0.0	0.0	55.0	**262**
0	55.0	262	0	N/A	None	0.0	0.0	0.0	135.0	16.6
135.0	16.6	0.0	1026.1	258.3	983.8	None	None	N/A	None	

Note: This is one of the cases (case # 9) of Table 2 listed below.

In the above example, we have the start time for ownship is 15s and start time for traffic is 0s. The separation distance between ownship and traffic is **262ft** and altitude being **0ft.**

Clearly this is a near collision case, and alerts were not issued thus falls into class II category

Collision:

Consider a collision case of RIAAS in a single runway scenario where the Owship state is in arrival and traffic state is in taxi. Assuming the type of evasive action taken on Ownship is none and RCA for traffic, number of missed detection being 338.

Summary	339	23.0	0	656.2	8202.5	0	0.0	0.0	38.5	**52ft**
15ft	38.5	50	15	N/A	None	0.0	0.0	0.0	135.0	20.0
135.0	20.0	0.0	684.3	41.1	655.7	None	None	N/A	None	

In the above example, we have the start time for ownship is 23s and start time for traffic is 0s. The separation distance between ownship and traffic is **52ft** and altitude being **15ft.** clearly this is a collision case, and alerts were not issued thus falls into class II category

4.2 Anomaly 2: All 10000 Iterations are not generated for some of the scenarios. For these cases no collision information is printed in the simulator output file.

Consider a collision case of RIAAS in a single runway scenario where the Owship state is in arrival and traffic state is in taxi. Assuming the type of evasive action taken on Ownship is RCA and RCA for traffic, with random generator ON for ownship and OFF for traffic.

Summary	8989	24.0	0.0	1804.6	8202.5	0	0.0	0.0	66.5	1734
0	66.5	1734	0	N/A	None	0.0	0.0	0.0	122.9	20.0	122.9
	20.0	0.0	1570.1	-1718.2		1804.1	None	None	N/A	None	

Note: This is one of the cases (case # 12) of Table 2 listed below.

In the above example, in the simulator output file summary, **8989** is the last run that got generated and stopped after that.(Complete 10000 iterations are not generated) and no collision count:0 is printed.

4.3 Anomaly3: Mismatch in the number of collisions and the number of near collisions printed in the simulator output file and scanned output.

Consider RSM, single runway scenario where the Owship state is in taxi and traffic state is in arrival. Assuming the type of evasive action taken on Ownship is none and none for traffic, with random generator ON for ownship and OFF for traffic.

Metric	Simulator output	Analyzer output
Number of collisions	1150	1281
Number of near-collisions	790	

Note: This is one of the cases (case # 2) of Table 3.

In the above example, in the simulator output file, the number of collisions occurring were 1150, but the actual number of collisions (as reported by the analyzer) were 1281.

4.4 Anomaly 4: In the simulator output file run numbers are being generated sequentially till a certain value, with a break in the middle and continuing again sequentially from there onwards.

Consider a case of RIAAS in a single runway scenario where the Owship state is in arrival and traffic state is in taxi. Assuming the type of evasive action taken on Ownship is RCA and RCA for traffic, with random generator ON for ownship and OFF for traffic.

Summary		**6084**	44.0	0.0	984.3	8202.5	0		0.0	0.0	82.5	2290
15	82.5	2290	15	N/A	None	0.0	0.0	0.0	135.0	20.0	135.0	
	20.0	0.0	684.3	-2270.1		983.8	None	None	N/A	None		
Summary		**6115**	34.0	0.0	3281.0	8202.5	0		0.0	0.0	83.0	2349
0	83.0	2349	0	N/A	None	0.0	0.0	0.0	91.3	20.0	91.3	
	20.0	0.0	2744.6	-2287.4		3280.5	None	None	N/A	None		

Note: This is one of the cases (case # 12) of Table 2 listed below.

In the above example, in the simulator output file, the run numbers were generated from 1 to 6084, the run numbers from 6084 to 6114 were missing, and from 6115 onwards the run numbers are generated again.

4.5 Anomaly 5: In the simulator output file some Run numbers are being repeated and the total number of run numbers generated is greater than 10000.

