

**Performance Analysis of Distributed Attack Detection (DAD)
Addendum to the Critical Infrastructure Security Showdown (CISS) 2019 Report**

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This report is an addendum to the CISS2019 report. It contains details of experimental evaluation of the Distributed Attack Detection (DAD) method and its corresponding tool, against the 4-days of data obtained during CISS2019.

While DAD was evaluated during CISS2019, due to miscommunications among the organizers, an older version of DAD, namely DAD-2018 was used and not the new version designed for use in CISS 2019. Soon after realizing the mistake, iTrust launched an investigation that led to the re-evaluation of DAD on exactly the same data collected during CISS2019, on which DAD2018 and other technologies were evaluated. Details of the re-evaluation, with results, are in this report.

All data used in the performance evaluation of DAD is publicly available and can be used to validate the results reported here.

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1. Introduction

The iTrust annual Critical Infrastructure Security Showdown (CISS 2019) event was conducted during August 27-30, 2019 at iTrust in SUTD. Distributed Attack Detection (DAD) was one of the several methods tested during this event for its effectiveness in detecting anomalies resulting from cyber-attacks. This report is a summary of the performance of a tool, also named DAD, that implements the anomaly detection method. This report is to be considered as an addendum to the original CISS2019 report.

2. Why this report?

Performance of DAD during CISS2019 came as a surprise to the inventors¹ of the design-centric method for detecting plant anomalies. The detection effectiveness was computed to be 33% with a false alarm rate of 52%. Inventors of DAD were convinced that unless something went wrong in the implementation of DAD, or its integration with the anomaly detection infrastructure used during CISS2019, DAD could not lead to such poor performance.

A thorough investigation was launched immediately by the authors of this report to determine what went wrong, and if possible, fix it without any change in the method used in DAD, i.e., design-centric approach for anomaly detection. The outcome of this investigation is presented in this report.

In this report DAD-2018 refers to the set of invariants² that were designed, tuned and tested on Secure Water Treatment (SWaT) testbed data collected during 2017. DAD-2019 refers to a modified and retuned set of invariants designed for use during CISS2019 but not used.

During CISS2019, by mistake an older version of DAD (DAD-2018), was integrated into PlantViz (see para 3). The mistake occurred due to several reasons the primary being (a) the developer of DAD left for USA before CISS2019 for a 6-month residency at CMU, and (b) miscommunication between the developer and the team responsible for integrating DAD with PlantViz.

3. Tools used in assessing DAD-2019

iTrust researchers have developed a rich set of tools to enable experimentation with anomaly detection in an operational plant. One such tool is PEPR used in the retesting of DAD. PEPR consists of PlantViz, Player, PlantIO, and a collection of detectors. PlantViz enables real time visualization of plant data using multi-plots of plant state. PlantIO enables integration of anomaly detectors into PEPR. Player can replay data collected from a past run of SWaT. Thus, PEPR enables a replay of the plant data as well as visualization. Anomaly detectors can be tested during the replay exactly as if the data is coming in real-time from the plant to the detector via PlantIO.

¹ DAD, the method, was conceived by Sridhar Adepur and Aditya Mathur.

² An “invariant” is a condition that, if violated, implies a process anomaly.

4. Dataset used for assessing the performance of DAD-2019

The entire assessment on DAD-2019 was done on 4-days of data collected during CISS-2019 from the SWaT testbed. This data is exactly the one that was input to DAD-2018 and also to all the other detectors whose performance was evaluated during CISS-2019 and reported. The data is also available publicly and can be downloaded upon request³.

The CISS2019 data consists of a total of 136,805 rows of state information. Each row contains measurements from 28 sensors as recorded in the SWaT Historian sampled at 1-second intervals. Some of these rows contain “Bad data” that was recorded when the plant was being reset while moving from one RED team (attack team) to the next⁴. The sensors measure, for example, the water level in each of the five tanks, all pumps, all valves, all switches, all chemical sensors, and all flow meters.

A complete list of attacks launched during CISS2019 and the anomalies generated, is in Table 1. This table also lists whether an attack was detected. Attacks indicated as not detected did not cause any process anomaly, i.e., were unsuccessful and hence were not detected. Such as situation is listed in the table as “Attack not realized in the data.”

5. Procedure used in assessing the performance of DAD-2019

A multi-phase procedure was used to evaluate DAD-2019 against CISS2019 data. Different phases in this procedure are described next.

Phase I: Integration: In this phase DAD-2019 was integrated into PEPR. Doing so enables the detector to receive plant data being replayed. Such integration is a standard procedure and was used in CISS-2019. The integration required coding of all 54 invariants in DAD-2019 in Python, adding code to interface with PlantIO and ensuring that DAD-2019 and PlantIO are communicating as expected. The entire integration was carried out by the developer in collaboration with the developer of PEPR.

Prior to integration, all invariants were updated with respect to current duration of actuator transitions. For example, motorized valve transition used to take 7 seconds (max) in 2016 where in 2020 that value is changed to 10 or 11 seconds. Thus, a lot of false alarms would be raised if we were to use the same time delay (7 seconds).

Phase II: Assessment: In this phase the Player in PEPR was used to extract data from the dataset, one row at a time, and input to DAD-2019. In turn, for each row of data received, DAD-2019 evaluated all invariants and reported either an alert or no alert. In case an alert was reported, the violated invariants were also made available to PEPR for display and recording.

Results from the experimental validation done in this phase are tabulated in Table 2. As shown, 16 attacks are detected out of a total 22 relevant attacks to DAD-2019 from the list of attacks in CISS 2019; the remaining six

³ https://itrust.sutd.edu.sg/itrust-labs_datasets/

⁴ CISS-2019 had multiple RED and BLUE teams. DAD was a part of the iTrust BLUE team that was tasked with evaluating the technologies developed in iTrust. The RED teams launched attacks on SWaT during the event.

attacks did not lead to any process anomaly. A total of 85 alerts are generated by DAD-2019. For most of the attacks DAD-2019 generated to ensure that the invariant violation is not accidental due perhaps to errors in coding or data transmission between PlantIO and DAD-2019.

Phase III: Validation of assessment results from Phase II: Results from experimental validation in Phase II were made available to another iTrust researcher. The task assigned was to validate data in Table 2. In this phase DAD-2019 was run again against the CISS2019 data in PlantIO. However, this time the alerts were being analysed by a different individual than in Phase II. A total of 108 alerts are generated by DAD. The outcome of this phase is included in Tables 3-A to 3-D.

Phase IV: Cross validation of assessment results: Discrepancies between the results obtained in Phase II and Phase III can be observed by comparing the data in Table 2 with that in Tables 3A through 3D. A detailed examination of the discrepancies followed. During this examination both members of the validation team were involved. A thorough analyses of the observed discrepancies led to a new set of results reported in Tables 4A-4D. The causes for the observed discrepancies are mentioned below.

- (a) During CISS2019 the attackers did not inform judges when carrying out attacks as most likely they were testing the attacks or finding ways to attack. This led to incomplete attack logs that were used during the analysis of CISS2019 data and reported earlier.
- (b) A few unsuccessful attacks, i.e., those that did not lead to any process anomaly, resulted in discrepancy in the CISS2019 data despite no changes made to the SWaT system. These discrepancies were not accounted for in Phase III analysis. Such discrepancies include, for example, alarm on Fri, 30 Aug 2019, 12:04:00. During CISS 2019, it was assumed that no changes were made as there were no visible changes in SCADA, but such alarms caused changes to the data recorded in the Historian.
- (c) There seems to be repeated behaviour of incorrect data in the Historian file. There were “BAD INPUTS” in the data every so often. For example, glitches on Day 1, 2 and 3 estimated cause the same behaviour and errors for these three days. DAD-2019 picked up such bad data and raised an alarm even though there were no attacks carried out during that period.
- (d) A software attack logger was used to log attacks launched during CISS2019. All logging, i.e., data entry, using this software was manual and based on information orally transmitted by the attackers to the human logger. The logs so created were used as the basis for the analysis presented in the CISS2019 report. Not all moves by the attackers were logged. Thus, while such unrecorded attacks led to anomalies, and were reported by DAD-2018, they were considered as false alarms by the data analysis team.

