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PROCESSES AND TOOLS TO MANAGE CERN PROGRAMMED STOPS APPLIED TO THE SECOND LONG SHUTDOWN OF THE ACCELERATOR COMPLEX

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Abstract

The preparation and follow-up of CERN accelerator complex programmed stops require clear processes and methodologies. The LHC and its Injectors were stopped in December 2018, to maintain, consolidate and upgrade the different equipment of the accelerator chain. During the Long Shutdown 2 (LS2), major projects were implemented such as the LHC Injectors upgrade and the LHC Dipoles Diodes consolidation. The installation of some equipment for the HL-LHC project took also place. This paper presents the application to the LS2 of the processes and tools to manage CERN programmed stops: it covers the preparation, implementation, and follow-up phases, as well as the KPIs, and the tools used to build a coherent schedule and to follow up and report the progress. The description of the methodology to create a linear schedule, as well as the construction of automatised broken lines and progress curves are detailed. It also describes the organizational set-up for the coordination of the works, the main activities, and the key milestones. The impact of COVID-19 on the long shutdown will be described, especially the strategy implemented to minimise its consequences.

INTRODUCTION

The CERN accelerator complex is compounded by a multidisciplinary set of systems and equipment. Due to the high-level technology required, the Large Hadron Collider (LHC) and its injectors chain (the LINAC 4, the Proton Synchrotron Booster [PSB], the Proton Synchrotron [PS], and the Super Proton Synchrotron [SPS]) have upgraded and consolidated several times during the so-called Programmed Stop periods to reach their current configuration.

A Programmed Stop is the time window where the conditions of the CERN accelerators are dedicated to standard maintenance and/or upgrades. The interventions vary from one programmed stop to another.

According to their duration, four different stops can be defined: Technical Stop (TS), if the duration goes from some hours to a few days; Year-End Technical Stop (YETS) and Extended YETS (EYETS), when the period includes the end of the year and lasts up to 4 months; Long Shutdown (LS), when major changes are implemented, requiring long intervention periods up to a few years.

Outside these periods, the accelerators are operational and exploit their functionality in the so-called Run period.

The execution of a structured and well-defined methodology is crucial to plan a huge number of activities meeting the highest safety and quality standards. We present the methodology followed and the specific tools implemented to coordinate the last Long Shutdown of the CERN accelerator complex (LS2) [1].

LS2 SCOPE

The LS2 [2] started in December 2018 with an initial duration of 2 years for the LHC and 1.5 years for the injectors; a major preparation effort began in 2016, 2 years ahead to optimise time and resources. The time window has been referred to as “the LS2 period”, as shown in Fig. 1.

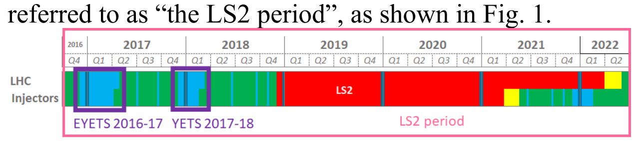

Figure 1: “LS2 period” timeline with the final durations.

The main objectives and challenges of the LS2 included:

- The LHC Injector Upgrade Project (LIU) [3] to increase the intensity and brightness of the injectors to match the LHC High Luminosity Project (HL-LHC) [4] requirements.
- Major maintenances and infrastructure consolidation activities.
- The Consolidation Project to increase the injector reliability and availability for the HL-LHC runs.
- Civil engineering works and beam equipment installation to anticipate the HL-LHC project.

Besides the LS2 original scope, new projects were added: LHC Diode Insulation and Superconducting MAgnet Consolidation (DISMAC) [5] project, SPS Fire Safety, SPS Access and Injectors De-cabling.

LS2 PROCESS: FROM PREPARATION TO EXECUTION

The LS2 management process is based on the previous experience [6] and the know-how of the Organisational, Scheduling and Support section (OSS). The applied methodology was designed to reduce the potential delays due to unexpected events with minimum contingency.

The Long-Term Schedule, the Master Schedule, and the Detailed Linear Planning are three scheduling levels with different granularity and information. While the Long-term schedule, defined a few years before each LS, provides a global overview of the CERN accelerators’ alternation between stops and beam run periods, for the entire accelerator’s lifecycle, as shown in Fig. 1.; the Master Schedule, defined about 2 years before the start, assigns the time dimension, according to the scope defined, as shown in Fig. 2; the Detailed Linear Planning, defined some months

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before the start, provides exhaustive information for each accelerator during the stop, as shown in Fig. 3.