Consider a case of RIAAS in a single runway scenario where the Owship state is in arrival and traffic state is in taxi. Assuming the type of evasive action taken on Ownship is RTA/RCA and RCA for traffic, with random generator ON for ownship and OFF for traffic.

Summary		**9**	45.0	0.0	3445.1	8202.5	0		0.0	0.0	94.5	2756
0	94.5	2756	0	N/A	None	0.0	0.0	0.0	88.8	20.0	88.8	
	20.0	0.0	2820.6	-2684.1		3444.6	None	None	N/A	None		
Summary		**1**	17.0	0.0	4101.3	8202.5	0		0.0	0.0	71.5	1994
	0	71.5	1994	0	N/A	None	0.0	0.0	0.0	64.5	20.0	
	64.5	20.0	0.0	3467.8	-1890.7		4100.8	None	None	N/A	None	

In the above example, in the simulator output file, the first run number generated is **9** and again started from **1**. The run number **9** is generated again thereafter. This is continued for some more run numbers.

4.6 Anomaly 6: The separation distance between the traffic and ownship is very large and the time at which they are closest is much greater and alert is given for one run. However, when their separation distance is small and the time at which they are closest is smaller, alert is generated for another run.

Consider a case of RIAAS in a single runway scenario where the Owship state is in arrival and traffic state is in taxi. Assuming the type of evasive action taken on Ownship is RCA and RCA for traffic, with random generator ON for ownship and OFF for traffic.

Example run:

Summary		10	14.0	51.0	820.3	8202.5	0	0.0	0.0	53.0	383
9	**53.0**	**383**	**9**	N/A	None	0.0	0.0	0.0	135.0	4.4	135.0
4.4	0.0	798.2	382.4	819.8	None	None	N/A	None			
Summary		1	17.0	22.0	3117.0	8202.5	0	0.0	0.0	**63.5**	**2403**
2161	65.5	937	2260	27.0	Climb	135.0	8.7	0.0	135.0	20.0	135.0
	20.0	0.0	2507.2	-855.8	3116.5	1	None	N/A	None		
Alert	1	RTA	26.5	0	-5924	362	355	3116	0	28.5	0
	-5468	432	319	3116	0						

Note: This is one of the cases (case # 12) of Table 2 listed below.

The separation distance in the 10th run is 383ft, which is very less and expects an alert. But the separation distance in the 1st run is 2403ft for which alert is given.

4.7 Anomaly 7: Alert is generated after the time at which both ownship and traffic are closest

Consider a case of RSM in a crossing runway scenario where the Owship state is in departure and traffic state is in departure. Assuming the type of evasive action taken on Ownship is none and none for traffic,with random generator OFF for ownship and ON for traffic.

Summary		6805	0.0	18.0	0.0	656.2	0	0.0	0.0	**13.5**	3589
0	13.5	3589	0	N/A	None	0.0	0.0	656.2	68.0	191.0	68.0
	191.0	3674.4	12646.1		6227.3	15168.1		None	1	N/A	None
Alert	6805	RCA	**28.5**	5545	10776	0	6227	14672	0	35.5	6806
	9514	183	6227	13839	0						

Note: This is one of the cases (case # 19) of Table 1 listed below.
In the above example the time at which both ownship and traffic are closest is **13.5s**, but alert is generated at **28.5s.**

As mentioned in the introduction, in consultations with NASA, we have run Monte Carlo runs on 24 scenarios. This sample represents typical scenarios of interest for collision detection and avoidance software. The scenarios for crossing runways are summarized in Table 3. The ones for single runway are summarized in Table 4.

Table 5 summarizes the output of RIAAS and the analysis output in each of the 24 scenarios for single runway (Table 4). For each case, the results from Rannoch's simulator as well as the output from our analysis program are included here. For example, in case 22, the simulator identified 376 collisions and 111 near-collisions. These are out of 10,000 Monte Carlo runs run with the same scenario (case 22). Further categorization of these cases is available through the analysis program output. Here, it shows an analysis of all 10,000 runs. 5805 resulted in no collisions and there were no alerts. This is a normal situation and classified under Class I. Then, 3059 resulted in no collisions but there was an alert. Some of the alerts may have been avoided due to the alerts generated by RIAAS while some may have been false alerts. But this table does not distinguish between these two cases. (The only way to separate these cases is to make an identical runs with and without invoking the alerts. But this was not possible due to Monte Carlo simulation with randomized inputs.)