All discrepancies found in Phase III were fully reconciled. A summary of the performance of DAD-2019, is in Table 5.

6. Evolution of DAD

The distributed attack detection method, referred to as DAD, was invented in iTrust by Sridhar, a PhD student, and his advisor Professor Aditya Mathur during 2015-2018. The first publication that reported an early version of DAD appeared in 2016¹. Several publications have reported the method and its effectiveness evaluated

experimentally. Table 6 provides a summary of all experimental evaluations performed since DAD was first evaluated and the results published.

7. Summary and Conclusion

Over the years DAD has evolved into a highly effective method for detecting process anomalies. Several detectors based on machine learning and control theory have been evaluated in iTrust. None of these falls anywhere close to DAD in terms of its high detection rate and low false alarms. While the goal of 100% detection rate with 0% false alarms is perhaps ideal and unachievable, DAD comes as close this goal as one can using any practical method.

Other than its high detection rate and a low rate of false alarms, DAD offers the advantage of locating the domain of a plant where the anomaly has occurred. Such location identification has been a challenge for detection algorithms based on machine learning. A method named PlantProtect for protecting a plant from any damage is being implemented in iTrust alongside DAD. Together, DAD and PlantProtect would provide an excellent set of tools for enhancing the security of a plant while simultaneously protecting it from damage.

The key challenge in creating DAD for a large plant lies in the generation of invariants. Generating invariants manually is error prone. Further, for plants with hundreds of sensors, manual creation of invariants is a practical impossibility. Hence the generation of DAD is currently being automated in iTrust. The automation begins with the plant design available as, for example a CSD or PID file, and a set of atomic invariants derived from the fundamental laws of Physics. Additional higher order invariants are generated automatically using components and their interactions derived from the design, and the atomic invariants.

8. Acknowledgements

Thanks to Muhammad Syuqri Bin Johanna for providing invaluable assistance in integrating DAD-2019 with PEPR.

References

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Appendix: Data tables

Table 1: Summary of attacks launched and detection by DAD

S.No	Attack ID	Time	Attack Description	Detected (D) / Not detected (N)	Remarks
1	CTO006	08/27/2019 11:18:00	Attempt to turn on pump 102	D	MV201 is open when LIT301 >1000 but pump P101 is not On in the data
2	CTO009	08/27/2019 11:41:00	Opened and Closed MV101 using Pycomm at 11:41 AM	D	Realized at 12:40:39 to 12:41:39
3	CTO010	08/27/2019 11:43:00	Turned On and OFF P101 using Pycomm	D	Realized at 12:43:19 to 12:44:22
4	CTO015	08/27/2019 12:21:00	Taking over control of pump P101 (over VNC)	N	Attack not realized in the data.
5	CTO016	08/27/2019 12:31:00	Control water level at 800 (over VNC)	N	Attack not realized in the data.
6	CTO017	08/27/2019 12:33:00	Control water level at 750 (over VNC)	N	Attack not realized in the data.
7	CCO023	08/27/2019 16:58:00	Attempting to close MV201	D	Attack realized during 16:56:44 to 17:00:22.
8	CCO024	08/27/2019 18:04:00	Attack on P101. P101 turned on via vnc	D	Realized at 18:07:51 to 18:10:27 Turn on is correct according to control logic to turn on Pump P101, due to the state of LIT301 (677)
9	CCO025	08/27/2019 18:04:00	Attempt to bring down water level to 700 at stage 1 via vnc	D	Realized at 18:04:00 to 18:10:40
10	THO006	08/28/2019 09:51:00	Turned on and off P101	D	-
11	THO007	08/28/2019 09:53:00	Attempting to open MV101	D	Realized at 09:54:04 to 09:54:43.

12	THO008	08/28/2019 09:59:00	Attempting to turn on and off chemical doser pump P201	D	-
13	THO011	08/28/2019 10:36:00	Turn on both P101 and P102	D	Realized at 10:33:59
14	NSO004	08/28/2019 14:50:00	Attempting to do Layer 0 MITM attack on LIT101. Spoof water level to 300	D	-
15	NSO012	08/28/2019 17:07:00	Launch on DPIT pressure	N	Attack not realized in the data.
16	ITO004	08/29/2019 10:10:00	Attack open MV201 using pycomm.	D	Realized at 10:11:49 to 10:13:23
17	ITO006	08/29/2019 10:20:00	Turned on P601 to flood Tank 101 using pycomm.	D	-
18	ITO007	08/29/2019 10:24:00	Opened P401. Force P403 P404 to close so that AIT401 remains high.	N	AIT401 is not high in the data. Attack not realized in the data.
19	ITO009	08/29/2019 10:41:00	Change the LIT101 values to 222 using the phone from the Internet.	D	-
20	ITO020	08/29/2019 11:10:00	Attack on MV303. Set to open.	N	Realized at 11:21:41 to 11:24:02
21	ITO022	08/29/2019 11:25:00	Read the LIT101 values on the phone from the internet and changed the LIT101 values to 100 using an app.	D	-
22	ITO025	08/29/2019 11:44:00	UV turned off by sending command to PLC and RIO.	N	Attack not realized in the data. 11:42:13 to 11:42:37

Table 2: List of alarms raised and cause

S.No	Timestamp	Cause	False alarm? [Yes/No]
		27 th Aug	
1	27/08/2019 11:09:15 AM	P101 ON but FIT201 is less	No
2	27/08/2019 11:19:05 AM	MV201 Open	No (1 from Table 2)
3	27/08/2019 11:41:33 AM	MV101 Open	No (2 from Table 2)
4	27/08/2019 11:42:23 AM	P101 P102 ON	No
5	27/08/2019 12:00:42 PM	MV302 Open	No
6	27/08/2019 12:01:28 PM	P301 P302 ON	No
7	27/08/2019 12:01:31 PM	P301 P302 ON	No
8	27/08/2019 12:03:35 PM	P301 P302 ON	No
9	27/08/2019 12:20:36 PM	MV201 changed	No
10	27/08/2019 12:23:07 PM	MV101 changed	No
11	27/08/2019 12:40:55 PM	MV101 changed	No
12	27/08/2019 12:41:39 PM	P101, P102 OFF when LIT301 Low	No (3 from Table 2)
13	27/08/2019 12:50:17 PM	P101 P102 ON	No
14	27/08/2019 12:51:44 PM	LIT101 changed	No
15	27/08/2019 12:52:26 PM	LIT101 changed	No
16	27/08/2019 12:52:46 PM	P101 P102 ON	No
17	27/08/2019 12:53:21 PM	LIT101 changed	No
18	27/08/2019 12:53:49 PM	MV101 changed	No
19	27/08/2019 01:18:05 PM	LIT101 changed	No
20	27/08/2019 01:19:23 PM	LIT101 changed	No
21	27/08/2019 01:22:47 PM	LIT401 changed	No
22	27/08/2019 01:22:56 PM	LIT401 changed	No
23	27/08/2019 01:29:25 PM	LIT101 changed	No
24	27/08/2019 01:31:13 PM	LIT101 changed	No
25	27/08/2019 03:50:53 PM	MV201 closed when LIT301 Low	No (7 from Table 2)
26	27/08/2019 03:55:05 PM	Changed MV301, 302, 303	No
27	27/08/2019 03:55:06 PM	P301 P302 ON	No
28	27/08/2019 04:51:41 PM	P101 P102 OFF when LIT301 Low	No
29	27/08/2019 04:57:03 PM	P101 P102 OFF when LIT301 Low	No
30	27/08/2019 05:03:39 PM	P101 P102 OFF when LIT301 Low	No
31	27/08/2019 06:01:37 PM	MV101 changed	No
32	27/08/2019 06:04:06 PM	P101 P102 ON	No (9 from Table 2)
33	27/08/2019 06:06:31 PM	P101 P102 OFF when LIT301 Low	No (8 from Table 2)

