AVAILABILITY WORKING GROUP & ACCELERATOR FAULT TRACKER – WHERE DO WE GO FROM HERE?

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Abstract

Numerous fault tracking concepts and requirements have been developed and defined by the LHC Availability Working Group (AWG). During Long-Shutdown 1 (LS1), these requirements were converted and integrated into an Accelerator Fault Tracking (AFT) system, developed as part of a BE/CO, BE/OP and TE/MPE initiative.

This paper presents an overview of the concepts and requirements from the AWG and the approach used in the AFT. The evaluation techniques used in Run 1 before the AFT are compared and contrasted to those used with the AFT in 2015.

The AFT has significantly influenced the concepts of availability capture being used by the AWG, thanks to more detailed and coherent data capture, important influences on availability can be quantified, allowing more complete and detailed models to be created.

The paper concludes by outlining the potential future plans of the AWG and next steps for the AFT development.

AVAILABILITY WORKING GROUP

In 2012, the LHC Availability Working Group (AWG) was established, reporting to the LHC Machine Committee (LMC). The goal of the AWG is to establish ways of improving the LHC integrated luminosity by considering the impact of availability on LHC performance [1].

The AWG established three key aspects required in order to create a coherent picture of availability and to achieve the goals of the AWG, as shown in Figure 1;

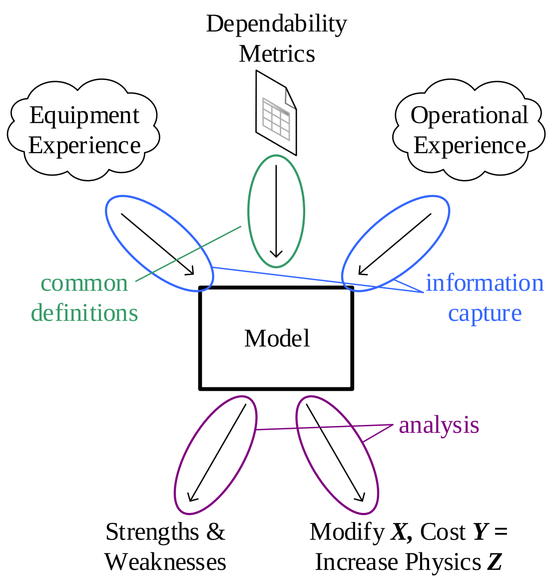

Figure 1: AWG Aspects of Availability Analysis

Information capture – where all relevant information related to availability has to be collected and stored in a coherent and easily mineable format. The two key domains from which to retrieve this data are *operations* and *equipment*.

Common definitions – required to merge and analyse information from the various sources, creating a coherent and global understanding of availability.

Analysis – using models, and interpretation. The output of such models are typically availability strengths and weaknesses of the LHC machine, and indicators of potential changes, associated costs and improvements that could be made regarding LHC availability.

Availability is directly linked to production of integrated luminosity. The two main classifications of un-availability are *beam* related events leading to loss of physics production, and *hardware* failures, combining these two sources of information allows models to be made that predict the integrated luminosity production based on known failure rates.

AVAILABILITITY VIEWPOINTS

AWG meetings and studies in 2012 [2, 3] revealed that there are distinct viewpoints to availability that need to be considered simultaneously in order to draw coherent conclusions and produce trustworthy models, the primary two viewpoints being *operations* and *equipment*.

Operations Viewpoint

In this case the primary availability optimisation and Key Performance Indicator (KPI) is *integrated luminosity*, dependent on several effects, typically:

- Physics performance during stable beams
- Stable beams duration during physics fills
- Turnaround time between physics fills
- Time lost due to faults

Equipment Viewpoint

In this case the KPI is generally the *Mean Time Between Failure* (MTBF), implying an understanding of:

- Diagnosis time
- Repair time
- Failure modes

Combined Viewpoint

These two viewpoints share some information, having a certain overlap, as shown in Figure 2.

At the same time, these viewpoints do not always create a coherent optimisation strategy. Equipment failures may last just seconds, having a lower impact on measured MTBF, but the impact of such failures on LHC operations may imply several hours of recovery, having a higher impact on integrated luminosity. In addition, optimising one does not necessarily mean the other is improved.

The aim of the AWG is to provide a means to objectively combine these two views to draw solid conclusions and recommendations for improving the LHC availability, and hence the integrated luminosity production.

