CONTROLS AND THE AFT TOOL

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Abstract

This paper summarises accelerator Controls and the Accelerator Fault Tracking (AFT) tool for LHC during Run 2. Concerning Controls, the performance and evolution will be covered, with a particular focus on the so-called "Smooth Upgrades" process. Subsequently, the major changes linked with Long Shutdown 2 (LS2) will be described, including End-Of-Life, changes to the GUI strategy, and the introduction of the new Logging system – NXCALS. Finally, re-commissioning considerations and the outlook for Run 3 will be covered.

The AFT tool will be described in terms of what value it brought during Run 2, and in what direction it should, or could evolve going forwards.

CONTROLS PERFORMANCE

From a functional point of view, the Controls performed as expected throughout Run 2. Therefore, the performance can be considered from an availability perspective, using the data from the Accelerator Fault Tracking (AFT) tool [1] to give objective measures.

General Controls Availability

Figure 1 shows an AFT dashboard [2] that highlights Controls availability, fault counts and durations for each year of Run 2.

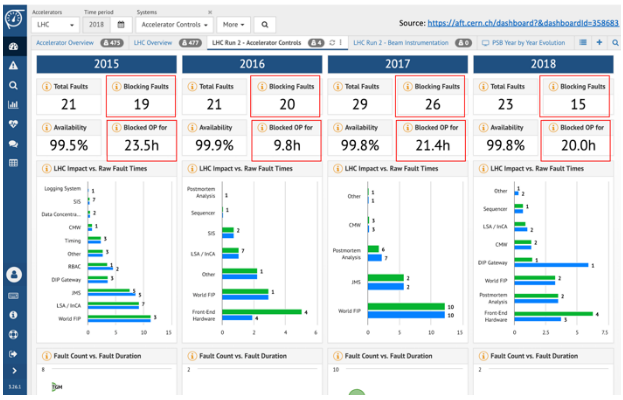

Figure 1: Controls general availability during Run 2

The Controls availability was consistently high, starting with 99.5% in 2015, rising to 99.9% in 2016 and remaining at 99.8% throughout 2017 and 2018.

The number of faults that blocked operation varied slightly – ranging from 15 to 26. Likewise, the total duration for which operations were blocked ranged from a low of 9.8 hours in 2016 to a high of 23.5 hours in 2015.

Controls Sub-system Availability

Figure 2 shows a different section of the aforementioned AFT dashboard which displays the breakdown of faults and durations across different sub-systems and elements that comprise the Control system.

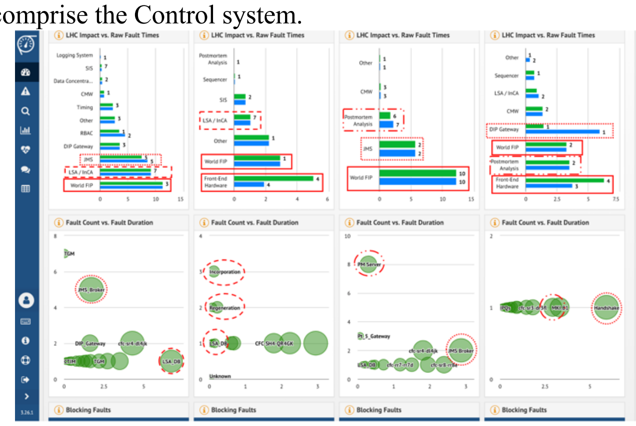

Figure 2: Controls sub-system availability during Run 2

Starting from the bottom of the top row of charts, the WorldFIP and related Front-End Hardware elements stand out as consistently being the largest contributors to Controls un-availability throughout Run 2. Measures are planned to address these issues during the Long Shutdown 2 (LS2) as described later in this paper.

During 2015 and 2016, LSA issues impacted operations, with LSA database performance the main cause. Corrective measures were taken in 2016 and the problems did not repeat for the rest of the run.

In the first half of 2015, the JMS infrastructure presented some instabilities which were addressed with relevant upgrades and configuration changes. JMS problems re-emerged in 2017 and were once again mitigated through software upgrades and improved monitoring and automatic restart procedures.

In 2017 and 2018, some problems were encountered with the Post-mortem infrastructure which were solved by hardware upgrades and a reduction in the processing workload.