34	27/08/2019 06:10:29 PM	P101 P102 ON	No (9 from Table 2)
		28 th August	
35	28/08/2019 09:51:01 AM	Pumps P101, P102 ON	No
36	28/08/2019 09:51:18 AM	Pumps P101, P102 ON	No (10 from Table 2)
37	28/08/2019 09:51:52 AM	Pumps P101, P102 ON	No
38	28/08/2019 09:54:19 AM	MV101 value change	No (11 from Table 2)
39	28/08/2019 09:58:00 AM	P201 and P201 ON	No (12 from Table 2)
40	28/08/2019 10:33:59 AM	Pumps P101, P102 ON	No (13 from Table 2)
41	28/08/2019 10:58:17 AM	MV101 value change	No
42	28/08/2019 11:09:54 AM	LIT101 value change	No
43	28/08/2019 11:10:13 AM	LIT101 value change	No
44	28/08/2019 11:11:16 AM	LIT101 value change	No
45	28/08/2019 11:11:49 AM	LIT101 value change	No
46	28/08/2019 11:33:57 AM	Pumps P101, P102 ON	No
47	28/08/2019 01:12:49 PM	LIT101 value change	No
48	28/08/2019 01:12:58 PM	LIT101 value change	No
49	28/08/2019 01:15:18 PM	LIT401 value change	No
50	28/08/2019 01:15:28 PM	LIT401 value change	No
51	28/08/2019 02:49:56 PM	LIT101 value change	No
52	28/08/2019 02:50:51 PM	LIT101 value change	No
53	28/08/2019 02:51:29 PM	LIT101 value change	No (14 from Table 2)
54	28/08/2019 02:51:42 PM	LIT101 value change	No
55	28/08/2019 02:52:40 PM	LIT101 value change	No
56	28/08/2019 02:52:51 PM	LIT101 value change	No
57	28/08/2019 04:16:41 PM	P601 on when LIT101 high	No
58	28/08/2019 05:21:52 PM	MV201 value change	No
59	28/08/2019 05:21:59 PM	MV101 value change	No
		29 th Aug	
60	29/08/2019 09:10:57 AM	LIT101 value change	No
61	29/08/2019 10:12:02 AM	MV201 open	No (16 from Table 2)
62	29/08/2019 10:21:26 AM	P601 abnormal	No (17 from Table 2)
63	29/08/2019 10:41:00 AM	LIT101 value change	No
64	29/08/2019 10:42:54 AM	LIT101 value change	No
65	29/08/2019 10:53:14 AM	LIT401 value change	No
66	29/08/2019 10:53:26 AM	LIT101 value change	No
67	29/08/2019 10:54:30 AM	LIT101 value change	No
68	29/08/2019 10:54:35 AM	LIT401 value change	No
69	29/08/2019 11:17:33 AM	LIT101 value change	No
70	29/08/2019 11:18:00 AM	LIT101 value change	No
71	29/08/2019 11:21:09 AM	LIT101 value change	No (19 from Table 2)
72	29/08/2019 11:21:42 AM	MV303 open	No (20 from Table 2)

73	29/08/2019 11:21:52 AM	LIT101 value change	No
74	29/08/2019 11:24:08 AM	LIT101 value change	No
75	29/08/2019 11:24:19 AM	LIT101 value change	No (21 from Table 2)
76	29/08/2019 11:25:18 AM	LIT101 value change	No
77	29/08/2019 11:31:22 AM	AIT402 and P403 change	No
78	29/08/2019 11:54:15 AM	AIT402 and P403 change	No
79	29/08/2019 01:04:10 PM	LIT101 value change	No
80	29/08/2019 01:06:56 PM	LIT101 value change	No
81	29/08/2019 01:15:51 PM	LIT101 value change	No
82	29/08/2019 01:16:27 PM	LIT101 value change	No
83	29/08/2019 01:21:18 PM	LIT401 value change	No
84	29/08/2019 01:21:30 PM	LIT401 value change	No
85	29/08/2019 05:05:31 PM	LIT101 value change	No

* Bold in the table are due to set point violation

Table 3A: Performance of DAD on DAY 1 CISS-2019 Data

S.No	Timestamp	Detector tag / cause	False alarm? [Yes/No]	Rremarks
CTO006	Tue, 27 Aug 2019, 11:09:00	Tags Affected: "CPS_ALID_P1_SD7" Actual Values: 0.000128167 Predicted Values: "Pumps P101, P102"	No	Time differs
CTO006	Tue, 27 Aug 2019, 11:19:00	Tags Affected: "CPS_ALID_P2_SD2" Actual Values: 1012.28052 Predicted Values: "Check LIT301"	No	Time differs
CTO015	Tue, 27 Aug 2019, 12:52:00	Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 716.3236 Predicted Values: "Check LIT101"	No	Time differs
CTO015	Tue, 27 Aug 2019, 12:52:00	Tags Affected: "CPS_ALID_P1_SD8" Actual Values: 2 Predicted Values: "Pumps P101, P102"	No	Time differs
CTO016	Tue, 27 Aug 2019, 12:53:00	Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 693.3215 Predicted Values: "Check LIT101"	No	
CTO016	Tue, 27 Aug 2019, 12:53:00	Tags Affected: "CPS_ALID_P1_SD9" Actual Values: 694.4598 Predicted Values: "Check LIT101"	No	
-	Tue, 27 Aug 2019, 13:12:00	Tags Affected: "CPS_ALID_P1_SD5" Actual Values: 595.1599 Predicted Values: "Pumps P101, P102"	Yes	
-	Tue, 27 Aug 2019, 13:18:00	Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 608.9673 Predicted Values: "Check LIT101"	Yes	
-	Tue, 27 Aug 2019, 13:19:00	Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 749.4529 Predicted Values: "Check LIT101"	Yes	
-	Tue, 27 Aug 2019, 13:21:00	Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 870.7303 Predicted Values: "Check LIT301"	Yes	
-	Tue, 27 Aug 2019, 13:22:00	Tags Affected: "CPS_ALID_P4_SA1" Actual Values: 665.790833 Predicted Values: "Check LIT401"	Yes	
-	27 Aug 2019, 13:22:00	Tags Affected: "CPS_ALID_P4_SA1" Actual Values: 753.191467 Predicted Values: "Check LIT401"	Yes	

-	Tue, 27 Aug 2019, 13:29:00	Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 608.9673 Predicted Values: "Check LIT101"	Yes	
-	27 Aug 2019, 13:31:00	Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 751.337036 Predicted Values: "Check LIT101"	Yes	
CCO016	Tue, 27 Aug 2019, 15:50:00	Tags Affected: "CPS_ALID_P2_SD1" Actual Values: 796.590637 Predicted Values: "Check LIT301"	No	
-	Tue, 27 Aug 2019, 15:55:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SD6" Actual Values: 99 Predicted Values: "Check MV301, 302, 303"	Not attack but possibility of cascading effect.	
-	Tue, 27 Aug 2019, 15:55:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SD5" Actual Values: 2 Predicted Values: "Check P301 P302"	Not attack but possibility of cascading effect.	
-	Tue, 27 Aug 2019, 15:59:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD9" Actual Values: 727.549866 Predicted Values: "Check LIT101"	Not attack but possibility of cascading effect.	
CCO024	Tue, 27 Aug 2019, 18:04:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD8" Actual Values: 2 Predicted Values: "Pumps P101, P102"	No	
CCO025	Tue, 27 Aug 2019, 18:10:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD8" Actual Values: 2 Predicted Values: "Pumps P101, P102"	No	
-	Tue, 27 Aug 2019, 18:12:00	Process Affected: "stage2" Tags Affected: "CPS_ALID_P2_SD14" Actual Values: 2 Predicted Values: "Check p201"	Not attack but possibility of cascading effect.	

