# Graph-based algorithm for the understanding of failures in the ATLAS infrastructure

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## Abstract

The ATLAS Technical Coordination Expert System is a knowledge-based application describing and simulating the ATLAS infrastructure, its components, and their relationships, in order to facilitate the sharing of knowledge, improve the communication among experts, and foresee potential consequences of interventions and failures. The developed software is key for planning ahead of the future interventions and upgrades, and for discovering the most effective ways to improve the ATLAS operation and reliability. Currently, the system's database describes more than 13.000 elements and 89.000 relationships among them. It gathers information from diverse domains such as detector control and safety systems, gas and water supplies, cooling, ventilation, cryogenics, and electricity distribution. Recently, a tool to identify the most probable cause of a failure state has been developed. This paper discusses the current graph-based algorithm implemented by the tool, and its behaviour based on the parameters entered by the user. A simulation of a real event is explained as an example and demonstrates the potential of this Expert System in understanding major failures in a considerably reduced amount of time.

## Introduction

The ATLAS experiment is composed of more than 13.000 monitorable and controllable components[1]. All these components are distributed in subsystems as shown in Figure 1. In this complex environment, it is crucial to support the coordination of the experiment through tools that can use explicit and formally represented knowledge from diverse experts. The ATLAS Technical Coordination Expert System (ATCES) has been created gathering the knowledge of experts that enables the foresee of the potential impact of interventions and failures, and **identify the faulty elements when a failure occurs**.

