The Workshop on Machine Availability and Dependability for Post-LS1 LHC

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Overview:

Following the initial work of the Reliability Sub Working Group (**RSWG**) before LHC start-up, many equipment teams are now revisiting their dependability calculations in light of the operational experience of the past 4 years and future upgrades and improvements of the systems. The main goal of this workshop was to provide a forum for exchange and advertisement of the ongoing work as well as to discuss and guarantee the coherence of ongoing and future efforts. With the focus of LHC exploitation increasingly shifting towards machine availability, an attempt to quantify the impact of ongoing improvements and their effect on integrated luminosity in the post LS1 and HL-LHC era was made. In addition the status and future needs for tools and methodologies to reliably track and quantify the dependability of equipment systems was addressed.

Organising Committee:

A. Apollonio (TE/MPE)	C. Mugnier (TE/EPC)	L. Ponce (BE/OP)
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Registered Attendees:

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Introduction – Session 1

Motivation and goals of Workshop – B. TODD

The focus of LHC run 1 has been driven by safely commission and operating the LHC. Machine performance rapidly increased due to understanding and probing machine limits.

In Post-LS1 short term, it will already be difficult to achieve the same availability as 2012.

In Post-LS1 long term, peak luminosity is predicted to exceed the acceptance of the experiments so the focus of optimising physics production will shift to providing long periods of stable beams, in other words, to availability.

In 2004 a Reliability Sub-Working Group (**RSWG**) was established by the Machine Protection Working Group (**MPWG**) to consider the reliability of the core of the machine protection system, and in 2011 the Availability Working Group (**AWG**) was established via the LHC Machine Committee (LMC), the AWG is a central place for considering availability, and this workshop. The goal of the workshop is therefore four-fold:

1. Provide a forum for exchange and advertisement of work related to availability for CERN's machines.
2. Predict and quantify the impact of changes to key systems to the LHC physics performance.
3. Propose tools and methodologies to understanding post-LS1 availability consistently.
4. Discuss and reinforce coherence between approaches. E.G. AWG and MMP

Speakers have been asked to attempt to address five points:

1. Looking back at LHC Run 1: On the observed availability of systems…..
    a. If predictions were made, how did they compare?
    b. What stood out?
2. Looking back at LHC Run 1: On the observed availability of systems…..
    a. What tools were used?
3. Looking forward Post-LS1: On the changes to systems in LS1…..
    a. What will affect safety / availability?
    b. What will be the sensitivity to operating conditions?
4. Looking forward Post-LS1: On future reliability studies…..
    a. What studies are foreseen?
5. Looking Forward Post-LS1: On future data collection…..
    a. What tools will be used after LS1?

Dependability calculations prior to 2008 & operational experience during run 1 – J. UYTHOVEN

The RSWG existed from 2004-5, where it was charged with studying the safety and availability of a sub-set of the LHC Machine Protection Systems (**MPS**). Several of the people involved in the RSWG are still at CERN today.

The RSWG addressed the basic ideas of redundancy. That which is within the same system, for example having multiple Beam Loss Monitors (**BLM**) detecting beam loss events. And that which is between systems, for example having a slow beam loss first be detected by a BLM, and if that failed to produce a protective action, a quench would occur, which would cause the protective action to be carried out by the Quench Protection System (**QPS**) and Powering Interlock Controller (**PIC**).

The RSWG estimated that around 10.5% of all fills would be dumped by false aborts generated by internal failure of the MPS. In 2010-12 this has been observed as 12.7-14.0%, which is a close match to predictions. This model is intended to infer that if the observed failure rates are comparable to those that were derived during the studies (based on military handbooks and manufacturer data), and one can assume the failure modes are the same, then by definition the safety is assured. However, the observation of 12.7-14.0% beam aborts comes only from a sub-set of recorded failures, widening the scope to all failures (not only those themselves causing a beam abort), this figure is not correct. Moreover the basic model considered 2 fills per day, each of 10 hours, which is not a true reflection of todays LHC operation.