Table 3B: Performance of DAD on DAY 2 CISS-2019 Data

S.No	Timestamp	Detector tag / cause	False alarm? [Yes/No]	Remarks
THO006	Wed, 28 Aug 2019, 09:51:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD8" Actual Values: 2 Predicted Values: "Pumps P101, P102"	No	
THO006	Wed, 28 Aug 2019, 09:51:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD8" Actual Values: 2 Predicted Values: "Pumps P101, P102"	No	
THO006	Wed, 28 Aug 2019, 09:51:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD8" Actual Values: 2 Predicted Values: "Pumps P101, P102"	No	
THO007	Wed, 28 Aug 2019, 09:54:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD9" Actual Values: 592.127869 Predicted Values: "Check LIT101"	No	
THO008	Wed, 28 Aug 2019, 09:58:00	Process Affected: "stage2" Tags Affected: "CPS_ALID_P2_SD14" Actual Values: 2 Predicted Values: "Check p201"	No	
THO010	Wed, 28 Aug 2019, 10:12:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD3" Actual Values: 821.952759 Predicted Values: "Check LIT101"	No	
THO011	Wed, 28 Aug 2019, 10:33:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD8" Actual Values: 2 Predicted Values: "Pumps P101, P102"	No	
THO013	Wed, 28 Aug 2019, 10:58:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD9" Actual Values: 595.5036 Predicted Values: "Check LIT101"	No	
THO013	Wed, 28 Aug 2019, 11:02:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD3" Actual Values: 820.3826 Predicted Values: "Check LIT101"	No	
THO014	Date/Time: Wed, 28 Aug 2019, 11:09:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 500	No	

		Predicted Values: "Check LIT101"		
THO014	Wed, 28 Aug 2019, 11:10:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 866.504639 Predicted Values: "Check LIT101"	No	
THO014	Wed, 28 Aug 2019, 11:11:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 999 Predicted Values: "Check LIT101"	No	
THO014	Wed, 28 Aug 2019, 11:11:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 895.7872 Predicted Values: "Check LIT101"	No	
THI019	28 Aug 2019, 11:33:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD8" Actual Values: 2 Predicted Values: "Pumps P101, P102"	No	Timing differs
-	Wed, 28 Aug 2019, 13:02:00	Process Affected: "stage6" Tags Affected: "CPS_ALID_P6_SD1" Actual Values: 2 Predicted Values: "Check p601"	Yes	
-	Wed, 28 Aug 2019, 13:12:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 608.9673 Predicted Values: "Check LIT101"	Yes	
	Wed, 28 Aug 2019, 13:12:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 590.3222 Predicted Values: "Check LIT101"	Yes	
-	Wed, 28 Aug 2019, 13:14:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 870.7303 Predicted Values: "Check LIT301"	Yes	
-	Wed, 28 Aug 2019, 13:14:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 1008.23511 Predicted Values: "Check LIT301"	Yes	
-	Wed, 28 Aug 2019, 13:15:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SA1" Actual Values: 665.790833 Predicted Values: "Check LIT401"	Yes	

-	Wed, 28 Aug 2019, 13:15:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SA1" Actual Values: 945.6806 Predicted Values: "Check LIT401"	Yes	
NSO004	Wed, 28 Aug 2019, 14:49:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 499.962372 Predicted Values: "Check LIT101"	No	
NSO004	Wed, 28 Aug 2019, 14:50:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 739.9145 Predicted Values: "Check LIT101"		
NSO004	Wed, 28 Aug 2019, 14:51:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 299.969574 Predicted Values: "Check LIT101"		Time differs slightly
NSO004	Wed, 28 Aug 2019, 14:51:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 802.8759 Predicted Values: "Check LIT101"		Time differs slightly
NSO004	Wed, 28 Aug 2019, 14:52:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 299.969574 Predicted Values: "Check LIT101"		Time differs slightly
NSO004	Wed, 28 Aug 2019, 14:52:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 802.247864 Predicted Values: "Check LIT101"		Time differs slightly
-	Wed, 28 Aug 2019, 15:29:00	Process Affected: "stage2" Tags Affected: "CPS_ALID_P2_SD1" Actual Values: 796.9511 Predicted Values: "Check LIT301"	Yes	
NSO012	Wed, 28 Aug 2019, 17:20:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SD6" Actual Values: 99 Predicted Values: "Check MV301, 302, 303"	No	
NSO012	Wed, 28 Aug 2019, 17:20:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SD5" Actual Values: 2 Predicted Values: "Check P301 P302"	No	
NSO014	Wed, 28 Aug 2019, 17:22:00	Process Affected: "stage2" Tags Affected: "CPS_ALID_P2_SD15" Actual Values: 950.7578 Predicted Values: "Check LIT301"	No	Stop plant

Table 3C: Performance of DAD on DAY 3 CISS-2019 Data

S.No	Timestamp	Detector tag / cause	False alarm? [Yes/No]	Remarks
-	Thu, 29 Aug 2019, 09:10:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 634.167542 Predicted Values: "Check LIT101"	Yes	
ITO001	Thu, 29 Aug 2019, 09:26:00	Process Affected: "stage3" Tags Affected: "CPS_AZ_SIZE1_DC21" Actual Values: 2 Predicted Values: "Check MV302"	No	
ITO002	Thu, 29 Aug 2019, 09:27:00	Process Affected: "stage3" Tags Affected: "CPS_AZ_SIZE1_DC21" Actual Values: 2 Predicted Values: "Check MV302"	No	
ITO004	Thu, 29 Aug 2019, 10:11:00	Process Affected: "stage2" Tags Affected: "CPS_ALID_P2_SD2" Actual Values: 1010.11761 Predicted Values: "Check LIT301"	No	
	Thu, 29 Aug 2019, 10:21:00	Process Affected: "stage6" Tags Affected: "CPS_ALID_P6_SD1" Actual Values: 2 Predicted Values: "Check p601"	No	
ITO006	Thu, 29 Aug 2019, 10:26:00	Process Affected: "stage2" Tags Affected: "CPS_ALID_P2_SD15" Actual Values: 908.260742 Predicted Values: "Check LIT301"	No	Time differs
ITO009	Thu, 29 Aug 2019, 10:41:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 222 Predicted Values: "Check LIT101"	No	
ITO009	Thu, 29 Aug 2019, 10:42:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 810.373169 Predicted Values: "Check LIT101"	No	
ITO012	Thu, 29 Aug 2019, 10:53:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SA1" Actual Values: 665.790833 Predicted Values: "Check LIT401"	No	
ITO013	Thu, 29 Aug 2019, 10:53:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 539.764648	No	