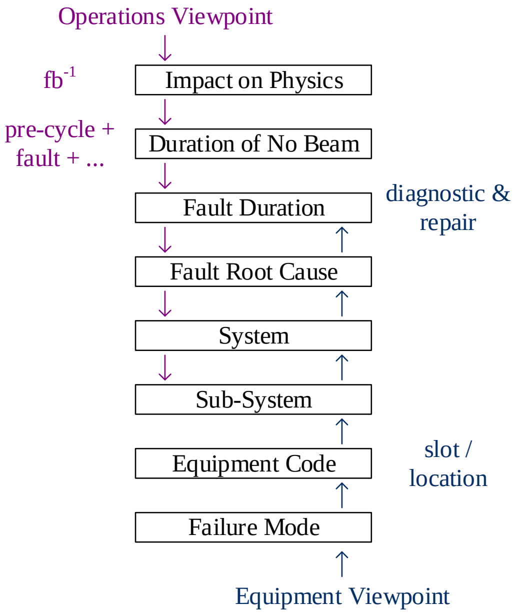

Figure 2: Combining Operations & Equipment Views

DATA INTERPRETATION

The AWG developed several unique data views, aimed at addressing the interpretation of data in the LHC environment, emphasising the connection between the operations and equipment viewpoints. The three data interpretations vital to this understanding are the LHC *Cardiogram*, *Availability Matrices* and *Hybrid Pareto*.

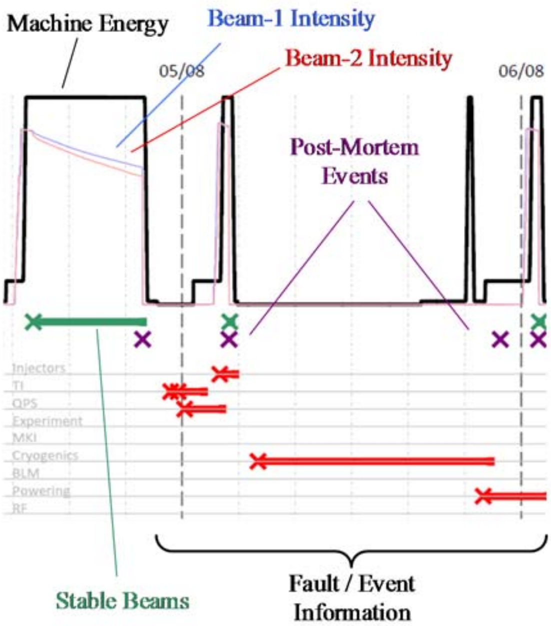

Figure 3: LHC Cardiogram Example

LHC Cardiogram

The LHC Cardiogram is a means to show the *operations viewpoint* in a clear and concise manner, Figure 3 shows the construction of a cardiogram, first proposed and presented in the LMC in March 2013 [2].

The cardiogram shows in a single view, the understanding operations have of the way the LHC is running with respect to fault conditions for sub-systems.

The KPI of operations in this respect is to optimise the length of time the machine is in stable beams, indicated by the green bar in the centre of the plot, shown in Figure 3.

Availability Matrices

From the *equipment viewpoint*, the most useful means of showing the impact on availability is the availability matrix, where failure mode, failure rate, and impact of failure are correlated, the availability matrix was proposed and presented in the Machine Protection Workshop in 2013 [4], Figure 4 shows the key elements;

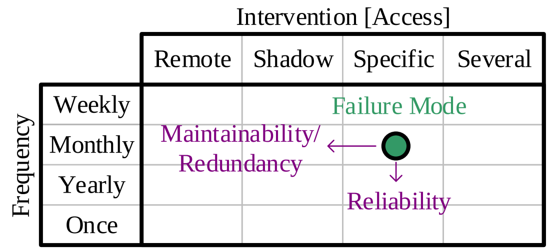

Figure 4: Availability Matrix Example

The aim of the equipment team is to optimise the availability using the matrix, which can be done using several approaches:

- Redesign a system to remove the failure mode
- Make the impact of the failure mode lower, by improving diagnostics, or maintainability, or adding redundancy etc.
- Make the likelihood of the failure less, by increasing the basic reliability of equipment.

Hybrid Pareto

Combining the two viewpoints on a Pareto gives a combinational view of root causes and associated un-availability.

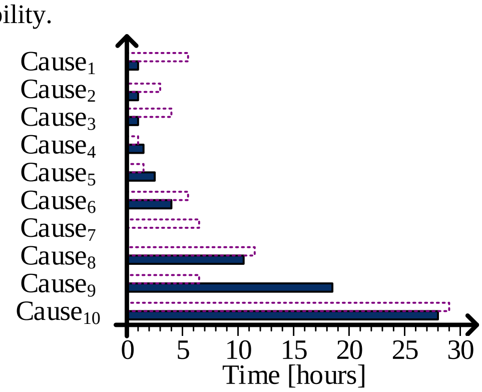

Figure 5: Hybrid Pareto Example

Plotting the observed time in fault from both the equipment view and operations view on the same axis can infer more information: Three particular cases emerge:

1. The equipment duration longer than operations duration: this implies that the repair or recovery of the equipment is taking place in the shadow of other things, thus a fault is not having an equivalent impact on operations.
2. The operations duration longer than equipment duration: this is used when the recovery for operations is generally longer than that for the equipment concerned. For example an access fault requires a pre-cycle to be added.
3. Zero equipment duration for a given cause, only operation duration: used for cases which are not due to equipment, such root causes are:
   - **Beam** – the beam itself led to a condition where the accelerator had to be stopped, and hence led to unavailability, such as beam instabilities.
   - **Operational Error** – leading to a beam abort, such as an incorrect setting or manipulation.