It can be concluded that the RSWG model is likely accurate for the safety, but is limited when considering availability, this needs to be extended.

The LHC AWG has continued the working style of the RSWG, and has been charged with the creation of similar models, on a similar basis. These models are needed to draw more solid conclusions on machine availability.

Ongoing Improvements for Increasing the Availability of the LHC – Session 2

Cryogenics – E. DURET & S. CLAUDET

This talk concerns **Cryogenics**. The LHC cryogenic systems represent a large, distributed industrial system. In 2012 the system failure rate was low, but the time to recover from failures of the cryogenic system is high. Therefore it was determined as being the system having the largest impact on physics in the 2012 Evian presentation. This is not the case when viewed from the equipment point of view, where the availability is almost 95% for 2012.

Run1:

The Cryogenics team put in place indicators (cryo-maintain, and cryo-start) according to the EN 15341 T2 criteria, which allowed them to monitor availability from their point of view. This information gave them measurable parameters to be used as a basis to improve availability.

Whenever the cryo-maintain signal transitions from ok → not ok, a record is created by the cryogenics team to track the failure. Tools used for this are an eLogbook, keeping track of the initial trigger and the key facts. Excel sheets that are used to record information sectioned by sector. Longer stops have their own dedicated Excel sheet and are treated separately.

Bi-weekly, TE/CRG reviews events with support teams and management to address issues.

Initial needs were to try and get sector level availability = 98%, in order to have a global availability = 80%. By the end of 2012 the sector level availability= 99.3%, leading to 95% global availability.

Changes during LS1 increasing availability:

- Major overhauls of rotating machinery, to avoid end of life wear-out.
- Magnetic bearing controllers in the cold compressors, reinforced against EMC.
- Remote reset and R2E mitigations in P2, 4 and 6.

Changes during LS1 decreasing availability:

- The re-adjustment of tolerance to 3.3kV glitches, which is necessary for motor protection may induce additional downtime.

Sensitivity to Operating Conditions:

- Higher energy means that resistive heat loads will increase (factor 4). Operating point moved closer to the maximum possible, although still within design values.
- Failures of rotating machinery will be more visible; near misses from before will now cause a stop with an impact on availability or physics.
- Quenches will take longer to recover from

Future Tools and Studies:

- A new metric will be produced [0-100%] which indicates the cooling capacity available
- A combination of tools is needed and being investigated to merge the cryogenics viewpoint with that of operations.

Discussion:

- pre-cycles should accounted in the downtime
- not all systems have an easy observable which could represent their availability
- Could the data be used from the logging service in the future?

Power Converters – S. UZNANSKI

This talk covers Power Converters (**PCs**). Over 1700 power converters are used to power the LHC machine, of which around 1050 are in zones affected by radiation. A power converter can be considered as having three main sections.

1. The Voltage Source (**VS**) which converts AC mains electricity into DC current.
2. The Controller (**FGC**) which defines the converter state and operating point.
3. The current measurement device (**DCCT**) used to read back the operating point as part of the closed loop regulation. The DCCT failure rate is not significant compared to the other two parts.

Run1:

- The power converters were the third highest cause of loss-of-physics as determined by the Evian 2012 study. Power converter failure was identified as the root cause of **35** beam aborts. At the same time power converter faults were noted **59** times in the eLogbook. Of these only **52** entries were found in the TE/EPC database. In addition to this, the radiation working group found **16** more faults which were not identified by either of these sources. A worst case analysis using these sources was performed.

- For the VS, 23% of failures were linked to radiation induced effects, 77% to random hardware failure. 14 or 15 radiation induced failures were the same failure mode on a 600A converter which has been identified and mitigated during LS1.
- For the FGC, 67% of failures were linked to radiation induced effects, 33% to random hardware failure.
- Extrapolation of these figures into the post LS1 (2017) era means that there would be ~69 failures per year of VS and over 200 failures per year of FGC. Unacceptable for the LHC, meaning a new controller is needed.