		Predicted Values: "Check LIT101"		
ITO014	Thu, 29 Aug 2019, 10:54:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 870.7303 Predicted Values: "Check LIT301"	No	
ITO014	Thu, 29 Aug 2019, 10:54:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 993.4953 Predicted Values: "Check LIT301"	No	
ITO013	Thu, 29 Aug 2019, 10:54:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 582.74646 Predicted Values: "Check LIT101"	No	Time differs
ITO012	Thu, 29 Aug 2019, 10:54:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SA1" Actual Values: 946.834167 Predicted Values: "Check LIT401"	No	Time differs
	Thu, 29 Aug 2019, 11:16:00	Process Affected: "stage2" Tags Affected: "CPS_ALID_P2_SD15" Actual Values: 914.1887 Predicted Values: "Check LIT301"	Yes	
ITO022	Thu, 29 Aug 2019, 11:17:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 222 Predicted Values: "Check LIT101"	No	Time differs / not recorded
ITO022	Thu, 29 Aug 2019, 11:18:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 589.2624 Predicted Values: "Check LIT101"	No	Time differs / not recorded
ITO022	Thu, 29 Aug 2019, 11:20:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SD2" Actual Values: 2 Predicted Values: "Check LIT301"	No	Time differs / not recorded
ITO022	Thu, 29 Aug 2019, 11:21:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 222 Predicted Values: "Check LIT101"	No	Time differs / not recorded
ITO020	Thu, 29 Aug 2019, 11:21:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SD6" Actual Values: 99 Predicted Values: "Check MV301, 302, 303"	No	

ITO022	Thu, 29 Aug 2019, 11:21:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 250 Predicted Values: "Check LIT101"	No	Time differs / not recorded
ITO022	Thu, 29 Aug 2019, 11:24:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 903.1667 Predicted Values: "Check LIT101"	No	
ITO022	Thu, 29 Aug 2019, 11:24:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 100 Predicted Values: "Check LIT101"	No	
ITO022	Thu, 29 Aug 2019, 11:25:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 969.7786 Predicted Values: "Check LIT101"	No	
ITO023	Thu, 29 Aug 2019, 11:31:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SD6" Actual Values: 300.0769 Predicted Values: "Check AIT402"	No	
ITO025	Thu, 29 Aug 2019, 11:42:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SD2" Actual Values: 0.034189127 Predicted Values: "Check fIT401"	No	
ITO025	Thu, 29 Aug 2019, 11:47:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SD2" Actual Values: 0.128177226 Predicted Values: "Check fIT401"	No	Time differs
-	Thu, 29 Aug 2019, 11:54:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SD6" Actual Values: 300.3589 Predicted Values: "Check AIT402"	Not attack but possibility of cascading effect.	
-	Thu, 29 Aug 2019, 13:04:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 608.9673 Predicted Values: "Check LIT101"	Yes	
-	Thu, 29 Aug 2019, 13:06:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 813.0031 Predicted Values: "Check LIT101"	Yes	
-	Thu, 29 Aug 2019, 13:15:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1"	Yes	

		Actual Values: 608.9673 Predicted Values: "Check LIT101"		
-	Thu, 29 Aug 2019, 13:16:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 812.963867 Predicted Values: "Check LIT101"	Yes	
-	Thu, 29 Aug 2019, 13:19:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 870.7303 Predicted Values: "Check LIT301"	Yes	
-	Thu, 29 Aug 2019, 13:19:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 1009.23645 Predicted Values: "Check LIT301"	Yes	
-	Thu, 29 Aug 2019, 13:21:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SA1" Actual Values: 665.790833 Predicted Values: "Check LIT401"	Yes	
-	Thu, 29 Aug 2019, 13:21:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SA1" Actual Values: 827.672363 Predicted Values: "Check LIT401"	Yes	
-	Thu, 29 Aug 2019, 13:27:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SD6" Actual Values: 374.596252 Predicted Values: "Check AIT402"	Yes	
NAO011	Thu, 29 Aug 2019, 15:52:00	Process Affected: "stage6" Tags Affected: "CPS_ALID_P6_SD1" Actual Values: 2 Predicted Values: "Check p601"	No	Attack stage 1
-	Thu, 29 Aug 2019, 16:14:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SD6" Actual Values: 99 Predicted Values: "Check MV301, 302, 303"	Yes	
-	Thu, 29 Aug 2019, 16:47:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SD4" Actual Values: 890.3567 Predicted Values: "Check LIT301"	Yes	
-	Thu, 29 Aug 2019, 16:51:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD9" Actual Values: 638.2106 Predicted Values: "Check LIT101"	Yes	

-	Thu, 29 Aug 2019, 16:53:00	Process Affected: "stage2" Tags Affected: "CPS_ALID_P2_SD15" Actual Values: 889.9561 Predicted Values: "Check LIT301"	Yes	
-	Thu, 29 Aug 2019, 16:53:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD8" Actual Values: 2 Predicted Values: "Pumps P101, P102"	Yes	
-	Thu, 29 Aug 2019, 17:05:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 517.9794 Predicted Values: "Check LIT101"	Yes	
-	Thu, 29 Aug 2019, 17:12:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 962.3334 Predicted Values: "Check LIT301"	Yes	
-	Thu, 29 Aug 2019, 17:17:00	Process Affected: "stage6" Tags Affected: "CPS_AZ_SIZE1_DC14" Actual Values: 0.6981066 Predicted Values: "Check FIT601"	Yes	
-	Thu, 29 Aug 2019, 17:50:00	Process Affected: "stage2" Tags Affected: "CPS_ALID_P2_SD2" Actual Values: 1004.1496 Predicted Values: "Check LIT301"	Yes	
-	Thu, 29 Aug 2019, 18:13:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 608.9673 Predicted Values: "Check LIT101"	Yes	
-	Thu, 29 Aug 2019, 18:13:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 832.551 Predicted Values: "Check LIT101"	Yes	
-	Thu, 29 Aug 2019, 18:15:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 870.7303 Predicted Values: "Check LIT301"	Yes	
-	Thu, 29 Aug 2019, 18:16:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 910.3836 Predicted Values: "Check LIT301"	Yes	
-	Thu, 29 Aug 2019, 18:16:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SA1"	Yes	

		Actual Values: 665.790833 Predicted Values: "Check LIT401"		
-	Thu, 29 Aug 2019, 18:16:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SA1" Actual Values: 991.168945 Predicted Values: "Check LIT401"	Yes	

Table 3D: Performance of DAD on DAY 4 CISS-2019 Data*

S.No	Timestamp	Detector tag / cause	False alarm? [Yes/No]	Remarks
-	Fri, 30 Aug 2019, 10:41:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SD6" Actual Values: 99 Predicted Values: "Check MV301, 302, 303"	Yes	
-	Fri, 30 Aug 2019, 11:08:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 500 Predicted Values: "Check LIT301"	Yes	
-	Fri, 30 Aug 2019, 11:09:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 899.3688 Predicted Values: "Check LIT301"	Yes	
-	Fri, 30 Aug 2019, 12:04:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 891.5583 Predicted Values: "Check LIT301"	Yes	

*There were few successful attacks on Day 4 and hence a shorter table.