Another noticeable fault in 2018 was with the DIP Gateway that is used to communicate between the LHC and the experiments. The DIP Gateway was subsequently replaced with a new major version, using more reliable and modern technology to address the issues observed.

CONTROLS EVOLUTION

In addition to the work to address the notable issues during Run 2, Controls evolved significantly during the run to ensure maximum stability, provide new functionality and prepare for the future.

In addition to the JMS and DIP Gateway consolidations and updates mentioned in the above section, the CMW Directory Service and RBAC Service were renovated to use scalable and fault tolerant architectures.

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Usability Improvements

Beyond the pure functional aspects of Controls, another important consideration is usability. During Run 2, a number of efforts were made to improve Controls usability, including:

- The introduction of the LSA App suite (see Fig. 3) which combines functionality from what was previously many tools into a single tool, with the aim of being shared across all accelerators and teams.

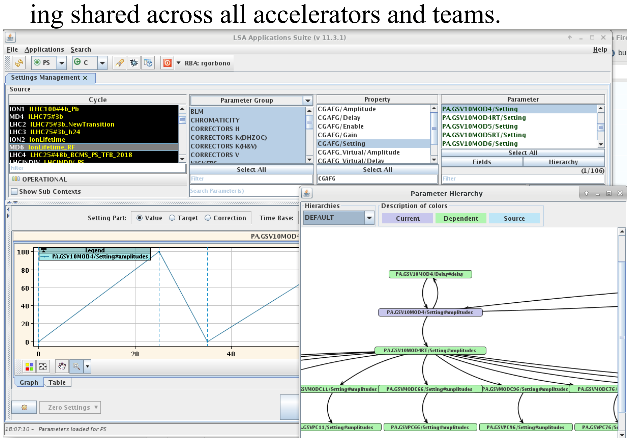

Figure 3: LSA App suite application

- The development of a new Controls Configuration Data Editor (CCDE) application (see Fig. 4) which integrates data from several systems such as FESA, RBAC, LSA, CALS, NXCALS, Layout and NetOps.

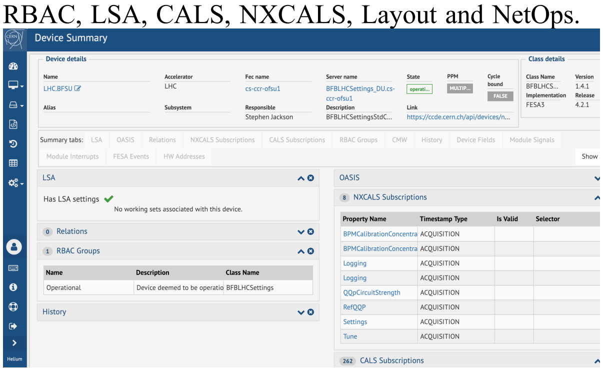

Figure 4: Controls Configuration Data Editor

- A number of FESA 3 improvements where implemented during the run resulting in very positive feedback from various users.

Development Tools

During Run 2, BE-CO deployed a new Java build system called “CBNG” based on Gradle, to replace the legacy “Commonbuild” system based on Apache Ant. All of the existing CERN libraries and applications plus 3rd party libraries were successfully migrated to work with CBNG.

The IT department announced their de-support of the SVN version control system and as such, BE-CO started adapting tools and workflows to use the IT-provided replacement Gitlab. This is an on-going activity that will be largely completed during LS2.

To support the TE-MPE “Magnet Powering & Protection Test Bed”, BE-CO collaborated to provide a “Controls Test Bed” facility which integrates the major Controls subsystems and allows teams to perform representative integration tests of new hardware and the corresponding Controls software.

Python Support

In 2017, BE-CO embraced the need to provide support for the Python programming language. BE-CO members joined the existing CERN Python community and subsequently launched a Focus Group “PyFG”. The first achievement was to reach a community agreement on the Python distribution. The agreed distribution is made in collaboration with the EP department, by using the EP-SFT prepared LCG (LHC Computing Grid) Python distribution and making it available on all relevant BE-CO infrastructure.

CO-OP Collaborative Development

Following the presentation of D. Jacquet at Evian 2016 [3], in 2017 members of BE-CO and BE-OP formed a team (Fig. 5) to work together on the development of software that would benefit from the combined knowledge of both domain and technical experts.