Changes during LS1 increasing availability:

- Known unreliable parts in the VS have been fixed.
- A new radiation tolerant power converter controller is being designed (FGClite) which is expected to be 20 times more reliable in radiation than the current FGC.

Changes during LS1 decreasing availability:

- The FGClite will not be ready for the restart of LHC after LS1. Therefore it is possible that the FGC2 remains in place, with the known failure rate.
- After the FGClite installation, an initial period of infant mortality with higher failure rate is to be expected.

Sensitivity to Operating Conditions:

- Higher current in the magnets mean that the VS will run at a higher operating point, which is expected to decrease the MTBF of the VS.
- Higher beam loading and local radiation mean that the current FGC will suffer more failures due to radiation induced effects until its replacement by the FGClite.

Future Tools and Studies:

- The different sources of information are inconsistent, they need to be consolidated. TE/EPC will migrate, or copy, information from the TE/EPC database to the solutions proposed by the Maintenance Management Project (MMP) as and when they become available.
- Failure rates must be observed in order to continue tracking if expected failure rates in radiation match observations.

Discussion:

- 2015 might have very high luminosity already, leading to a radiation problem with FGC2. However, can survive without some 60A converters, further analysis of expected dose needed for operation.
- interlocking of small power converters needs to be addressed
- the fieldbus becomes a critical element in the reliability of the power converters, reliability for this could be estimated from existing data.
- voltage source not addressed by presentation – but supposed to be less critical

LHC Beam Dumping System – R.FILIPPINI

This talk covers the LHC Beam Dumping System (**LBDS**) which is the final element of the beam related machine protection chain. There are two LBDS, one per beam.

2003-6 analyses were made to determine the safety of the LBDS with the focus on two aspects:

1) the likelihood that it carries out, on demand, a beam abort, when requested
2) the ability to cope with internal faults and errors by failsafe mechanisms (e.g. the so called false beam dumps)

These studies revealed that the LBDS is equivalent SIL4, with an expected number of false dumps of 8 +/-2 per year, with two asynchronous dumps expected per year.

Run1:

Analysis of 2010-12 operations was carried out to determine how close the 2003-6 predictions were to the observed performance. During the three years 139 failures were found, 90 internal to the LBDS, with the remainder due to external components.

Models predicted 99 failure modes of the equipment, 18 of which were observed. 7 new failure modes were identified during operation, which were not part of the model. The 70 remaining failure modes did not occur, which was in line with the predicted rate of occurrence of these failure modes.

The LBDS had 29 false beam dumps, versus the 24 predicted in three years of operation, which is close to the estimate of the model.

In addition to this study, the safety margins were identified. Too much safety margin means preventive actions are carried out before they are really needed leading to an unnecessary loss of availability. Conclusions are:

1. The LBDS has at least been observed to be SIL3.
2. The surveillance function is unbalanced against availability (it over-protects)
3. The control function is closest to safety margins

The LBDS is a primary safety apparatus of the LHC; it is designed to be highly safe, and needs to ensure the investment in LHC. Nevertheless, overprotection in the LBDS has been identified, and this could suggest areas to improve in the future. For example, by reducing the sensitivity to internal faults, especially those which have little impact on safety margins.

Changes during LS1 increasing availability:

- Problems with the vacuum gauges in the MKB are being resolved during LS1, 13 false dumps occurred during Run 1.
- Insulation is being added to the HV generators, preventing sparking and self triggering.
- The power supply of the pre trigger unit is being upgraded; the IGBT is being upgraded for one with a higher voltage.
- Shielding is being added in the cable ducts around UA63/7 and the associated RA; this will reduce the cross section for single event effects.

Changes during LS1 decreasing availability:

- An additional re-trigger is to be made between the Beam Interlock System (**BIS**) and LBDS, in case the trigger synchronisation unit (**TSU**) malfunctions. This is intended to increase safety but is predicted to have a very small (% level) increase in the asynchronous beam dump rate.
- The TSU board will be revised to add more surveillance; this is intended to increase safety. This is expected to increase the number of false triggers, and hence decrease availability.
- The powering strategy for the LBDS is to be revised to remove common cause failures, again increasing safety at the cost of lower availability.
- Two MKB magnets will be added per beam, this is to increase safety. This comes with an increased likelihood of erratic triggering, and an increased risk of magnet flashover. Again reducing availability.