Now let us consider the runs that resulted in collision or near-collision. There are (10,000-5805-3059) or 1136 of these. Of these, 480 (4.8% of all runs and 42.25% of all collisions/near collisions) were due to collisions without alerts. These are the cases that need further investigation to know why alerts were not generated. 540 (5.4% of all runs and 47.53% of all collisions/near-collisions) were due to collisions with alerts. Here, one needs to investigate whether alerts should have been much earlier than when they were by RIAAS. Of the remaining, 20 resulted in near collisions without alerts (0.2% of all runs and 1.76% of all collisions/near collisions). These need further investigation. The rest 96 (0.96% of all runs and 8.45% of all collisions/near collisions) were due to near-collisions with alerts. From here, the value of the analysis program and how it provides more useful information than the simulator should be evident.

Tables 6, 7, and 8 are similar to this one but deal with RSM and RIAAS and single and crossing runways.

Tables 9-16, also provided by our analysis program, further analyzes the cases of collisions and near-collisions. It gives a histogram of times between the start time of ownship and the time at which the traffic and ownship are the closest. So if this time is large enough, we can conclude that the collision could have been avoided. However, if this is small, we can conclude that the collision could not have been avoided.

Scenario#	Ownship	Traffic	Evasive Action of Ownship	Evasive Action of Traffic	Random Generator	
					Ownship	Traffic
1	Arrival	Arrival	None	None	OFF	ON
2	Arrival	Arrival	None	None	ON	OFF
3	Arrival	Arrival	RCA	None	OFF	ON
4	Arrival	Arrival	RCA	None	ON	OFF
5	Arrival	Arrival	RCA	RCA	OFF	ON
6	Arrival	Arrival	RCA	RCA	ON	OFF
7	Arrival	Departure	None	None	OFF	ON
8	Arrival	Departure	None	None	ON	OFF
9	Arrival	Departure	RCA	None	OFF	ON
10	Arrival	Departure	RCA	None	ON	OFF
11	Arrival	Departure	RCA	RCA	OFF	ON
12	Arrival	Departure	RCA	RCA	ON	OFF
13	Departure	Arrival	None	None	OFF	ON
14	Departure	Arrival	None	None	ON	OFF
15	Departure	Arrival	RCA	None	OFF	ON
16	Departure	Arrival	RCA	None	ON	OFF
17	Departure	Arrival	RCA	RCA	OFF	ON
18	Departure	Arrival	RCA	RCA	ON	OFF
19	Departure	Departure	None	None	OFF	ON
20	Departure	Departure	None	None	ON	OFF
21	Departure	Departure	RCA	None	OFF	ON
22	Departure	Departure	RCA	None	ON	OFF
23	Departure	Departure	RCA	RCA	OFF	ON
24	Departure	Departure	RCA	RCA	ON	OFF

Table 3. Blackbox Test Scenarios for Crossing Runway

Case#	Ownship	Traffic	Evasive Action of Ownship	Evasive Action of Traffic	Random Generator	
					Ownship	Traffic
1	Taxi	Arrival	None	None	OFF	ON
2	Taxi	Arrival	None	None	ON	OFF
3	Taxi	Arrival	RCA	None	OFF	ON
4	Taxi	Arrival	RCA	None	ON	OFF
5	Taxi	Arrival	RCA	RCA	OFF	ON
6	Taxi	Arrival	RCA	RCA	ON	OFF
7	Arrival	Taxi	None	None	OFF	ON
8	Arrival	Taxi	None	None	ON	OFF
9	Arrival	Taxi	RCA	None	OFF	ON
10	Arrival	Taxi	RCA	None	ON	OFF
11	Arrival	Taxi	RCA	RCA	OFF	ON
12	Arrival	Taxi	RCA	RCA	ON	OFF
13	Taxi	Departure	None	None	OFF	ON
14	Taxi	Departure	None	None	ON	OFF
15	Taxi	Departure	RCA	None	OFF	ON
16	Taxi	Departure	RCA	None	ON	OFF
17	Taxi	Departure	RCA	RCA	OFF	ON
18	Taxi	Departure	RCA	RCA	ON	OFF
19	Departure	Taxi	None	None	OFF	ON
20	Departure	Taxi	None	None	ON	OFF
21	Departure	Taxi	RCA	None	OFF	ON
22	Departure	Taxi	RCA	None	ON	OFF
23	Departure	Taxi	RCA	RCA	OFF	ON
24	Departure	Taxi	RCA	RCA	ON	OFF