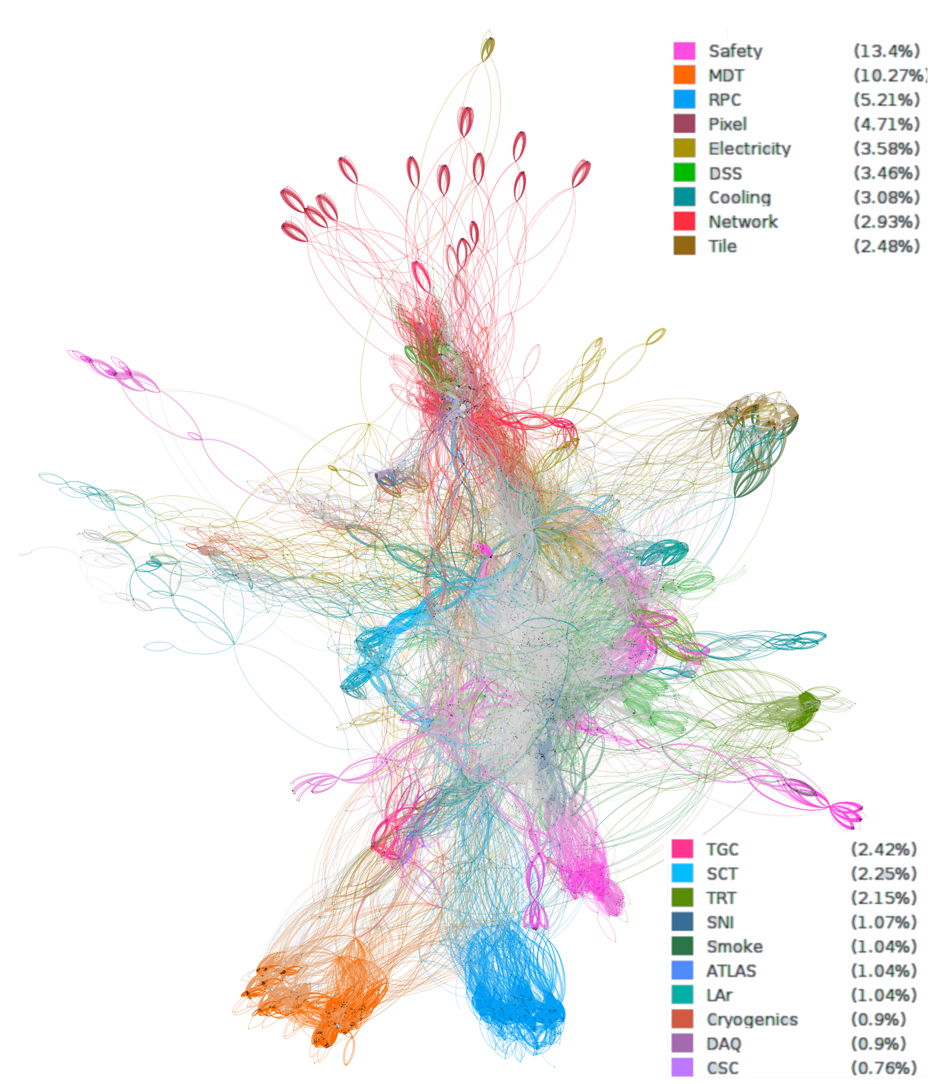



Figure 1:ATCES graph - components coloured by subsystem

## Methods

The ATCES is based on the OKS (Object Kernel Support) persistency system that manage the data following principles of the Object Oriented Programming[2]. In order to run graph algorithms over the OKS data, the NetworkX python library has been used. A multi directional graph was created replacing the OKS objects by nodes and the OKS relations by edges. NetworkX has been used for detecting circular dependencies (cycles), to propagate the changes in the simulations, and to list the Most Probable Causes (MPC) of a faulty state. In the MPC context the Algorithm 1 is followed. The current implementation of the algorithm uses the eigenvector centrality to sort the affected nodes (line 2) because this centrality algorithm ranks better the nodes based on its influence over other nodes. Degree, Harmonic, Betweenness, and Closeness centralities has been evaluated and compared using the recall and precision in the results. The algorithm is parametrized in order to return results before considering all the possible combinations reducing the execution time (see line 8). The user selects the average waiting time, then the max_results and max_trys parameters are set based on the performance evaluation done in the current infrastructure[3] (see Table 1).

## Results

The MPC tool of the ATCES has been used successfully in scenarios like the annual maintenance of the water circuit chillers[4],

| AverageTime[min] | AlgorithmParameters |
|---|---|
| 5 | max_results=16<br>max_trys=64 |
| 10 | max_results=128<br>max_trys=128 |
| ∞<br>(Unlimit) | max_results=2048<br>max_trys=2048 |

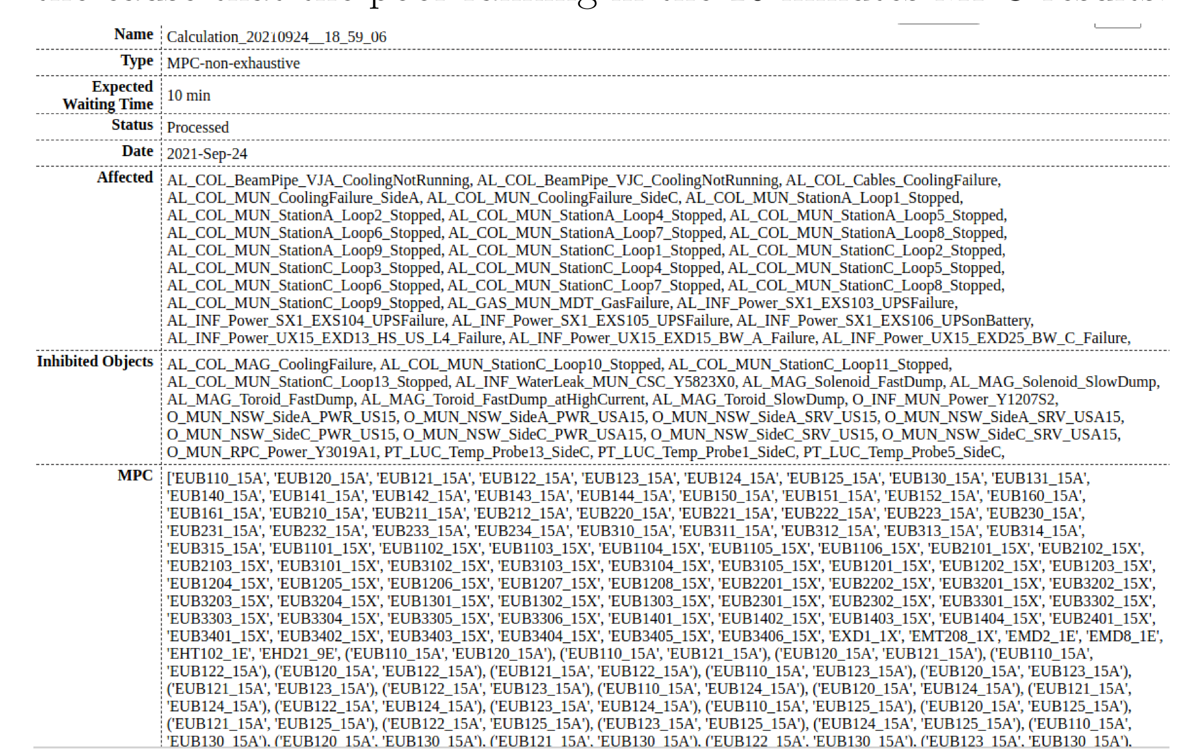
Table 1:Parameters per average waiting time