Sensitivity to Operating Conditions:

- As the machine energy is increased, the system will move the operating point closer to limits. This reduces operational margins.

Future Tools and Studies:

- The safety gauge concept could be rolled out to other critical systems to see where the trade-off between safety and availability needs to be improved.
- Failure tracking is needed to be sure that components are in the constant failure rate part of the bath-tub curve.

Discussion:

- Clearly defining system functionalities helps identifying failures, therefore reduces the possibility of 'unknown' failures

Magnet Protection and Interlocks – S. GABOURIN

The systems concerned are the Powering Interlock Controllers (**PIC**), Warm Magnet Interlock Controller (**WIC**), Fast Magnet Current Change Monitor (**FMCM**), Beam Interlock System (**BIS**), Safe Machine Parameters System (**SMP**) and Quench Protection System (**QPS**).

Run1:

JIRA and eLogbooks were used to track errors and faults for the first two years of Run 1, from April 2012 all faults and errors have been tracked in the TE-MPE-COMS JIRA tool.

PIC, the only unexpected failures were radiation induced faults on the PLC, which have been mitigated by relocation during run 1.

WIC, no significant faults affecting availability were observed during Run 1.

FMCM, power supply network glitches have caused the FMCM to trigger, although this is the design function of the FMCM.

BIS, optical fibre degradation during Run 1 was an unexpected failure mode.

SMP, no significant faults affecting availability were observed during Run 1.

QPS, three principle types of problems in 2012 operation that were unexpected. Radiation induced failures, spurious triggering of the energy extraction system mainly due to bad connections, spurious creation of errors in the quench detection electronics, mostly caused by bad connections.

Changes during LS1 increasing availability:

- BIS, addition of fibre optic monitoring system to predict failure of the optical infrastructure.
- QPS, relocation of equipment will mitigate around 30% of the single event effects.
- QPS, upgrade of electronics to be more radiation tolerant.
- QPS, a campaign has been initiated to check for bad cabling, which is the reason for spurious energy extraction opening.
- QPS, cable routing and twisting improved to increase the system robustness against EMC type problems.
- QPS, firmware upgrade allowing automatic reset when communications lost, remote reset for the local quench detectors.

Changes during LS1 decreasing availability:

- BIS, an additional interlock between the BIS and the LBDS, to ensure the protection of the LHC even in the case of failure of the TSU.

Discussion:

- Dependability models of the QPS / BIS / PIC from RSWG are not being updated
- Common tool in parallel to JIRA would be interesting.
- Electrolytic capacitors on QPS could be tricky, but are not critical components being used as input supply filter
- Fewer failures mean loss of knowledge on how to repair, leading to longer interventions: need regular exercises!
- Different thresholds of the QPS – interplay with tune feedback running corrector circuits at high current / fast changes. To be re-discussed

LHC Beam Instrumentation Systems – L. JENSEN

This presentation covers the Beam Loss Monitors (**BLM**), Beam Position Monitors (**BPM**), Abort-Gap Monitor (**BSRA**), Orbit Feedback (**OFB**), Tune Feedback (**QFB**), Beam Current Transformers (**BCT**) and the Synchrotron Light Monitor (**BSRT**) for bunch and beam size measurements, **wire scanners**, and dump beam screens (**BTVDD**).

Run1:

According to some metrics, these systems only accounted for 6% of all faults; this metric does not count the time to recover operating conditions as there are no clearly defined and agreed means to do so. Instrumentation systems are dependent on a number of external systems and operating conditions.

BLM, VME power supply faults due to overheating power supplies. The BLECF module has a high voltage detection threshold which is too low and has caused spurious triggers. Connectivity checks which are ran before each fill have failed on a number of occasions. Acquisition electronics have suffered from a high rate of failure due to faulty mezzanines and optical link failures.