Table 4A DAD-2019: Updated Performance summary on CISS2019 data. Day 1

S.No	Timestamp	Detector tag / cause	A		B		C
			False alarm? [Yes/No]	Remarks	False alarm? [Yes/No]	Remarks	Verified against CSV file
CTO006	Tue, 27 Aug 2019, 11:09:00	Tags Affected: "CPS_ALID_P1_SD7" Actual Values: 0.000128167 Predicted Values: "Pumps P101, P102"	No	Time differs			
CTO006	Tue, 27 Aug 2019, 11:19:00	Tags Affected: "CPS_ALID_P2_SD2" Actual Values: 1012.28052 Predicted Values: "Check LIT301"	No	Time differs			
CTO015	Tue, 27 Aug 2019, 12:52:00	Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 716.3236 Predicted Values: "Check LIT101"	No	Time differs			
CTO015	Tue, 27 Aug 2019, 12:52:00	Tags Affected: "CPS_ALID_P1_SD8" Actual Values: 2 Predicted Values: "Pumps P101, P102"	No	Time differs			
CTO016	Tue, 27 Aug 2019, 12:53:00	Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 693.3215 Predicted Values: "Check LIT101"	No				
CTO016	Tue, 27 Aug 2019, 12:53:00	Tags Affected: "CPS_ALID_P1_SD9" Actual Values: 694.4598 Predicted Values: "Check LIT101"	No				
-	Tue, 27 Aug 2019, 13:12:00	Tags Affected: "CPS_ALID_P1_SD5"	Yes		No	LIT301 is less than Low	True

		Actual Values: 595.1599 Predicted Values: "Pumps P101, P102"					
-	Tue, 27 Aug 2019, 13:18:00	Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 608.9673 Predicted Values: "Check LIT101"	Yes		No	LIT101 value changed from 749.8062 to 608.9673	True
-	Tue, 27 Aug 2019, 13:19:00	Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 749.4529 Predicted Values: "Check LIT101"	Yes		No	LIT101 value change from 608.9673 to 749.4529	True
-	Tue, 27 Aug 2019, 13:21:00	Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 870.7303 Predicted Values: "Check LIT301"	Yes		No	LIT301 changed from 598.6446 to 870.7303	True
-	Tue, 27 Aug 2019, 13:22:00	Tags Affected: "CPS_ALID_P4_SA1" Actual Values: 665.790833 Predicted Values: "Check LIT401"	Yes		No	LIT401 changed from 751.9995 to 665.790833	True
-	27 Aug 2019, 13:22:00	Tags Affected: "CPS_ALID_P4_SA1" Actual Values: 753.191467 Predicted Values: "Check LIT401"	Yes		No	LIT401 changed from 665.790833 to 753.191467	True
-	Tue, 27 Aug 2019, 13:29:00	Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 608.9673 Predicted Values: "Check LIT101"	Yes		No	LIT101 changed from 751.5726 to 608.9673	True
-	27 Aug 2019, 13:31:00	Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 751.337036 Predicted Values: "Check LIT101"	Yes		No	LIT101 changed from 608.9673 to 751.337036	True

CCO016	Tue, 27 Aug 2019, 15:50:00	Tags Affected: "CPS_ALID_P2_SD1" Actual Values: 796.590637 Predicted Values: "Check LIT301"	No				
-	Tue, 27 Aug 2019, 15:55:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SD6" Actual Values: 99 Predicted Values: "Check MV301, 302, 303"	Not attack but possibility of cascading effect.				
-	Tue, 27 Aug 2019, 15:55:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SD5" Actual Values: 2 Predicted Values: "Check P301 P302"	Not attack but possibility of cascading effect.				
-	Tue, 27 Aug 2019, 15:59:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD9" Actual Values: 727.549866 Predicted Values: "Check LIT101"	Not attack but possibility of cascading effect.				
CCO024	Tue, 27 Aug 2019, 18:04:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD8" Actual Values: 2 Predicted Values: "Pumps P101, P102"	No				
CCO025	Tue, 27 Aug 2019, 18:10:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD8" Actual Values: 2 Predicted Values: "Pumps P101, P102"	No				
-	Tue, 27 Aug 2019, 18:12:00	Process Affected: "stage2"	Not attack but possibility				

		Tags Affected: "CPS_ALID_P2_SD14" Actual Values: 2 Predicted Values: "Check p201"	of cascading effect.				
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Table 4B DAD-2019: Updated Performance summary on CISS2019 data. Day 2

S.No	Timestamp	Detector tag / cause	A		B		C
			False alarm? [Yes/No]	Remarks	False alarm? [Yes/No]	Remarks	Verified against CSV file
THO006	Wed, 28 Aug 2019, 09:51:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD8" Actual Values: 2 Predicted Values: "Pumps P101, P102"	No		No		
THO006	Wed, 28 Aug 2019, 09:51:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD8" Actual Values: 2 Predicted Values: "Pumps P101, P102"	No		No		
THO006	Wed, 28 Aug 2019, 09:51:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD8" Actual Values: 2 Predicted Values: "Pumps P101, P102"	No		No		
THO007	Wed, 28 Aug 2019, 09:54:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD9" Actual Values: 592.127869 Predicted Values: "Check LIT101"	No		No		
THO008	Wed, 28 Aug 2019, 09:58:00	Process Affected: "stage2" Tags Affected: "CPS_ALID_P2_SD14" Actual Values: 2 Predicted Values: "Check p201"	No		No		

THO010	Wed, 28 Aug 2019, 10:12:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD3" Actual Values: 821.952759 Predicted Values: "Check LIT101"	No		No		
THO011	Wed, 28 Aug 2019, 10:33:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD8" Actual Values: 2 Predicted Values: "Pumps P101, P102"	No		No		
THO013	Wed, 28 Aug 2019, 10:58:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD9" Actual Values: 595.5036 Predicted Values: "Check LIT101"	No		No		
THO013	Wed, 28 Aug 2019, 11:02:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD3" Actual Values: 820.3826 Predicted Values: "Check LIT101"	No		No		
THO014	Date/Time: Wed, 28 Aug 2019, 11:09:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 500 Predicted Values: "Check LIT101"	No		No		
THO014	Wed, 28 Aug 2019, 11:10:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 866.504639 Predicted Values: "Check LIT101"	No		No		

THO014	Wed, 28 Aug 2019, 11:11:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 999 Predicted Values: "Check LIT101"	No		No		
THO014	Wed, 28 Aug 2019, 11:11:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 895.7872 Predicted Values: "Check LIT101"	No		No		
THI019	28 Aug 2019, 11:33:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD8" Actual Values: 2 Predicted Values: "Pumps P101, P102"	No	Timing differs	No	Timing differs	
-	Wed, 28 Aug 2019, 13:02:00	Process Affected: "stage6" Tags Affected: "CPS_ALID_P6_SD1" Actual Values: 2 Predicted Values: "Check p601"	Yes		Yes	This is a false alarm. There is no anomaly in the data. When we run less speed this is not giving false alarm.	Alarm still raised at 1X speed. Based on email, Sridhar got false too. Error in documentation.
-	Wed, 28 Aug 2019, 13:12:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 608.9673 Predicted Values: "Check LIT101"	Yes		No	LIT101 value changed from 590.754 to 608.9673	True
-	Wed, 28 Aug 2019, 13:12:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1"	Yes		No	LIT101 value changed from	True

		Actual Values: 590.3222 Predicted Values: "Check LIT101"				608.9673 to 590.3222	
-	Wed, 28 Aug 2019, 13:14:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 870.7303 Predicted Values: "Check LIT301"	Yes		No	LIT301 value change from 1008.23511 to 870.7303	True
-	Wed, 28 Aug 2019, 13:14:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 1008.23511 Predicted Values: "Check LIT301"	Yes		No	LIT301 value change from 870.7303 to 1008.23511	True
-	Wed, 28 Aug 2019, 13:15:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SA1" Actual Values: 665.790833 Predicted Values: "Check LIT401"	Yes		No	LIT401 changed from 945.2961 to 665.790833	True
-	Wed, 28 Aug 2019, 13:15:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SA1" Actual Values: 945.6806 Predicted Values: "Check LIT401"	Yes		No	LIT401 changed from 665.790833 to 945.6806	True
NSO004	Wed, 28 Aug 2019, 14:49:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 499.962372 Predicted Values: "Check LIT101"	No		No		
NSO004	Wed, 28 Aug 2019, 14:50:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 739.9145 Predicted Values: "Check LIT101"	No		No		