however, on July 5th of 2021 happened a failure where the tool doesn't provide answers as expected. This failure is not fully understood but the behaviour match with a failure in the electrical power, specifically of the switchboard *EXD1_1X*. In all the simulations done for this failure, the list of affected nodes corresponds with the information gather on this date. However, the exhaustive mode (line 14) was not able to get results because some alarms that should be triggered due to the failure, were not triggered on this day. For example, the alarm *AL_GAS_MUN_TGC_GasFailure* was already trigged by another intervention, therefore, can not be trigged again. If an expert notice this and include the alarms already trigged in the tool, then the MPC results are correct in the 10 minutes mode (*EXD1_1X* and *EMT208_1X*). In case the user is not able to recognise the missing alarms, the MPC tool provides answers in the non-exhaustive mode using an average waiting time greater than 10 minutes, see Figure 2. The MPC results show combinations of 1 or 2 faulty nodes.

### Algorithm 1 - Most Probable Cause (MPC)

```
Require: out_centrality ← EIGENVECTOR_CENTRALITY(graph)
1: function FINDMPC(affected_nodes, elapsed_time, max_faulty_nodes, max_results, max_trys, is_exhaustive)
2:     SORT(affected_nodes, out_centrality)
3:     ancestors ← COMMON_ANCESTORS(affected_nodes)
4:     MPC ← []
5:     for combination_size ← 1, max_faulty_nodes + 1 do
6:         combinations ← COMBINATIONS(ancestors, combination_size)
7:         iteration ← 0
8:         for all combination do        ▷ While |MPC| < max_results&iteration < max_trys × combination_size
9:             iteration ← iteration + 1
10:            for all ancestor do
11:                SWITCH_OFF(ancestor)
12:                affected_nodes' ← PROPAGATE_CHANGE(ancestor, elapsed_time)   ▷ Uses breadth first search recursiverly
13:            end for
14:            if is_exhaustive then
15:                if affected_nodes = affected_nodes' then ▷ only nodes with the classes of the affected_nodes are evaluated
16:                    MPC ← MPC.ADD(combination)
17:                end if
18:            else        ▷ When the affected_ nodes is including only a partial list of the total of nodes impacted by a fault
19:                if affected_nodes ⊆ affected_nodes' then
20:                    MPC ← MPC.ADD(combination)
21:                end if
22:            end if
23:        end for
24:    end for
25:    return MPC
26: end function
```