BPM (interlocking), sensitivity settings have been troublesome (specifically with ions), as the intensity reaches the end of one window range and the start of the next. In the high sensitivity range this leads to spurious dumps.

BPM, dependency on ambient temperature has been a source of errors in Run 1. Real time orbit data issues have been observed with the PowerPC CPU.

BSRA, depends on the BSRT system's light extract mirrors, which failed during run 1 due to beam induced RF heating. A calibration was required after some technical stops, causing some delays.

OFB, has had numerous issues where feedback failed and caused beam instabilities leading to beam aborts.

QFB, has a measurement problem with lack of coherent signal with high damper again. The tune feedback system causes converters to change their set point in real-time. In some cases the QPS current limits (dI/dt) have been exceeded causing spurious quench system activation.

Fast and Slow BCT, no significant faults affecting availability were observed during Run 1.

BSRT, availability has been affected by the extraction mirror BSRA, and complexity of software algorithms, as several motors are required which feedback on beam position during the ramp.

Wire Scanners, no significant faults affecting availability during Run 1.

BTVDD, no significant faults affecting availability were observed during Run 1.

Changes during LS1 increasing availability:

- BLM, replacement of all fans in all VME power supplies.
- BLM, additional cron tasks to validate the integrity of the system, predicting failures before they occur, so that they can be mitigated before effecting availability.
- BPM (interlocking), strip-line detectors being modified to improve intensities at the upper limit of the high sensitivity range.
- BPM (interlocking), remote controlled attenuators are being introduced.
- BPM, additional cron tasks to detect modules starting to fail so that they can be preventatively repaired during technical stops.
- BPM, temperature compensated racks being added to decrease errors.
- BPM, real time issues to be resolved by using the new Linux CPUs.
- BSRA, light extraction system is being re-designed to reduce the risk of failure.
- BSRT, will be more available, as will have a more reliable light extraction system, and periodic performance checks will be put in place.
- BGI, will be repaired and corrections made.

Changes during LS1 decreasing availability:

- Abort gap monitoring system will be added to the Software Interlock System (SIS). This increases the protection of the machine, at the cost of a potential decrease in availability due to an additional interlock channel.
- QFB can possibly create an issue for the QPS.

Future Tools and Studies:

- Framework for periodic checking is being devised in collaboration with BE/CO and will be proposed for implementation before the end of LS1.

Discussion:

- The BLM dependability model, which was developed during the study of the RSWG was not mentioned.
- The language and metrics between equipment groups are not consistent.
- Effect on physics and luminosity not easy to measure.

RF and Damper – P.MAESEN

The principle subjects of this talk are **RF** and **Damper** The LHC RF system consists of 16 superconducting cavities, within four modules. Having around 1000 signals which are combined and used to generate interlocks. High Voltage interlocks switch off a complete module of four cavities, RF interlocks trip a single Klystron.

Run1:

In 2011 there were 78 faults generated by the RF system, accounting for 11% of all beam aborts, in 2012 there were 43. Unexpected faults have been:

- Thyratron crowbar spurious trips.
- Spurious filament current interlocks due to two failure modes, Klystron HV connectors have degraded, and the cable heads have had defective welding.

Faults have been followed with PVSS for the cryogenic and vacuum systems. An MS One-Note notebook, and the OP and RF eLogbooks have been used for detailed tracking. LASER has been used to some extent.

Changes during LS1 increasing availability:

- A solid state replacement for the Thyratron crowbar has been prototyped and tested, showing much higher availability.
- A new connector design has been made to mitigate one of the failure modes of the filament current interlocks.
- Cable heads with defective welds have been corrected to remove that failure mode.
- ACS cryogenic control racks will be moved to preventively mitigate radiation to electronics problems.

Changes during LS1 decreasing availability:

- The change to FESA 3 risks to have some unavailability problems due to the number of classes which have to be migrated and the little time available.