NSO004	Wed, 28 Aug 2019, 14:51:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 299.969574 Predicted Values: "Check LIT101"	No	Time differs slightly	No	Time differs slightly	
NSO004	Wed, 28 Aug 2019, 14:51:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 802.8759 Predicted Values: "Check LIT101"	No	Time differs slightly	No	Time differs slightly	
NSO004	Wed, 28 Aug 2019, 14:52:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 299.969574 Predicted Values: "Check LIT101"	No	Time differs slightly	No	Time differs slightly	
NSO004	Wed, 28 Aug 2019, 14:52:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 802.247864 Predicted Values: "Check LIT101"	No	Time differs slightly	No	Time differs slightly	
-	Wed, 28 Aug 2019, 15:29:00	Process Affected: "stage2" Tags Affected: "CPS_ALID_P2_SD1" Actual Values: 796.9511 Predicted Values: "Check LIT301"	Yes		No	LIT301 is low and MV201 is not Open	True
NSO012	Wed, 28 Aug 2019, 17:20:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SD6" Actual Values: 99 Predicted Values: "Check MV301, 302, 303"	No		No		
NSO012	Wed, 28 Aug 2019, 17:20:00	Process Affected: "stage3"	No		No		

		Tags Affected: "CPS_ALID_P3_SD5" Actual Values: 2 Predicted Values: "Check P301 P302"					
NSO014	Wed, 28 Aug 2019, 17:22:00	Process Affected: "stage2" Tags Affected: "CPS_ALID_P2_SD15" Actual Values: 950.7578 Predicted Values: "Check LIT301"	No	Stop plant	No	Stop plant	

Table 4C DAD-2019: Updated Performance summary on CISS2019 data. Day 3

S.No	Timestamp	Detector tag / cause	A		B		C
			False alarm? [Yes/No]	Remarks	False alarm? [Yes/No]	Remarks	Verified against CSV file
-	Thu, 29 Aug 2019, 09:10:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 634.167542 Predicted Values: "Check LIT101"	Yes		No	LIT101 changed from 680.0148 to 634.167542	True . Seems to be a incorrect reading from sensor.
ITO001	Thu, 29 Aug 2019, 09:26:00	Process Affected: "stage3" Tags Affected: "CPS_AZ_SIZE1_DC21" Actual Values: 2 Predicted Values: "Check MV302"	No		No		
ITO002	Thu, 29 Aug 2019, 09:27:00	Process Affected: "stage3" Tags Affected: "CPS_AZ_SIZE1_DC21" Actual Values: 2 Predicted Values: "Check MV302"	No		No		
ITO004	Thu, 29 Aug 2019, 10:11:00	Process Affected: "stage2" Tags Affected: "CPS_ALID_P2_SD2" Actual Values: 1010.11761 Predicted Values: "Check LIT301"	No		No		
	Thu, 29 Aug 2019, 10:21:00	Process Affected: "stage6" Tags Affected: "CPS_ALID_P6_SD1" Actual Values: 2 Predicted Values: "Check p601"	No		No		
ITO006	Thu, 29 Aug 2019, 10:26:00	Process Affected: "stage2" Tags Affected: "CPS_ALID_P2_SD15"	No	Time differs	No	Time differs	

		Actual Values: 908.260742 Predicted Values: "Check LIT301"					
ITO009	Thu, 29 Aug 2019, 10:41:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 222 Predicted Values: "Check LIT101"	No		No		
ITO009	Thu, 29 Aug 2019, 10:42:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 810.373169 Predicted Values: "Check LIT101"	No		No		
ITO012	Thu, 29 Aug 2019, 10:53:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SA1" Actual Values: 665.790833 Predicted Values: "Check LIT401"	No		No		
ITO013	Thu, 29 Aug 2019, 10:53:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 539.764648 Predicted Values: "Check LIT101"	No		No		
ITO014	Thu, 29 Aug 2019, 10:54:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 870.7303 Predicted Values: "Check LIT301"	No		No		
ITO014	Thu, 29 Aug 2019, 10:54:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 993.4953 Predicted Values: "Check LIT301"	No		No		

ITO013	Thu, 29 Aug 2019, 10:54:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 582.74646 Predicted Values: "Check LIT101"	No	Time differs	No	Time differs	
ITO012	Thu, 29 Aug 2019, 10:54:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SA1" Actual Values: 946.834167 Predicted Values: "Check LIT401"	No	Time differs	No	Time differs	
	Thu, 29 Aug 2019, 11:16:00	Process Affected: "stage2" Tags Affected: "CPS_ALID_P2_SD15" Actual Values: 914.1887 Predicted Values: "Check LIT301"	Yes		No	MV201 opened and closed when LIT301 is in between two set points Low and High (LIT301 value is 914.1887)	True
ITO022	Thu, 29 Aug 2019, 11:17:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 222 Predicted Values: "Check LIT101"	No	Time differs / not recorded	No	Time differs / not recorded	
ITO022	Thu, 29 Aug 2019, 11:18:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 589.2624 Predicted Values: "Check LIT101"	No	Time differs / not recorded	No	Time differs / not recorded	
ITO022	Thu, 29 Aug 2019, 11:20:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SD2" Actual Values: 2 Predicted Values: "Check LIT301"	No	Time differs / not recorded	No	Time differs / not recorded	
ITO022	Thu, 29 Aug 2019, 11:21:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1"	No	Time differs / not recorded	No	Time differs / not recorded	

		Actual Values: 222 Predicted Values: "Check LIT101"					
ITO020	Thu, 29 Aug 2019, 11:21:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SD6" Actual Values: 99 Predicted Values: "Check MV301, 302, 303"	No		No		
ITO022	Thu, 29 Aug 2019, 11:21:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 250 Predicted Values: "Check LIT101"	No	Time differs / not recorded	No	Time differs / not recorded	
ITO022	Thu, 29 Aug 2019, 11:24:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 903.1667 Predicted Values: "Check LIT101"	No		No		
ITO022	Thu, 29 Aug 2019, 11:24:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 100 Predicted Values: "Check LIT101"	No		No		
ITO022	Thu, 29 Aug 2019, 11:25:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 969.7786 Predicted Values: "Check LIT101"	No		No		
ITO023	Thu, 29 Aug 2019, 11:31:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SD6" Actual Values: 300.0769	No		No		

		Predicted Values: "Check AIT402"					
ITO025	Thu, 29 Aug 2019, 11:42:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SD2" Actual Values: 0.034189127 Predicted Values: "Check fIT401"	No		No		
ITO025	Thu, 29 Aug 2019, 11:47:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SD2" Actual Values: 0.128177226 Predicted Values: "Check fIT401"	No	Time differs	No	Time differs	
-	Thu, 29 Aug 2019, 11:54:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SD6" Actual Values: 300.3589 Predicted Values: "Check AIT402"	Not attack but possibility of cascading effect.		Not attack but possibility of cascading effect.		
-	Thu, 29 Aug 2019, 13:04:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 608.9673 Predicted Values: "Check LIT101"	Yes		No	LIT101 changed from 813.631165 to 608.9673	True
-	Thu, 29 Aug 2019, 13:06:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 813.0031 Predicted Values: "Check LIT101"	Yes		No	LIT101 changed from 608.9673 to 813.0031	True
-	Thu, 29 Aug 2019, 13:15:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 608.9673	Yes		No	LIT101 changed from 813.709656 to 608.9673	True