The switchboard *EXD1_1X* is located in position 97, after a series of emergency buttons that can be easily discarded by an expert as false positives. The non-exhaustive mode using an average waiting time of 5 minutes doesn't deliver any result because the algorithm used for sorting the common parents (eigenvector_centrality) rank poorly the faulty switch board. This is also the cause that the poor ranking in the 10 minutes MPC results.



| | |
|---|---|
| Name | Calculation_20210924__18_59_06 |
| Type | MPC-non-exhaustive |
| Expected Waiting Time | 10 min |
| Status | Processed |
| Date | 2021-Sep-24 |
| Affected | AL_COL_BeamPipe_VJA_CoolingNotRunning, AL_COL_BeamPipe_VJC_CoolingNotRunning, AL_COL_Cables_CoolingFailure, AL_COL_MUN_CoolingFailure_SideA, AL_COL_MUN_CoolingFailure_SideC, AL_COL_MUN_StationA_Loop1_Stopped, AL_COL_MUN_StationA_Loop2_Stopped, AL_COL_MUN_StationA_Loop4_Stopped, AL_COL_MUN_StationA_Loop5_Stopped, AL_COL_MUN_StationA_Loop6_Stopped, AL_COL_MUN_StationA_Loop7_Stopped, AL_COL_MUN_StationA_Loop8_Stopped, AL_COL_MUN_StationA_Loop9_Stopped, AL_COL_MUN_StationC_Loop1_Stopped, AL_COL_MUN_StationC_Loop2_Stopped, AL_COL_MUN_StationC_Loop3_Stopped, AL_COL_MUN_StationC_Loop4_Stopped, AL_COL_MUN_StationC_Loop5_Stopped, AL_COL_MUN_StationC_Loop6_Stopped, AL_COL_MUN_StationC_Loop7_Stopped, AL_COL_MUN_StationC_Loop8_Stopped, AL_COL_MUN_StationC_Loop9_Stopped, AL_GAS_MUN_MDT_GasFailure, AL_INF_Power_SX1_EXS103_UPSFailure, AL_INF_Power_SX1_EXS104_UPSFailure, AL_INF_Power_SX1_EXS105_UPSFailure, AL_INF_Power_SX1_EXS106_UPSonBattery, AL_INF_Power_UX15_EXD13_HS_US_L4_Failure, AL_INF_Power_UX15_EXD15_BW_A_Failure, AL_INF_Power_UX15_EXD25_BW_C_Failure, |
| Inhibited Objects | AL_COL_MAG_CoolingFailure, AL_COL_MUN_StationC_Loop10_Stopped, AL_COL_MUN_StationC_Loop11_Stopped, AL_COL_MUN_StationC_Loop13_Stopped, AL_INF_WaterLeak_MUN_CSC_Y5823X0, AL_MAG_Solenoid_FastDump, AL_MAG_Solenoid_SlowDump, AL_MAG_Toroid_FastDump, AL_MAG_Toroid_FastDump_atHighCurrent, AL_MAG_Toroid_SlowDump, O_INF_MUN_Power_Y1207S2, O_MUN_NSW_SideA_PWR_US15, O_MUN_NSW_SideA_PWR_USA15, O_MUN_NSW_SideA_SRV_US15, O_MUN_NSW_SideA_SRV_USA15, O_MUN_NSW_SideC_PWR_US15, O_MUN_NSW_SideC_PWR_USA15, O_MUN_NSW_SideC_SRV_US15, O_MUN_NSW_SideC_SRV_USA15, O_MUN_RPC_Power_Y3019A1, PT_LUC_Temp_Probe13_SideC, PT_LUC_Temp_Probe1_SideC, PT_LUC_Temp_Probe5_SideC, |