Future Tools and Studies:

- LASER should be re-considered to make it easier to identify faults and alarms.

Discussion:

- Need monitoring from home & piquet role
- More user friendly configuration of LASER
- Automatic event logging in RF logbook
- reliability runs start in February 2014 – injectors are up earlier, this may lead to problems coming with the FESA 3
- Dumping the beam to protect the cavity is the default behaviour. Can we make this interlocking more intelligent? Only need for high intensity, but these interlocks are not grouped together. Can be done, but expected to be little gains. Would need to recable interlocks. Not foreseen.

Methods to Improve Availability – Session 3

Operational availability – injector chain – K. CORNELIS

The central system of this talk is the **SPS**, which itself has injectors, of which **CPS** and **PSB** are implicitly part.

Run1:

- When beam intensity on fixed target or CNGS is below a predefined value, the BCT sends a “no beam” signal to the eLogbook.
- A comment is inserted and an “event” is created in the “End of Shift Log”.
- When beam returns the “event” is closed and beam back comment is inserted.
- The operator has to add pre-defined fault labels to every event in the “End of Shift Log”

This makes the measurement of availability quite straight forward; data can be extracted for predefined time windows. But operations have a choice to be made, sometimes the wrong system is indicated.

- In general, beam present = machine available. Even if the beam is the wrong quality
- Seen from the LHC, the injectors was 85% available
- Sometimes the unavailability is known, and so no beam is requested. This still creates the no beam label, so statistics can be incorrect.

The same indicators cannot be used for the LHC, as sometimes it is normal to have no beam in a cycle for LHC. It’s not easy to reach 95% in the SPS already, if you let things go, they will slowly degrade to a critical point.

Changes during LS1 increasing availability:

- About 10 to 15 magnets are changed as a preventive measure
- 18 kV cables renewed
- Procedures and sequencers optimised to reduce down time due to operations (since 2011)

Future Tools and Studies:

Automated logbook entries are the first step, then having it filled by an operator is the next. More automated entries mean that there will be more work time lost in filling them in.

Discussion:

- Automatic entries in logbook are good when related to PM, but they need more than that

Operational availability - Optimizing LHC – L. PONCE

The central topics of this talk are those events that are "**not equipment faults**". This is principally

- Aborts due to exceeded thresholds
- Hidden effects, no PM, no fault, set-up, cooling, mistakes

The method is to determine what dumped the beams other than trips or faults, and make a list of events that only needed a turn-around of the machine, without any intervention to repair. In addition try to determine from the eLogbook what other times are lost in the process.

Run1:

870 beam aborts were found in the physics period of 2012. Threshold exceeded is 252 of 870 events = 30%. The main contributions of false dumps and delays are

- UFO
- BPM false triggers
- Injection quality checks
- MKI over-heating
- TDI not correctly detected as in parking position
- Transfer line steering

It's not possible to determine the time lost due to turn-around and the pre-cycles, as the information is not coherently captured.

The definition of faults in the SPS machines doesn't work in the LHC, as a period without beam is normal for the LHC. The duration of faults is not fair, as:

1. Precycles may (or may not be) included
2. Parallel faults are not completely accommodated
3. Faults cannot be suspended
4. Fault duration is not correctly assigned

Changes during LS1 increasing availability:

- Ceramic chamber of the MKI will be changed to reduce heating

- Complete servicing of the TDI stepper motors and replacement of the beam screen will be made to avoid parking position and heating related problems.
- Can a coherent set of definitions be made for faults, and can tools be made to properly visualise them?
- Proper tagging of the time spent for e.g. transfer line steering

Future Studies:

- Can we further relax the thresholds to avoid UFOs?
- Can a coherent set of definitions be made for faults, and can tools be made to properly visualise them?
- Now we know more what we need to track, we can impose a better idea.