Figure 5: The CO-OP team in 2017

According to the team members, this was both motivating and productive. The team was able to develop powerful luminosity levelling software that works with separation and crossing angles (Fig. 6) and which already satisfies some HL-LHC Controls requirements.

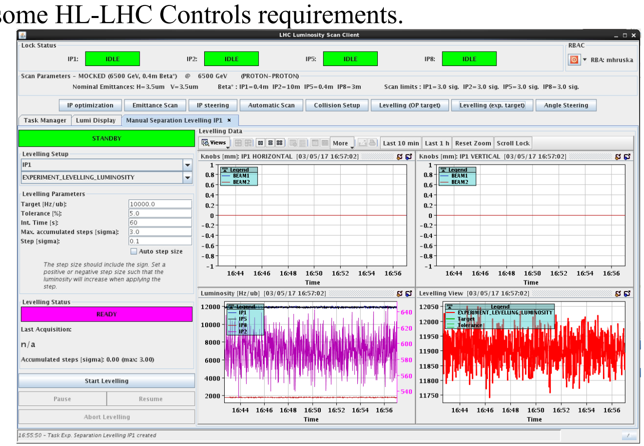

Figure 6: LHC Luminosity Levelling software application

Given the overall positive experience, there is a clear intention to continue with this type of collaboration in 2019 and beyond.

Smooth Upgrades

The Smooth Upgrades Working Group (SUWG) is a co-ordination body, mandated by the LMC [4] with approximately 25 participants from Equipment groups, BE-OP and BE-CO. The SUWG was introduced in 2012 by V. Baggiolini and since early in Run2 – led by M. Gourber-Pace. The principal aim is to ensure that necessary Control system upgrades can be applied during Technical Stops and (E)YETS whilst avoiding unplanned down time.

As requested by BE-OP, the process to introduce Controls changes was increasingly formalised during Run 2. In 2017 an ASM Controls Changes tool [5] was developed with the goal of tracking all changes. The tool (Fig. 7) also provides a workflow for people to register foreseen changes which can subsequently be approved by relevant Operations teams.

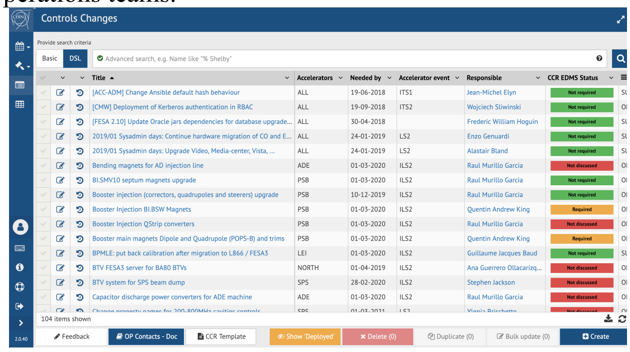

Figure 7: The ASM Controls Changes tool

At the end of Run 2, in preparation for this paper – relevant stakeholders were asked if the SUWG and Controls Changes process works. In response – there is foremost a global consensus that making Controls changes during a run is desirable in order to deliver new and / or improved functionality for Operations, test new things with beam, avoid big bang changes later on, etc.

In general, the SUWG and registration of Controls changes is seen positively. Having a trace of what was changed and why, with Operations in the loop ahead of time, is considered a good thing. The related meetings organised around Technical Stops and (E)YETS are also perceived as being valuable for the participants.

Having to register changes in advance, forces people to plan and coordinate work and seriously consider the potential impact. Nevertheless, there is still some scepticism about changes announced as being transparent. While the overall process is well established, some details continue to be refined. For example, during 2018 TS1, 1 change (out of ~70) failed with a big impact on the LHC restart. This was due to the change not having been properly validated prior to deployment. As a result, a pre-deployment CCC validation step was added to the process, whereby the outcome of the validation determines the approval for the operational deployment.

Although the registration of changes is viewed positively, it was also emphasised that this is not a replacement for direct communication between Equipment groups, BE-OP colleagues in the CCC and CO teams.

Some LHC Operators consider it to be preferable to deploy significant system changes between LHC Fills in co-ordination with the LHC operations team. This allows for a fast reaction in case of problems, however an efficient rollback strategy must be readily available.