		Predicted Values: "Check LIT101"					
-	Thu, 29 Aug 2019, 13:16:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 812.963867 Predicted Values: "Check LIT101"	Yes		No	LIT101 changed from 608.9673 to 812.963867	True
-	Thu, 29 Aug 2019, 13:19:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 870.7303 Predicted Values: "Check LIT301"	Yes		No	LIT301 changed from 1009.9574 to 870.7303	True
-	Thu, 29 Aug 2019, 13:19:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 1009.23645 Predicted Values: "Check LIT301"	Yes		No	LIT301 changed from 870.7303 to 1009.23645	True
-	Thu, 29 Aug 2019, 13:21:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SA1" Actual Values: 665.790833 Predicted Values: "Check LIT401"	Yes		No	LIT401 value changed from 828.5183 to 665.790833	True
-	Thu, 29 Aug 2019, 13:21:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SA1" Actual Values: 827.672363 Predicted Values: "Check LIT401"	Yes		No	LIT401 value changed from 665.790833 to 827.672363	True
-	Thu, 29 Aug 2019, 13:27:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SD6" Actual Values: 374.596252 Predicted Values: "Check AIT402"	Yes		No	It is a cascading effect from FIT401 and P401	

NAO011	Thu, 29 Aug 2019, 15:52:00	Process Affected: "stage6" Tags Affected: "CPS_ALID_P6_SD1" Actual Values: 2 Predicted Values: "Check p601"	No	Attack stage 1	No	Attack stage 1	
-	Thu, 29 Aug 2019, 16:14:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SD6" Actual Values: 99 Predicted Values: "Check MV301, 302, 303"	Yes		No	MV302 is open when PLC state is idle	True. MV302 starts to open at 15:45:00. P3 state changes to 99 in 16:14:00.
-	Thu, 29 Aug 2019, 16:47:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SD4" Actual Values: 890.3567 Predicted Values: "Check LIT301"	Yes		No	LIT401 is Low and pump P301 or P302 are OFF.	True
-	Thu, 29 Aug 2019, 16:51:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD9" Actual Values: 638.2106 Predicted Values: "Check LIT101"	Yes		No	MV101 is Closed when LIT101 (638.2106) in between Low and High	True. Status of MV101 is changed for a brief milliseconds.
-	Thu, 29 Aug 2019, 16:53:00	Process Affected: "stage2" Tags Affected: "CPS_ALID_P2_SD15" Actual Values: 889.9561 Predicted Values: "Check LIT301"	Yes		No	MV201 changed state when LIT301 (889.9561) is in between Low and High	True. M201 state is changed. Possible cascading effect.
-	Thu, 29 Aug 2019, 16:53:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SD8" Actual Values: 2 Predicted Values: "Pumps P101, P102"	Yes		No	Both pumps on at a time	True. NAO011 (time differs alot).

-	Thu, 29 Aug 2019, 17:05:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 517.9794 Predicted Values: "Check LIT101"	Yes		No	LIT101 changed from 638.2106 to 517.9794	True.
-	Thu, 29 Aug 2019, 17:12:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 962.3334 Predicted Values: "Check LIT301"	Yes		No	LIT301 value changed from 948.5949 to 962.3334	True
-	Thu, 29 Aug 2019, 17:17:00	Process Affected: "stage6" Tags Affected: "CPS_AZ_SIZE1_DC14" Actual Values: 0.6981066 Predicted Values: "Check FIT601"	Yes		Yes	It is a false alarm. In the data it looks fine. if we run less speed it may not raise an alarm.	No alarm raised when run in 1X speed.
-	Thu, 29 Aug 2019, 17:50:00	Process Affected: "stage2" Tags Affected: "CPS_ALID_P2_SD2" Actual Values: 1004.1496 Predicted Values: "Check LIT301"	Yes		No	MV201 is open for 34 seconds after reaching LIT301 is High	True.
-	Thu, 29 Aug 2019, 18:13:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 608.9673 Predicted Values: "Check LIT101"	Yes		No	LIT101 changed from 833.414551 to 608.9673	True
-	Thu, 29 Aug 2019, 18:13:00	Process Affected: "stage1" Tags Affected: "CPS_ALID_P1_SA1" Actual Values: 832.551 Predicted Values: "Check LIT101"	Yes		No	LIT101 changed from 608.9673 to 832.551	True
-	Thu, 29 Aug 2019, 18:15:00	Process Affected: "stage3"	Yes		No	LIT301 changed from 913.0271	True

		Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 870.7303 Predicted Values: "Check LIT301"				to 870.7303	
-	Thu, 29 Aug 2019, 18:16:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 910.3836 Predicted Values: "Check LIT301" No	Yes		No	LIT301 changed from 870.7303 to 910.3836	True
-	Thu, 29 Aug 2019, 18:16:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SA1" Actual Values: 665.790833 Predicted Values: "Check LIT401"	Yes		No	LIT401 changed from 990.746 to 665.790833	True
-	Thu, 29 Aug 2019, 18:16:00	Process Affected: "stage4" Tags Affected: "CPS_ALID_P4_SA1" Actual Values: 991.168945 Predicted Values: "Check LIT401"	Yes		No	LIT401 changed from 665.790833 to 991.168945	True

Table 4D DAD-2019: Updated Performance summary on CISS2019 data. Day 4

S.No	Timestamp	Detector tag / cause	A		B		C
			False alarm? [Yes/No]	remarks	False alarm? [Yes/No]	remarks	Verified against CSV file
-	Fri, 30 Aug 2019, 10:41:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SD6" Actual Values: 99 Predicted Values: "Check MV301, 302, 303"	Yes		Yes	It is a false alarm. In general MV201 closes in 5 seconds but this instance it closed in 8 seconds that's why raised an alarm.	True
-	Fri, 30 Aug 2019, 11:08:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 500 Predicted Values: "Check LIT301"	Yes		No	LIT301 changed from 908.420959 to 500	True
-	Fri, 30 Aug 2019, 11:09:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 899.3688 Predicted Values: "Check LIT301"	Yes		No	LIT301 changed from 500 to 899.3688	True
-	Fri, 30 Aug 2019, 12:04:00	Process Affected: "stage3" Tags Affected: "CPS_ALID_P3_SA1" Actual Values: 891.5583 Predicted Values: "Check LIT301"	Yes		No	LIT301 is from 798.1527 to 891.5583	True. ABO007

Table 5: DAD-2019: Performance summary on CISS2019 data

Item	Quantity
Attacks launched ¹	131
Successful attacks ²	16
Unsuccessful attacks ³	115
Alarms raised by DAD	108
Alarms due to anomalies	108
Alarms due to setpoint violation ⁴	10
Detection rate	100
False alarm rate ³	0

1. This table includes ALL attacks launched over the course of the CISS2019 event. Some of these attacks were launched via the SWaT communications network while the remaining were launched directly from the SCADA workstation. DAD is intended to detect an anomaly in the plant state regardless of how an attack was launched.
2. Attacks that cause an anomaly in the plant state are considered successful; others are unsuccessful.
3. A setpoint is a marker set by a PLC. For example, H and L markers for each tank are some of the setpoints.
4. An alarm generated by DAD is considered a “False alarm” if it is generated when there is no anomaly in the plant state and no setpoint is violated.

Table 6. Performance of various versions of DAD

Attribute	DAD-2016 [2]	DAD-2018 [3]	DAD-2019
	#	#	#
Invariants	16	38	54
Attacks launched	70	38	22
Process anomalies*	70	38	108
Anomalies detected	70	33	108
False alarms	0	0	0

*During the evaluation of DAD2016 and DAD2018, the attacks were designed to create process anomalies and hence the number of process anomalies is the same as the number attacks launched. However, during the evaluation of DAD2019, reported here, the data is from CISS2019 where several attacks launched by the RED teams did not lead to any process anomaly.