Table 4. Blackbox Test Scenarios for Single Runway

Case#	Analysis Program Output						Simulator Output	
	No Collisions, No alerts (Class I)	No Collisions, with alerts (Class III)	Collisions + Near Collisions, with alerts and without alerts (Class2 + Class4)				Collisions + Near Collisions, with alerts and without alerts (class2 +class4)	
			Collisions without Alerts	Collisions with Alerts	Near Collisions Without Alerts	Near Collisions With Alerts	Collisions	Near Collisions
1	6903	3097	0	0	0	0	0	0
2	1655	6265	0	1283	0	797	1150	765
3	5635	4365	0	0	0	0	0	0
4	1656	7732	0	295	0	317	253	355
5	5728	3232	0	0	0	0	0	0
6	1655	8252	0	42	0	51	0	24
7	2120	5800	0	1283	0	797	1150	765
8	7237	2763	0	0	0	0	0	0
9	7233	2767	0	0	0	0	0	0
10	2344	7656	0	0	0	0	0	0
11	7929	0	1283	0	797	0	1150	765
12	6517	2448	0	0	0	0	0	0
13	6352	2342	570	461	4	271	415	320
14	1718	6404	0	1132	0	746	1129	950
15	6785	434	480	685	21	390	541	511
16	6404	3322	0	0	0	274	0	358
17	6206	3082	480	490	21	169	49	121
18	3453	6547	0	0	0	0	0	0
19	6837	1287	0	1129	0	747	1129	950
20	4972	1861	480	1146	20	539	982	320
21	6837	1916	0	711	0	536	711	739
22	5805	3059	480	540	20	96	376	111
23	6837	3161	0	0	0	2	0	565
24	5616	3398	480	406	20	80	361	77

Table 5. RIAAS, Single Runway–Comparison of Analysis Program output with Simulator output

Case#	Analysis Program Output						Simulator Output	
	No Collisions, No alerts (Class I)	No Collisions, with alerts (Class III)	Collisions + Near Collisions, with alerts and without alerts (Class2 + Class4)				Collisions + Near Collisions, with alerts and without alerts (class2 +class4)	
			Collisions without Alerts	Collisions with Alerts	Near Collisions Without Alerts	Near Collisions With Alerts	Collisions	Near Collisions
1	4533	5467	0	0	0	0	0	0
2	1601	6328	0	1281	0	790	1150	790
3	2234	7766	0	0	0	0	0	0
4	1604	8341	0	4	0	51	0	0
5	5434	4566	0	0	0	0	0	0
6	1604	8340	0	4	0	52	0	0
7	4564	5436	0	0	0	0	0	0
8	3345	6655	0	0	0	0	0	0
9	7456	2544	0	0	0	0	0	0
10	7648	2352	0	0	0	0	0	0
11	4544	5456	0	0	0	0	0	0
12	7657	2343	0	0	0	0	0	0
13	5914	2916	512	486	2	144	450	144
14	3443	6557	0	0	0	0	0	
15	6145	2750	555	112	5	433	326	557
16	5681	3432	0	0	0	0	0	0
17	6143	3109	556	153	5	34	0	30
18	6243	3757	0	0	0	0	0	0
19	6304	1820	0	1129	0	747	1129	750
20	5616	3078	480	551	0	275	982	350
21	3454	6566	0	0	0	0	0	0
22	4564	5436	0	0	0	0	0	0
23	3456	6544	0	0	0	0	0	0
24	5597	3693	480	184	0	0	354	24

Table 6. RSM, Single Runway– Comparison of Analysis Program output with Simulator Output