Some people expressed a wish to go further with the SUWG processes and start to track and manage dependencies between Controls changes. This will help ensure changes are applied in the correct order. Likewise, it was expressed that an additional detailed follow-up of exactly which changes were deployed would be useful.

Post-Technical Stop restarts of LHC which are typically on a Friday evening are not ideal for all parties (Operators, Equipment groups, Controls teams) and many people suggest restarting earlier e.g. early on Friday afternoons.

MAJOR CONTROLS CHANGES IN LS2

Controls changes during LS2 are aimed at providing the best possible functionality and usability, whilst ensuring a continued high-availability.

BE-CO's offering in terms of tools and technologies is enlarging (e.g. Python, Web, AFT, ASM, etc.) and the outside world is evolving (both hardware & software). As such, there is a need to remove legacy components and upgrade in order to be able to continue to provide stable and usable Controls.

In general, Long Shutdowns are perceived as the main opportunity to tackle technical debt and make necessary breaking changes. However, LS2 represents an increased challenge due to the continued running of some facilities (i.e. no "shutdown") – this is also the case for many Equipment Groups.

To properly prepare for LS2, the feedback from the post-LS1 Controls Review [6] (summarised during Evian 2015 [7]) has been fully taken into account. Most notably, this includes:

- To "Publish a global planning, in advance, with all upgrades". This planning has been integrated into the LS2 Master Planning (Fig. 8) and presented at the "LS2 Days" workshop in 2018 [8].

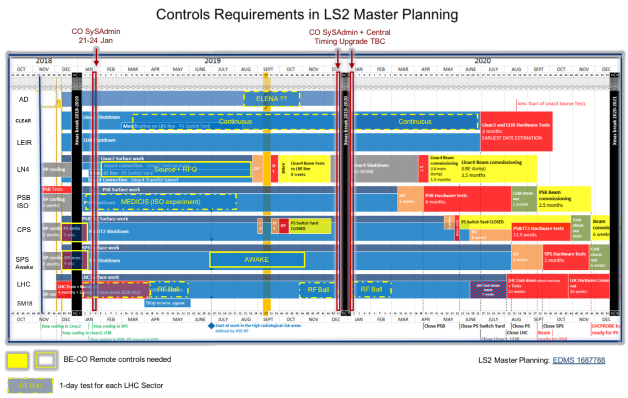

Figure 8: Accelerator Controls in LS2 Master Planning

- To satisfy the "Need for stable Controls at the start of the LS". In January 2019, BE-CO delivered as widely-announced [9] – the first "Controls Baseline" release.

This is a coherent set of Controls software with support until LS3.

Following the planning and preparation for the start of the LS2, many upgrades and new approaches will be deployed during LS2. These are described below.

LHC WorldFIP

As highlighted earlier in this paper, WorldFIP and related Front-End hardware were the largest contributors to the unavailability of Controls during Run 2. During LS2, there will be a complete overhaul comprised of:

- Migration of Industrial Front-end computers from Kontron to Siemens for a full replacement of the 200 LHC WorldFIP machines.
- Renovation of the WorldFIP MASTER by deploying the CERN-designed bus arbiters & software stack to replace proprietary Alstom solution.
- Replacement of the Alstom Cu/Opt repeaters by the CERN-designed GOFIP repeaters.

The WorldFIP MASTER updates were successfully validated on LHC FGCs in 2018 (thanks to the early adoption by TE-EPC) and address the instabilities experienced during Run 2.

End-Of-Life

The accelerator Controls LS2 End-Of-Life program was announced to stakeholders in 2015 and describes what will no longer be supported from a given date and will be supported for Run 3. Essentially, only RDA3, FESA3 (version 7+) and CentOS 7 will be supported for Run 3 onwards.

The January 2019 Controls Baseline release described above will remain compatible with future BE-CO releases until LS3. This means that Equipment groups can adapt to Controls changes from the start of LS2 and will not be forced to update again until LS3.

Overall, Equipment groups understand the need for the changes, but are nevertheless concerned about the amount of work required to not only adapt, but also to re-commission. All of this time takes away from their core activities.

Device Lifecycle Improvements

Aware of the challenges for Equipment groups to update to the latest Controls infrastructure, significant efforts were made during Run 2 to develop new Device deletion, promotion & migration tools ahead of LS2.