ACCELERATOR FAULT TRACKER

One of the outcomes from the data mining in 2010-2012 was that the initial data used to produce these views needed to be much more robust if it were to be used as an input to fundamental choices regarding investment in the LHC and the accelerator complex [5, 6, 7, 8].

During Long-Shutdown 1, the Accelerator Fault Tracking project was launched as a BE/CO, BE/OP and TE/MPE initiative [9], planned for deployment in three major releases:

AFT 1.0

Create a fault tracking infrastructure to capture LHC fault data from the operations viewpoint. Making this data exploitable in order to analyse areas to improve accelerator availability for physics. The AFT infrastructure is to allow the capture of fault data from equipment viewpoints.

AFT 2.0

The second stage of the project is to focus on detailed data capture from the equipment groups, incorporating the equipment viewpoint into the operations viewpoint.

AFT 3.0

Once equipment group data is being coherently captured, the AFT will explore integration of fault data with other data management systems at CERN, such as Layout, Impact, and Infor EAM in order to allow deeper analyses of system and equipment availability.

2010-12 ANALYSIS – WITHOUT AFT

Before the AFT, statistics were mined manually on an annual basis from several sources of information, creating global views of LHC availability, Figure 6 shows the approach that was generally used.

The operations perspective was mostly contained in the eLogbook, whereas each equipment group maintained an independent means for identifying their faults, failure modes and corrective actions. This all needed to be folded into the machine states and modes, which were derived from information stored in the Logging and Post-mortem systems.

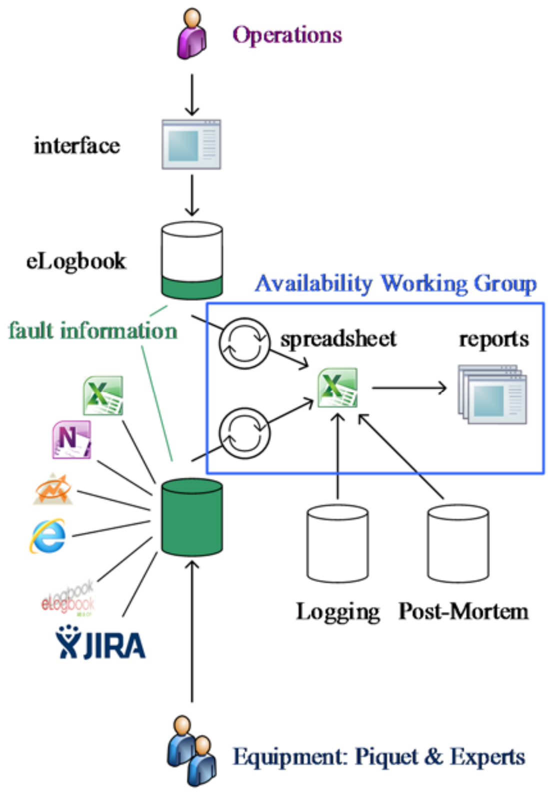

Figure 6: 2010-2012 Analysis Technique – without AFT

This investment of time in order to generate these analyses was around 0.2 FTE per year, divided between three staff and a research fellow.

This is a relatively small investment of time and at a first order, gives an idea on overall availability [8].

However, as it was only done once per year, the feedback between operations and equipment was limited, and more detailed analyses were not possible, due to the inaccuracy of the source information.

In addition, the work was not transparent, and could only be subjectively interpreted. And as such, only a cursory attempt could be made to link the operations and equipment viewpoints.

Finally a big weakness was the delay in generating data, production of curves from data-sets required several hours of manipulation, which made the whole system inefficient.

2015 ANALYSIS – AFT 1.0

In 2015, the AFT 1.0 was released and was used throughout the year to manage fault information capture.

The goal of AFT 1.0 was to ensure that the operations viewpoint was correctly captured, and hence the most important data viewer was the cardiogram. In this case the manner the AWG used to determine the information was to primarily use the cardiogram output of the AFT tool, and feedback corrections directly to the equipment and operations experts.