Discussion:

- PM is selected from a list of predefined causes: Should be updated
- There is an avalanche effect of faults (glitch of network, patrol needed,…) which needs accounting for.
- State information when one steers could be stored from the logbook -> logging

LHC Availability Tracking Past and Future – B. TODD

The LHC Availability Working Group has been looking into methods of exploiting machine statistics; this presentation covered a proposal for a future direction of fault tracking to standardise the way it is recorded at CERN.

It is considered that availability in the CERN sense really means "impact on physics". This can be theoretically split into four parameters which are linked.

1. Time colliding physics beams = availability
2. Turnaround between successive fills = machine understanding and operator skill
3. Time to clear faults = availability
4. Physics performance during colliding beams = machine understanding and operator skill

These aren't independent.

Run1:

Operators record information about faults and the machine state in the eLogbook

Equipment teams independently record their own information in their own way, working on availability at the system level, and not looking at the machine level. A survey revealed a variety of recording tools and methods in place, with no common metric established.

Post-LS1:

The eLogbook should be modified to record information in a more coherent way, generating information seen from the machine level which reflects down on equipment performance. This requires work on three parts:

1. Establishing a common data format
2. Establishing interpreters to convert equipment information to the common format
3. Tools to convert the information stored into statistics and charts.

Several charts are proposed, including the "cardiogram" which allows a time-based view of machine performance overlaid with fault and event information. Cardiogram before, and after

It is clear this has some relationship with Maintenance Management Project (MMP), but this can be seen as limited. MMP will not catch information related to events that do not need an intervention or corrective action to be restored.

Future Work – 2014:

- Establish the new eLogbook format (small changes to existing)
- Generate the first interpreters
- Implement the first version of the viewer
- Have version 1.0 ready for the LHC restart in 2015.

Future Work – 2015:

- Every week corroborate data between experts and operations.
- Every technical stop make a snap shot of availability data
- At the end of 2015 review all of the data
- Determine the usefulness of the data produced to justify whether this work is of value

Future Work – 2015+:

- Integrate the solution into the MMP, by changing the data sources, but by keeping the interpretation tools.

Discussion:

- Mismatches occur where there is no problem recorded but no physics
- Dependencies between faults, (sub)systems need to be defined
- It is important to maintain effort, it's a lot of work.
- TI has something similar based on a logbook
- TI have one meeting every week, going through all the events
- It is important to have a person dedicated to this, for it to be taken seriously. Entries are made but they need to be more accurate

MMP Project – methods and tools to support LHC operation post LS1 – C. MUGNIER

At the end of 2011 a new project was started with two goals: centralise technical information, formalise a global approach to maintenance management.

The project has begun the implementation phase, and is intended to be at the end of the deployment phase by the end of LS1. Three main activities are in progress now, documentation management, parts management and issue management.

Document management: begins by defining the equipment hierarchy in DFS by establishing the functional breakdown of equipment. Then collecting, sorting, formatting and cleaning files before making them in the uniform dataset of DFS. Empty documents are created in EDMS to represent the parts, then metafiles and information is loaded into these prepared EDMS documents.

Parts Management: global rules are made between the different departments, classes and custom fields are proposed by experts, collection is made, and records are validated as they are added. The process is three steps:

1. Predefine and format classes and custom fields for parts
2. Collect, sort parts and record characteristics n the external system
3. Set up a store management in the asset management tool EAM.

Issues Management: are intended to create common processes for first line. Tools have to be provided to make sure that this is coherently done between the CCC, and the piquet services.

Discussion:

- Several links with AWG
- Coherent with AWG: share information, common fields to be filled in for interventions
- To be useful for the AWG it needs to be ready for start-up of Run 2. It must also trace faults not related to equipment (injectors, steering) as often for the LHC no piquet is necessary to solve a problem.
- Software faults are not treated by MMP. Configuration failures etc. are not hardware
- MMP should also apply to 'best effort', not only to piquet.

Potentials of Petri nets for Availability Modelling and Analysis – P. ZEILER

Availability modelling is complex, and has numerous interactions. The key motivation of such a model is to predict operational availability and make decisions regarding the best way to optimise.