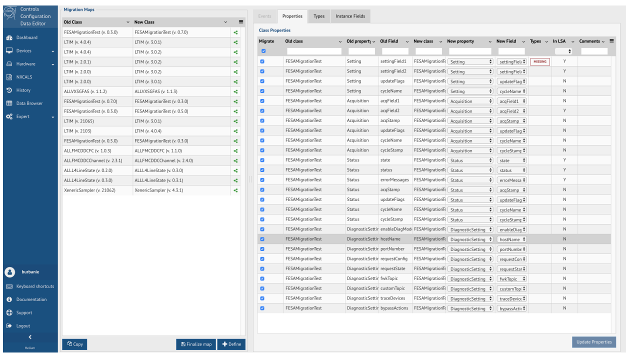

Figure 9: Device Migration application

The new Device Migration tool (Fig. 9) greatly facilitates the move to the latest version of FESA 3. It provides a single Migration entry point to validate, simulate and perform the subsequent migration in all CO related systems: FESA, RBAC, LSA, NXCALS. This is a clear step forwards to move away from the islands-like view of Controls described at Evian 2015 [10] to a more unified view advocated at Evian 2016 [11].

NXCALS

NXCALS is the next generation CERN Accelerator Logging System based on modern “Big Data” technologies. It is foreseen to fully replace the existing CALS system for Run 3 onwards. The current status of NXCALS is as follows:

- The core of the new system (including internal storage compaction, metadata service, etc.) is ready and running on production hardware (20 machines, 960 Cores, 8 TB RAM) since April 2018. Part of the core has been developed via a very positive collaboration between BE-CO and TE-MPE, with the aim of using NXCALS for the new Post Mortem Archiving.
- CMW data ingestion processes are fully operational.
- New logging can be configured with a click in the CCDE [12] (no more Excel).
- WinCCOA data ingestion processes have been developed in collaboration between BE-CO and BE-ICS and are undergoing final performance testing.
- Apache Spark based data extraction / analysis software is available and additionally integrated with the CERN SWAN tool (Web based analysis notebooks) [13].

Data can be extracted or analysed via the NXCALS client API (based on Apache Spark). For the best performance, the actual execution of data analysis code should be performed directly on the NXCALS cluster and then only return the results. This can be achieved by submitting a Spark job to run on the cluster. NXCALS data extraction documentation is in place with CALS equivalent code examples that continue to be extended and improved [14].

In addition to the new data extraction facilities, work is about to start on adapting the current CALS data extraction client API to retrieve data from NXCALS. The aim is to enable existing CALS clients to move to NXCALS without re-writing their code. A first release with only the most common methods will be provided ASAP and before mid-2019.

Concerning NXCALS data extraction performance compared with CALS – based on feedback from early adopters in BE-ABP, BE-BI & BE-ABT:

- CALS currently outperforms NXCALS for extraction of relatively small data sets.
- There is a lot of scope to tune NXCALS, but this is time consuming and not currently a priority. This topic will be addressed in the not so distant future. On-going 3rd party developments should also help improve.
- NXCALS far outperforms CALS for analysis of big data sets.

To get the most out of NXCALS requires users learning and using Spark in order to run their analyses on the cluster.

In 2018, NXCALS has already proven that it can satisfy use cases not possible with CALS e.g.:

- Diamond BLM analysis at IP7 & 16L2 (20-50GB/day in ~1 hour) by J. Kral, BE-BI.
- Annual intensity analysis (in ~2 hours) A. Huschauer, BE-ABP.

The CALS concept of "Variables" (signals names that abstract from the core underlying data mechanisms such as CMW and WinCCOA) continue to exist in NXCALS. In addition, new support for Device/Property based data extraction and analysis is also possible, which in turn, can facilitate "replay" functionality.

The popular Python library "PyTIMBER" will continue to exist and work with NXCALS, such that users will not need to change their existing code. Nevertheless, users should eventually switch to use PySpark for the best possible performance.

A new TIMBER web application will replace the current Java Swing application and a first version is foreseen to be provided before the end of 2019. Ideally, it will integrate the Accelerator Performance Statistics needs and be accessible from outside CERN. This requires further analysis & discussions with IT.

Migration of historical CALS data into NXCALS is a huge undertaking that requires to extract, transform and load >1PB of data for ~2.1E6 signals. A lot of work has been done, around 50% of CMW data has been migrated and non-QPS Industrial Controls data should be transferred by May 2019. Many corner cases are still to be looked at and will form the basis of on-going development and configuration activities in 2019.