| MPC | ['EUB110_15A', 'EUB120_15A', 'EUB121_15A', 'EUB122_15A', 'EUB123_15A', 'EUB124_15A', 'EUB125_15A', 'EUB130_15A', 'EUB131_15A', 'EUB140_15A', 'EUB141_15A', 'EUB142_15A', 'EUB143_15A', 'EUB144_15A', 'EUB150_15A', 'EUB151_15A', 'EUB152_15A', 'EUB160_15A', 'EUB161_15A', 'EUB210_15A', 'EUB211_15A', 'EUB212_15A', 'EUB220_15A', 'EUB221_15A', 'EUB222_15A', 'EUB223_15A', 'EUB230_15A', 'EUB231_15A', 'EUB232_15A', 'EUB233_15A', 'EUB234_15A', 'EUB310_15A', 'EUB311_15A', 'EUB312_15A', 'EUB313_15A', 'EUB314_15A', 'EUB315_15A', 'EUB1101_15X', 'EUB1102_15X', 'EUB1103_15X', 'EUB1104_15X', 'EUB1105_15X', 'EUB1106_15X', 'EUB2101_15X', 'EUB2102_15X', 'EUB2103_15X', 'EUB3101_15X', 'EUB3102_15X', 'EUB3103_15X', 'EUB3104_15X', 'EUB3105_15X', 'EUB1201_15X', 'EUB1202_15X', 'EUB1203_15X', 'EUB1204_15X', 'EUB1205_15X', 'EUB1206_15X', 'EUB1207_15X', 'EUB1208_15X', 'EUB2201_15X', 'EUB2202_15X', 'EUB3201_15X', 'EUB3202_15X', 'EUB3203_15X', 'EUB3204_15X', 'EUB1301_15X', 'EUB1302_15X', 'EUB1303_15X', 'EUB2301_15X', 'EUB2302_15X', 'EUB3301_15X', 'EUB3302_15X', 'EUB3303_15X', 'EUB3304_15X', 'EUB3305_15X', 'EUB3306_15X', 'EUB1401_15X', 'EUB1402_15X', 'EUB1403_15X', 'EUB1404_15X', 'EUB2401_15X', 'EUB3401_15X', 'EUB3402_15X', 'EUB3403_15X', 'EUB3404_15X', 'EUB3405_15X', 'EUB3406_15X', 'EXD1_1X', 'EMT208_1X', 'EMD2_1E', 'EMD8_1E', 'EHT102_1E', 'EHD21_9E', ('EUB110_15A', 'EUB120_15A'), ('EUB110_15A', 'EUB121_15A'), ('EUB120_15A', 'EUB121_15A'), ('EUB110_15A', 'EUB122_15A'), ('EUB120_15A', 'EUB122_15A'), ('EUB121_15A', 'EUB122_15A'), ('EUB110_15A', 'EUB123_15A'), ('EUB120_15A', 'EUB123_15A'), ('EUB121_15A', 'EUB123_15A'), ('EUB122_15A', 'EUB123_15A'), ('EUB110_15A', 'EUB124_15A'), ('EUB120_15A', 'EUB124_15A'), ('EUB121_15A', 'EUB124_15A'), ('EUB122_15A', 'EUB124_15A'), ('EUB123_15A', 'EUB124_15A'), ('EUB110_15A', 'EUB125_15A'), ('EUB120_15A', 'EUB125_15A'), ('EUB121_15A', 'EUB125_15A'), ('EUB122_15A', 'EUB125_15A'), ('EUB123_15A', 'EUB125_15A'), ('EUB124_15A', 'EUB125_15A'), ('EUB110_15A', 'EUB130_15A'), ('EUB120_15A', 'EUB130_15A'), ('EUB121_15A', 'EUB130_15A'), ('EUB122_15A', 'EUB130_15A'), ('EUB123_15A', 'EUB130_15A'), |

Figure 2:MPC results for normal power failure

## Conclusion

The MPC tool continues demonstrating being useful in the understanding of failures in the ATLAS infrastructure. With the experience of July 5th, 2021, the need of a pruning in the centrality algorithm is identify. In addition, the MPC results can be sorted using the number of common elements between affected_nodes and affected_nodes', and the probability of failure of the elements. This would allow to get a better ranking for the correct results.

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