Several different types of models exist, amongst which is the Extended Coloured Stochastic Petri Net (ECSPN). This can be combined with a reliability block diagram to make a Conjoined System Model (CSM) to make a complete model.

The CSM can generate information focusing on different aspects of a system:

- Operational
- Production
- Reliability
- System Dependencies
- Maintenance and logistics
- Costs

This complete model can then be used to evaluate reliability and performance. The Institute of Machine Components have a software package called REALIST which can be used to make such models.

Discussion:

•Petri nets allows 'everything' to be modelled, but when you go down to component level they may be overwhelming.   The correct level of abstraction should be chosen

Availability predictions for post LS1 operation and HL-LHC – A. APOLLONIO

A Monte Carlo model has been used to make availability predictions for post-LS1 and HL-LHC operation. Data from 2012 has been generalised, and a model created which simulates operation conditions.

The key input parameters were:

1. Fault Time Distributions – from the eLogbook
2. Turnaround Time – average used from post-mortem and eLogbook
3. Stable Beams Time – A fit to PM data
4. Peak Luminosity – A fit to logged data
5. Luminosity Lifetime – A fit to logged data
6. Machine Failure Rate – (fills aborted by faults/total fills) from PM data.

Six Scenarios were modelled, for both the operational scenario of the Batch-Compression, Bunch-Merge and Spilt scheme (**BCMS**), and the scenario with Linac 4 (**L4**), in Run 2, and for the HL-LHC with the following results:

1. 2012-like
   Uses the same distributions as 2012
   Run 2: BCMS = 42.5 fb^{-1}, L4 = 42.7 fb^{-1}
   HL-LHC: L4 = 213.0 fb^{-1}

2. Increased UFO Rate
   Increased random fault, with no repair (100 per year)
   Run 2: BCMS = 38.6 fb^{-1}, L4 = 39.0 fb^{-1}
   HL-LHC: L4 = 179.5 fb^{-1}

3. Increased BLM Thresholds
   Increased Beam Induced Quenches (3 per year)
   Decreased Dumps from BLM System (33 UFOs instead of 100)
   Run 2: BCMS = 41.4 fb^{-1}, L4 = 41.5 fb^{-1}
   HL-LHC: L4 = 203.0 fb^{-1}

4. Decreased Radiation Induced Errors
   Modelling the LS1 mitigations
   Reduced number of failures due to single event effects (20 SEU dumps = 66% of 2012)
   Run 2: BCMS = 43.3 fb^{-1}, L4 = 43.6 fb^{-1}
   HL-LHC: L4 = 220.5 fb^{-1}

5. Increased Radiation Induced Errors

Increased number of failures due to single event effects (60 SEU dumps = 150% of 2012)
Run 2: BCMS = 41.7 fb^{-1}, L4 = 41.9 fb^{-1}
HL-LHC: L4 = 206.0 fb^{-1}

6. Increased BLM Thresholds and Decreased Radiation Induced Errors (3 BIQ, 33 UFO, 20 SEU)
 Run 2: BCMS = 41.8 fb^{-1}, L4 = 42.1 fb^{-1}
 HL-LHC: L4 = 208.5 fb^{-1}

The model includes levelling for HL-LHC predictions, and petri-nets could be a powerful tool to help improve this model.

Discussion:

- 213 fb^{-1} is significantly less compared to 300 needed for HL-LHC
- Increased UFO rate gives -15 % integrated luminosity
- Model will be extended to introduce correlation between radiation induced faults with intensity and energy.

Discussion – ALL

On the Workshop:

- Controls software was not included in the discussion, and there are potential areas of improvement to be found there.
- A summary and conclusions with recommendations will be drawn up and presented in LMC or LSC, with a smaller committee first.

On Post LS1 Targets:

- Many assumptions for HL-LHC have been made, that need to be improved over time.
- To achieve the HL-LHC goals basic requirements look to be long stable fills
- We cannot guarantee this, so to get this, we must write this as investing *xxxx* in availability
- For this we need models & data, to see where to invest.
- For this we need to get the raw data = run II data