The current CALS system will be phased out before the end of LS2, once the following criteria have been satisfied:

- NXCALS contains all of the required historical CALS data.
- A backwards compatible Java client API has been provided.
- A new version of TIMBER is available in production.
- The data extraction performance is at least comparable with CALS.

Concerning users switching to start using NXCALS, the system is operational, and all feedback is welcome. In particular, it can help solve challenging analysis use cases. CALS users who just want to extract data without changing their code are advised to wait for the adapted CALS client to be available.

GUI Strategy

LS2 will see the realisation of an important new BE-CO strategy for the development of Graphical User Interfaces (as presented by V. Baggiolini at the CO3 in October 2018 [15]). The essential message was that use of Java on the client is in decline, while Python Qt and Web are emerging. Therefore, the BE-CO strategy is as follows BE-CO:

- Is committed to Python and has resources.
- Will support PyQt as the obvious GUI choice.
- Will investigate PyDM or Taurus for Python RAD.
- Will not take over the RF Inspector.
- Will keep Java Swing alive but recommend to abandon JavaFX.
- Wants to explore Web technologies as an alternative to Java desktop.
- Is actively seeking for collaborations.

Python Support

As described earlier in this paper BE-CO began supporting Python as an official language (next to Java and C++) during Run 2. Usage includes for Controls, MDs, operational GUIs, RAD, Prototyping, HW Testing, etc. The provided support for the ATS sector can be summarised as:

- Provision of a Python environment (based on EP-SFT work) with a coherent set of tools (e.g. dependency management, building/packaging, a package repository, testing and CI/CD, deployment, monitoring, etc.).
- Python APIs to the controls system (taking over support for existing PyJAPC and PyLSA APIs).
- Promotion of Python as the language for operational GUIs (using PyQt and providing a framework and components) and RAD, including a RAD framework (probably based on SLAC's PyDM).
- Establishing guidelines and best practices for development of operational GUIs.

The timeline for the above work is to provide a first incomplete offering by the end Q2 2019, followed by a more complete version at the end of 2019.

Settings Management

LSA work is strongly influenced by the Settings Management Working Group – led by D. Jacquet, with the aim of simplifying and homogenising settings management across machines. Members of BE-OP and BE-CO make up the working group and a number of developments are foreseen during LS2 including improvements in trim usability; merge of LINAC4 and PSB settings; introduction of multiple non-PPM contexts for ISOLDE, CLEAR, AD and AWAKE; etc. There is also a growing interest to increase protection of settings and configuration against accidental changes.

OUTLOOK FOR RUN 3

A key takeaway from the post LS1 re-commissioning was the clear need for dedicated commissioning time for Controls. It is widely believed that this should be a collaborative effort driven by the Beam Commissioning Working Group (BCWG) and with relevant Operations, Controls and Equipment experts present. This organisation will be already needed for LINAC4 in 2019 which will give experience on the effectiveness of the process.

In terms of outlook, no major changes are foreseen during Run 3. Nevertheless, the next wave of End-Of-Life needs to be anticipated and applied during LS3. One such example will be the required eradication of JavaFX applications. The CERN-wide Microsoft reduction may also have an impact and necessitate a reduction in the use of Windows for Controls.

Run 3 will be the first operational experience with the new NXCALS system and may highlight the need to introduce a storage policy in order to scale. Possible options to be investigated further include:

- Introducing a revised retention policy on a case-by-case basis e.g. removing data older than a certain date.
- Invoicing for storage above a certain threshold.

ACCELERATOR FAULT TRACKING

Where we came from

In 2012, the initial members of the then new Availability Working Group (AWG), made significant efforts to gather data from a variety of sources to try to analyse the LHC availability that year [16]. Despite their best efforts and the time invested, the AWG commented on data inconsistencies, lack of responsibility assignments for faults, absence of dependencies between faults, and different data when seen from the perspective of operations (ELogbook data) or from Equipment groups. They summarised by stating that it was simply “not possible to have correct data” and highlighted the need to improve the capabilities in this area.

In 2014, during LS1, the Accelerator Fault Tracking project (AFT) was launched and resulted in first production tools that were successfully used from the start of Run 2. In Evian 2015, the AWG presentation of the 2015 Availability Summary [17] was based fully on the AFT data and a new standardised approach to fault tracking.