Case#	Analysis Program Output						Simulator Output	
	No Collisions, No alerts (Class I)	No Collisions, with alerts (Class III)	Collisions + Near Collisions, with alerts and without alerts (Class2 + Class4)				Collisions + Near Collisions, with alerts and without alerts (class2 +class4)	
			Collisions without Alerts	Collisions with Alerts	Near Collisions Without Alerts	Near Collisions With Alerts	Collisions	Near Collisions
1	2323	7677	0	0	0	0	0	0
2	1223	8777	0	0	0	0	0	0
3	4353	5647	0	0	0	0	0	0
4	3243	6757	0	0	0	0	0	0
5	3422	6578	0	0	0	0	0	0
6	2342	7658	0	0	0	0	0	0
7	0	10000	0	0	0	0	0	0
8	3214	6786	0	0	0	0	0	0
9	2342	7658	0	0	0	0	0	0
10	4564	5436	0	0	0	0	0	0
11	0	10000	0	0	0	0	0	0
12	4354	5646	0	0	0	0	0	0
13	3214	6786	0	0	0	0	0	0
14	0	10000	0	0	0	0	0	0
15	5365	4635	0	0	0	0	0	0
16	4353	5647	0	0	0	0	0	0
17	4354	5646	0	0	0	0	0	0
18	2342	7658	0	0	0	0	0	0
19	2323	7677	0	0	0	0	0	0
20	3243	6757	0	0	0	0	0	0
21	3214	6786	0	0	0	0	0	0
22	4629	5203	0	0	0	0	168	179
23	4334	5666	0	0	0	0	0	0
24	4631	5201	0	168	0	0	168	179

Table 7. RIAAS, Crossing Runway– Comparison of Analysis Program output with Simulator Output

Case#	Analysis Program Output						Simulator Output	
	No Collisions, No alerts (Class I)	No Collisions, with alerts (Class III)	Collisions + Near Collisions, with alerts and without alerts (Class2 + Class4)				Collisions + Near Collisions, with alerts and without alerts (Class2 + Class4)	
			Collisions without Alerts	Collisions with Alerts	Near Collisions Without Alerts	Near Collisions With Alerts	Collisions	Near Collisions
1	8358	1642	0	0	0	0	0	0
2	8121	1879	0	0	0	0	0	0
3	0	10000	0	0	0	0	0	0
4	6363	3637	0	0	0	0	0	0
5	9463	547	0	0	0	0	0	0
6	9126	874	0	0	0	0	0	0
7	0	10000	0	0	0	0	0	0
8	4786	5214	0	0	0	0	0	0
9	0	10000	0	0	0	0	0	0
10	4801	5199	0	0	0	0	0	0
11	3723	6277	0	0	0	0	0	0
12	4807	5193	0	0	0	0	0	0
13	2868	7132	0	0	0	0	0	0
14	2869	7131	0	0	0	0	0	0
15	4567	5433	0	0	0	0	0	0
16	5424	4576	0	0	0	0	0	0
17	7632	2368	0	0	0	0	0	0
18	2858	7142	0	0	0	0	0	0
19	0	10000	0	0	0	0	0	0
20	3902	5930	0	168	0	0	168	179
21	1231	8769	0	0	0	0	0	0
22	3891	6109	0	0	0	0	0	0
23	5596	4404	0	0	0	0	0	0
24	4328	5672	0	0	0	0	0	0

Table 8. RSM, Crossing Runway– Comparison of Analysis Program output with Simulator Output

Case#	The time gap between the start time of ownship or traffic to the time at which both ownship and traffic are closest.													
	Collision without alerts							Collision with alerts						
	<0	0-5	5-10	10-15	15-20	20-25	>25	<0	0-5	5-10	10-15	15-20	20-25	>25
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	1	0	421	673	188	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	279
4	0	0	0	0	0	0	0	0	1	0	0	42	252	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	1	0	0	35	0	6
7	0	0	0	0	0	0	0	0	1	0	421	673	188	0
8	0	1	0	421	673	186	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	1	0	421	673	188	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	556	4	0	0	0	0	0	0	72	111	148	105	25	0
14	0	0	0	0	0	0	0	0	1	0	478	480	173	0
15	479	1	0	0	0	0	0	87	76	97	144	83	67	131
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	479	1	0	0	0	0	0	87	82	50	19	0	0	5
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	1	0	478	480	170	0
20	479	1	0	0	0	0	0	0	87	75	111	148	105	25
21	0	0	0	0	0	0	0	0	1	0	335	324	51	0
22	479	1	0	0	0	0	0	87	67	52	31	15	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	479	1	0	0	0	0	0	87	67	49	0	0	0	0

Table 9. Statistics of RIAAS-Single Runway, Collision Information.