LS2 Preparation

The first LS2 Master Schedule integrated across all the accelerators has been built starting from a time estimation of the LS2 scope and spanned along the time window fixed in the Long-Term schedule. The Master Schedule furnishes the handover among the Run (driven by the Beam Operation team) and the Programmed Stop (led by the OSS team), as shown in yellow and red in Fig. 2. The Individual System Test (IST) and the Hardware Commissioning characterized the transition, requiring strong collaboration between operation and equipment owners.

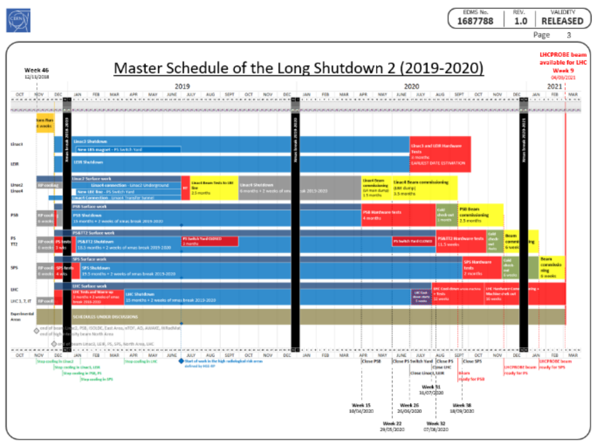

Figure 2: The First LS2 Master Schedule was approved in September 2016 by the LMC, IEFC, and LS2 committees.

The OSS team has gathered all the requests for interventions to set the LS2 Detailed Linear Planning framed in the time window provided by the Master Schedule for each accelerator.

Each Group performed a Work Package Analysis (WPA) exercise to describe the intervention, safety constraints, associated logistics and resources. Moreover, the CERN tool named PLAN has centralised all the activities foreseen by the Groups, to have a global strategic view, assessing priorities across CERN. In March 2018, conflicts arose regarding co-activities or missing resources (time, budget, manpower); therefore, the PLAN Coordinator led an arbitration process, together with Groups and Departments.

In this scenario, the OSS role is to coordinate all the inputs to generate one single overall planning for each accelerator, managing all the installation phases, access, interfaces and logistics.

The first objective was to fix the activities on the critical path, which consolidated the final duration of the LS2. The other activities were coordinated around, using Microsoft (MS) Project. The OSS section expertise in the infrastructures, systems and interfaces was essential in building a Detailed Planning that allowed anticipating potential delays and implementing mitigation measures.

Several resource levelling exercises were carried out using MS Excel spreadsheets and Visual Basic Application for Excel (VBA), to ensure a relevant, fair, and weighted allocation to prove the feasibility of all interventions.

The final optimised schedule had to ensure the safety, quality, and feasibility of the interventions, following the methodology applied by the Accelerators Coordination and Engineering Group at CERN [1].

The LS2 Detailed Plannings were officially approved by the LHC Machine Committee (LMC), LHC Injector and Experimental Facilities Committee (IEFC) and LS2 Committee in late 2018 and released as LS2 Baselines. Figure 3 shows the Baseline planning, where the location is shown on the horizontal axis and the timeline, on the vertical axis. Each colour block represents an activity scheduled.

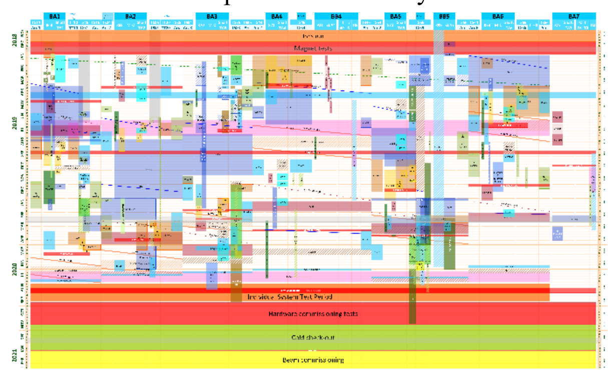

Figure 3: Linear View of the SPS LS2 Baseline Planning.

The approval process starts with the document "Under Approval" being checked by the stakeholders. The acceptance turns the planning into a "Released" Baseline.