The AFT system was further developed in the following years such that in 2016:

- At the Chamonix workshop, the CERN Machine Advisory Committee (CMAC) recommended to extend AFT to cover the Injector Complex.
- Improved LHC availability data quality & tools were used throughout the year and results presented at Evian 2016 [18].
- The Injector Complex was identified as the number 1 cause of LHC unavailability [19].

In 2017:

- AFT was deployed for the Injector Complex.
- A. Apollonio conducted weekly reviews with Machine Supervisors and an AFT expert to further improve data quality and gather feedback on the AFT tool.
- Efforts were made to align the meta-data between the Technical Infrastructure systems and the TIOC, with AFT in order to streamline subsequent analysis and correlation.
- The quality of data in the LHC Evian Availability report was further improved [20].
- The first AFT-based availability report for the Injector Complex was also presented at Evian [21].

In 2018, the AFT tool was heavily developed (with 15 releases), providing more powerful reporting and features to extend and improve the quality of AFT data managed by Equipment experts. The resulting data was once again used in the annual Evian Availability report [22].

What AFT brought

First and foremost, the AFT tool requires high-quality data in order to provide real value. Therefore, the work done by the AWG, Machine Supervisors and Equipment experts to review, correct and complete the fault data is extremely important.

The AFT platform has enabled a streamlined approach to fault tracking across all CERN accelerators and systems. It offers powerful and objective reporting that people agree on – something that was not the case during Run 1.

Throughout Run 2, AFT was used as a basis for regular and periodic reporting (e.g. FOM, LMC, AWG, Evian etc.). This eased the work of the people required to produce such reports and bringing consistency across different reporters and over time.

Some teams already use AFT as a basis for planning consolidation work. This is also the foreseen usage of AFT in the SPS North Area for Run 3.

Where we should go next

Concerning the evolution of AFT in terms of functionality and how it is used, a number of viewpoints were expressed, including:

- “Management should use the data to direct consolidation”.
- “Automatic fault registration should be made possible for some systems”.
- “Generation of periodic reports should be made fully automatic”.
- “An API should be provided to allow programmatic registration or annotation of faults with analysis data”.
- “Better integration (or less problems) between ELogbook and AFT”. Concerning this point, there is currently some uncertainty about the future evolution and scope of the ELogbook with respect to AFT. The situation and direction need to be clarified as soon as possible in 2019.

Thanks to the regular AWG-driven fault review process – the fault data is of a high-quality concerning the impact on operation. Nevertheless, there is clearly room for improvement concerning equipment specific data. Therefore, a recommendation for Run 3 is the increased usage of AFT by Equipment experts e.g. providing faulty equipment details (see Fig. 10).

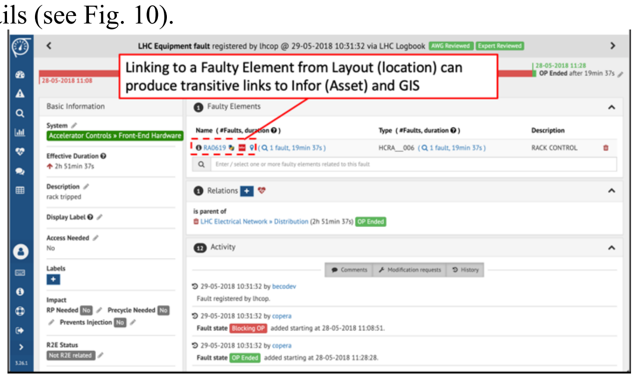

Figure 10: Linking AFT faults to Layout, Infor & GIS

AFT is integrated with the Layout system, and in turn the InforEAM asset management system and the GIS system. Therefore, assigning Layout elements to faults and as such – knowing where a fault occurred and the corresponding asset details opens up interesting possibilities to get more value from the data. For example, there is a potential to combine AFT and NXCALS data as a basis for advanced analysis or machine learning: If it is known where a fault happens and which logging signals represent data acquired in proximity to the fault – it is possible to look for events or hidden correlations in the data. Another possibility could be to look for possible radiation related affects: if it is known since when an asset is installed (from InforEAM), it is possible to calculate the integrated dose received by the failing equipment and look for patterns and start to predict failures. A similar use case could be for looking at temperature related effects. There are currently 2.1E6 signals declared in the logging system and potentially a lot of patterns waiting to be discovered.