Note: The above table has an immediate implication of the case where a collision can be avoided. If To be the Ownship Start time and Tt be the traffic Start Time and the closest seperation between Ownship and traffic be Tc. The time gap between the start time of ownship or traffic to the time at which both ownship and traffic are closest. Is Tg= Tc-maximum(Tt,To). As long as Tg is smaller than 5 seconds, the collision is very difficult to avoid, even if an alert is generated. However, if the Tg is between 10-15, a collision can be avoided upon noting an alert. In the particular case #7 of collisions with alerts, there are 421 cases for which the time gap Tg is about 10-15 secs. These are all collisions generated with alerts with longer time gap, hence a collision can be avoided.10-15 seconds of time and collision can be avoided. Collision cannot be avoided in the cases for time gap which lies between 0-5secs.

Case#	The time gap between the start time of ownship or traffic to the time at which both ownship and traffic are closest.													
	Collision without alerts							Collision with alerts						
	<0	0-5	5-10	10-15	15-20	20-25	>25	<0	0-5	5-10	10-15	15-20	20-25	>25
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	345	254	423	59	200	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	279
4	0	0	0	0	0	0	0	0	0	4	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	4	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	506	6	0	0	0	0	0	34	46	213	24	75	44	50
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	550	5	0	0	0	0	0	12	34	12	42	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	550	6	0	0	0	0	0	51	36	66	0	0	0	0
18	0	0	0	0	0	0	0	0	0	00	0	0	0	0
19	0	0	0	0	0	0	0	343	454	232	32	48	20	0
20	479	1	0	0	0	0	0	0	87	75	111	148	105	25
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	479	1	0	0	0	0	0	0	23	76	50	35	0	0

Table 10. Statistics of RSM-Single Runway, Collision Information

Note: As Mentioned in the above note of table 7, if Tg is between 10-15, a collision can be avoided upon noting an alert. In the particular case #2 of collisions with alerts, there are 423 cases for which the time gap Tg is about 10-15 secs. These are all collisions generated with alerts with longer time gap, hence a collision can be avoided.10-15 seconds of time and collision can be avoided. Collision cannot be avoided in the cases for time gap which lies between 0-5secs.

Case#	The time gap between the start time of ownship or traffic to the time at which both ownship and traffic are closest.													
	NearCollision without alerts							NearCollision with alerts						
	<0	0-5	5-10	10-15	15-20	20-25	>25	<0	0-5	5-10	10-15	15-20	20-25	>25
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	1	239	109	102	339	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	1	0	16	32	0	2
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	1	0	7	32	0	12
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	2	0	0	0	0	0	0	44	65	34	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	5	0	0	0	0	0	0	76	87	95	86	45	50
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	5	0	0	0	0	0	0	34	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	1	404	101	0	201	40
20	0	0	0	0	0	0	0	0	33	83	41	67	51	0
21	0	0	0	0	0	0	0	0	54	87	45	49	40	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 11. Statistics of RSM-Single Runway, Near Collision Information

Note: As mentioned in the above note of table 7, if the Tg is between 10-15, a collision can be avoided upon noting an alert. In the particular case #2 of collisions with alerts, there are 109 cases for which the time gap Tg is about 10-15 secs. These are all collisions generated with alerts with longer time gap, hence a collision can be avoided. 10-15 seconds of time and collision can be avoided. Collision cannot be avoided in the cases for time gap which lies between 0-5secs.