This feedback was done on a weekly basis, and the information logged by operations was validated on a shift-by-shift basis. This is shown in Figure 7:

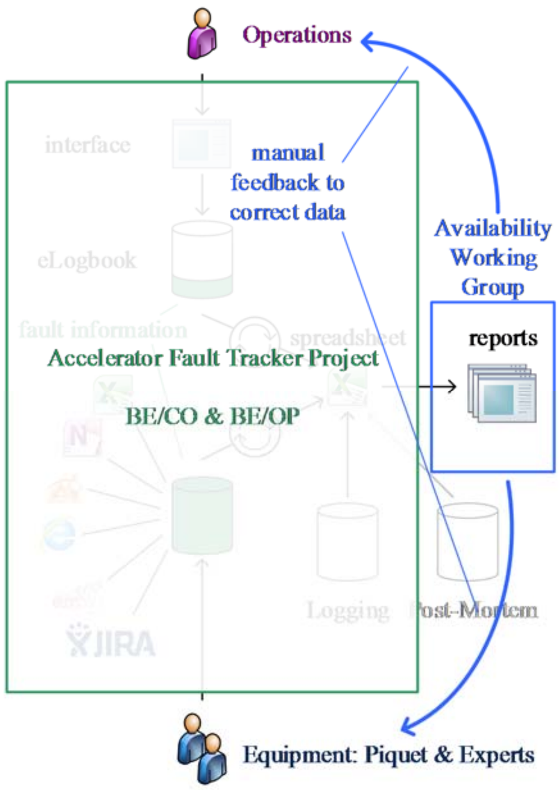

Figure 7: 2015 Analysis Technique – AFT Phase 1

This investment of time in this analysis was larger, estimates from BE/CO are around 1.5 FTE for the on-going development and maintenance of the AFT system, from the AWG, around 0.75 FTE were used for the data entry and on-going improvements of the AFT requirements, around 20 eLogbook entries a week being created and corrected in order to provide coherency of information [11]. This gives an overall investment of 2-2.5 FTE

The information created by the tool in 2015 is much more robust, having been analysed and agreed from the operations viewpoint on a weekly basis. The equipment viewpoint was integrated in stages with experts; from 2016 this will be done using an automatic system, whereby equipment groups are automatically informed when the operations team attributes faults to them.

In addition the data was completely transparent, as anyone at CERN could re-run the data extraction, and draw their own conclusions. The feedback with equipment groups created objective information about availability [10].

Finally, the speed of analysis was much improved, allowing data to be extracted and visualised almost in real-time.

BEYOND 2015

Following the successful exploitation of the AFT 1.0 in 2015, several areas are still to be explored.

Sensitivity Analyses

- As the fault information stored is now more robust, it should be possible to correlate this with other data. For example, what is the influence of intensity/energy? The AFT and AWG should be able to answer questions related to these kinds of sensitivity analyses.

AFT 2.0

- Following AFT 1.0, the next step is to begin to tap into equipment data; several groups have agreed to start, including TE/EPC and TE/MPE, in the early part of 2016, to see how this could proceed.

AFT in the Injectors

- The system has been designed for use in any accelerator, though so far the focus has only been on the LHC. It is possible to propagate the tool to some injectors, but this will still require additional development effort.

Day-to-Day LHC vs Strategic View

- For the LHC, data validation and continuous improvement of the AFT is to remain a core aspect of the AWG, at the same time, the effort to maintain fault data has increased quite dramatically. For data capture the increase is around a factor of 3, what used to be a part time role for a handful of people has become more than that.
- The information created for the LHC can be exploited for the successor machines at CERN, for example, HL-LHC, FCC.
- Several new and existing machines are being designed, which face the challenges of availability. The information that is being captured via the AFT should be usable to model other things. [11]
- Modelling and strategic aspects are becoming more detailed and heavier to manage, with several parties involved. In addition, the mandate of the AWG only covered the LHC, therefore, these aspects should be centralised and concentrated into dedicated (sub-) working group.

CONCLUSIONS

The AFT has extended the existing eLogbook and fault capture infrastructure to create a robust and objective data set for the management of fault information in the LHC.

This has come at a cost of increased manpower, with the return being significantly higher data quality. For the first time it has been possible to accurately quantify sources of unavailability related to *beam events* and *hardware failure*. It has also been possible to provide a vertical view matching *operations* and *equipment*, showing the differences between these two viewpoints

In addition, the infrastructure and platform interleaves with existing platforms at CERN, at the same time as being extensible, having the potential to automate certain tasks in the future, such as the creation of entries, and informing of equipment groups.

Next Steps

The AWG and AFT should move to the next phases – working to study potential improvements to the LHC machine availability, this may require a more long-term resource attached, and a more dedicated (sub-) working group, to concentrate on modelling and simulation of LHC and other machines.

ACKNOWLEDGMENTS

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