SUMMARY

The Control system performed well during Run 2, with few faults, a high availability, and no known limitations remaining for Run 3. It continues to evolve based on user feedback, at the same time focusing on maintaining the existing reliability. BE-CO engaged in a number of successful collaborations during Run 2 and would like to continue to participate in such endeavours. A number of important End-Of-Life changes come into force during LS2, which are necessary to ensure continuity of the high Controls availability. In some cases, they are also needed due to external influences. A coherent Controls Baseline is available since January 2019 and will remain valid until LS3. This ensures stability for Controls users during Run 3.

The Accelerator Fault Tracking tool arrived at start of Run 2 and evolved throughout. It brings tangible added value, though there is still a lot of untapped potential to be explored. Additional development investments and increased data completion by Equipment groups are now prerequisites to go to the next level of having the knowledge about ways to further increase availability in the medium term.

REFERENCES

[1] Accelerator Fault Tracking Tool, https://aft.cern.ch

[2] AFT Controls Run2 Performance Dashboard, https://aft.cern.ch/dashboard?dashboardId=358683

[3] Breaking the wall between operational and expert tools, Evian 2016, https://indico.cern.ch/event/578001/contributions/2366926/attachments/1387323/2115048/tmp_29582-ExpertApplications_v1-843397176.pdf

[4] Smooth Upgrades WG – mandate, ongoing work and plans for 2015, LMC 194 04-11-2014, https://indico.cern.ch/event/350524/

[5] Accelerator Schedule Management Tool, https://asm.cern.ch/cc

[6] LS1 Controls Review, https://indico.cern.ch/event/448799/

[7] Feedback on Controls from 2015 operation, Evian 2015, https://indico.cern.ch/event/434129/contributions/1917205/attachments/1205086/1757363/MarineTalk_Evian2015-FINAL.pdf

[8] Controls presentation @ "LS2 Days" 2018, https://indico.cern.ch/event/760158/contributions/3153275/attachments/1730664/2797136/LS2Days_9Oct2018_MarinePace.pdf

[9] BE-CO's Plans for LS2, https://edms.cern.ch/document/1997812/2

[10] (LHC) Controls – an OP perspective, Evian 2015, https://indico.cern.ch/event/434129/contributions/1917181/attachments/1193272/1757065/controls-an-op-perspective.pdf

[11] How to improve interactions with the Control System?, Evian 2016, https://indico.cern.ch/event/578001/contributions/2366929/attachments/1384960/2113507/slides.pptx

[12] Controls Configuration Data Editor (CCDE), https://ccde.cern.ch

[13] SWAN, https://swan.cern.ch

[14] NXCALS Data Extraction Documentation, http://nxcals-docs.web.cern.ch

[15] GUI toolkits, RAD solutions and latest news on Java, https://indico.cern.ch/event/711479/

[16] Step back on availability, Evian 2012, https://indico.cern.ch/event/211614/contributions/423755/attachments/332035/463277/availability_summary_BT_AA_1v2_public.pptx

[17] 2015 availability analysis, Evian 2015, https://indico.cern.ch/event/434129/contributions/1917192/attachments/1202509/1755646/20151215_availability_summary_AA.pptx

[18] LHC Availability 2016 Proton Run, Evian 2016, https://indico.cern.ch/event/578001/contributions/2366294/attachments/1386690/2112791/2016_availability_evian.pptx

[19] Injectors: Unavailability By Machine, Root Causes, Strategy and Limitations, Evian 2016, https://indico.cern.ch/event/578001/contributions/2366305/attachments/1387896/2113012/Injector_Availability.pptx

[20] Availability 2017: Setting the scene, Evian 2017, https://indico.cern.ch/event/663598/contributions/2781458/attachments/1573332/2484581/awg_report_2017_p_11.pptx

[21] Availability 2017: Injectors, Evian 2017, https://indico.cern.ch/event/663598/contributions/2781768/attachments/1573469/2485223/Availability_Injectors.ppt

[22] LHC & Injectors Availability Run 2, Evian 2018, https://indico.cern.ch/event/751857/contributions/3259371/attachments/1781592/2910459/evian2018_availability_bt.pptx