Case#	The time gap between the start time of ownship or traffic to the time at which both ownship and traffic are closest.													
	NearCollision without alerts							NearCollision with alerts						
	<0	0-5	5-10	10-15	15-20	20-25	>25	<0	0-5	5-10	10-15	15-20	20-25	>25
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	1	239	109	102	339	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	1	0	0	50	0	266
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	1	0	9	31	1	9
7	0	0	0	0	0	0	0	0	1	239	109	102	339	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	1	239	109	102	339	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	2	0	0	0	0	0	0	44	65	34	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	1	20	0	0	0	0	0	39	57	57	84	39	114
16	0	0	0	0	0	0	0	0	1	13	33	44	41	142
17	0	1	20	0	0	0	0	0	1	51	17	0	0	8
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	1	404	101	0	201	40
20	0	7	13	0	0	0	0	0	27	69	41	67	51	0
21	0	0	0	0	0	0	0	0	54	87	45	49	40	0
22	0	7	13	0	0	0	0	0	1	15	15	9	0	0
23	0	0	0	0	0	0	0	0	1	0	0	0	0	0
24	0	7	13	0	0	0	4	0	1	35	0	0	0	4

Table 12. Statistics of RIAAS-Single Runway, Near Collision Information

Note: As mentioned in the above note of table 7, if Tg is between 10-15, a collision can be avoided upon noting an alert. In the particular case #2 of collisions with alerts, there are 109 cases for which the time gap Tg is about 10-15 secs. These are all collisions generated with alerts with longer time gap, hence a collision can be avoided. 10-15 seconds of time and collision can be avoided. Collision cannot be avoided in the cases for time gap which lies between 0-5secs.

Case#	The time gap between the start time of ownship or traffic to the time at which both ownship and traffic are closest.													
	Collision without alerts							Collision with alerts						
	<0	0-5	5-10	10-15	15-20	20-25	>25	<0	0-5	5-10	10-15	15-20	20-25	>25
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	1	0	0	0	0	167
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	1	0	0	0	0	167

Table 13. Statistics of RIAAS-Crossing Runway, Collision Information

Note: As mentioned in the above note of table 7, if Tg is greater than 25s, a collision can be avoided upon noting an alert. In the particular case #22 of collisions with alerts, there are 167 cases for which the time gap Tg is greater than 25 secs. These are all collisions generated with alerts with longer time gap, hence a collision can be avoided. Greater than 25 seconds of time and collision can be avoided. Collision cannot be avoided in the cases for time gap which lies between 0-5secs.

Case#	The time gap between the start time of ownship or traffic to the time at which both ownship and traffic are closest.													
	Collision without alerts							Collision with alerts						
	<0	0-5	5-10	10-15	15-20	20-25	>25	<0	0-5	5-10	10-15	15-20	20-25	>25
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	1	0	0	0	0	167
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 14. Statistics of RSM-Crossing Runway, Collision Information

Note: As mentioned in the above note of table 7, if Tg is greater than 25s, a collision can be avoided upon noting an alert. In the particular case #20 of collisions with alerts, there are 167 cases for which the time gap Tg is greater than 25 secs. These are all collisions generated with alerts with longer time gap, hence a collision can be avoided. Greater than 25 seconds of time and collision can be avoided. Collision cannot be avoided in the cases for time gap which lies between 0-5secs.

Case#	The time gap between the start time of ownship or traffic to the time at which both ownship and traffic are closest.													
	NearCollision without alerts							NearCollision with alerts						
	<0	0-5	5-10	10-15	15-20	20-25	>25	<0	0-5	5-10	10-15	15-20	20-25	>25
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 15. Statistics of RIAAS-Crossing Runway, Near Collision Information

Note: There is no information related to the above mentioned note of table 9.

Case#	The time gap between the start time of ownship or traffic to the time at which both ownship and traffic are closest.													
	Near Collision without alerts							Near Collision with alerts						
	<0	0-5	5-10	10-15	15-20	20-25	>25	<0	0-5	5-10	10-15	15-20	20-25	>25
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table16. Statistics of RSM-Crossing Runway, Near Collision Information

Note: There is no information related to the above mentioned note of table 9.

5. Conclusion

In this report, we have summarized the results that we obtained in running the RIAAS and RSM software and attempted to evaluate their efficacy in avoiding collision/near-collision situations. In this process, we have categorized different runs into four primary classes depending the outcome. The information provided here should be used to further improve RIAAS and RSM software.