LS2 Execution and Follow-Up

The LS2 execution phase started in December 2018. The works included in the released Baselines were declared in the IMPACT tool [7] by the activity responsible and accepted by the OSS team. This tool was effective to manage on-site work access, especially for critical activities.

The LS2 follow-up counted on two main actions. On one side, the tools used to track the baseline deviations to the advancement of the works: Broken Lines and progress curves were defined, using KPIs such as meters of vacuum sectors opened/closed, and equipment installation readiness. Weekly coordination meetings and on-site follow-up monitored these inputs. On the other side, the LS2 executive meetings concerned all the technical, organizational, and performance aspects. Regular reports to the LMC, IEFC and to the LS2 Committees guaranteed a continuous alignment to guidelines given by the management, especially when unexpected events were raised, and consequently new prioritization and strategies needed to be defined. During the LS2, non-conformities came up, sometimes with a major impact on the planning requiring 5 properly documented time re-baselining processes.

One of the greatest challenges arrived with the worldwide COVID-19 crisis during the LS2 execution. A unique pool managed the accelerators' coordination, based on the same methodology applied in the preparation phase, with a bottom-up approach. The Department leaders prioritized the remaining activities, which were re-scheduled, keeping the same sequence in the linear planning, to get the new Master Schedule. The WPAs and the onsite Visit d'Inspection Commun (VIC) were re-assessed, with the support of

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OSS, to coordinate the works and to adapt the procedures to the new constraints and COVID-19 conditions. The strong effort of the OSS team to create a solid and reliable LS2 planning database together with constant communication with all the stakeholders were essential to re-schedule the Baseline with the new management guidelines (i.e., sanitary measures), minimizing delays. The bottom-up approach has been implemented for the other non-conformities encountered during the LS2 (e.g., asbestos in the Injectors or short-circuits in some LHC cryomagnet).

SCHEDULING TOOLS

The methodology explained requires reliable tools. In this frame, the Scheduling Tools Project (STP), was put in place during LS2 with two main objectives: to gather all the data in a unique repository and to deploy a web-based platform allowing the visualization of the plannings CERN wide without an MS Project license. Merging these two aspects, all the files were stored in the Project Online cloud and transferred into a CERN ORACLE database to ensure the availability and reliability of the planning working with a high-performance open-source. A web GANTT viewer has been put in place to allow all the users to check the synchronized schedules, as the data is extracted through the database. The tools adapted and developed within the STP are described hereafter:

Linear views: views of the scheduling data developed in Visual Basic Application for Excel (VBA), keeping always as a unique data source the MS Project files. Each activity is translated into a shape, as shown in Figure 3. The user declares the activity to be plotted and the shape's characteristics (colour, text size, etc), according to the visualization needs. The result is a global view of the planning in one sheet, with a granularity of one day. Once a baseline is set up, the activity information is frozen. The reverse engineering process is being consolidated to translate the linear view into an MS Project file.

Constraint Planning (Fig. 4.: The granularity of this linear view is one hour. The activities that generate access or system constraint are displayed at the exact time (vertical axis) and in a certain location (horizontal axis).

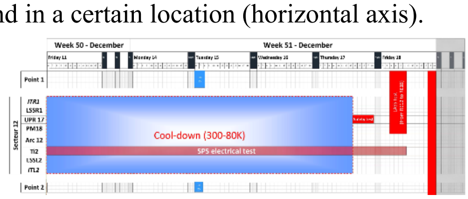

Figure 4: Constraint Planning View of the LHC.

Broken Line (Fig. 5): Monitoring indicator giving two types of information for the activities: current status wrt the baseline, calculated as follows ('actual' is referred to the dates with a baseline in the past, while 'current' referred to the dates/duration that can change):

- The progress of the activity (grey shadow):

$$Current\ Duration = Current\ Finish - Actual\ Start$$

$$Progress\ [\%] = \frac{Today - Actual\ Start}{Current\ Duration}\ [\%]$$

- Forecast of completion: the yellow line indicates the days missing to complete an activity.

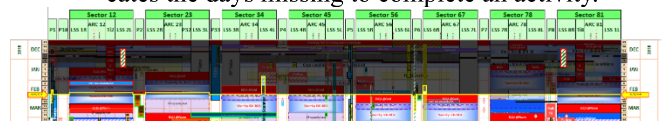

Figure 5: Broken Line.

Schematic view (Fig. 6): synoptic of the main structure of the accelerator generated automatically using the CERN Layout Database to support the co-activity coordination.

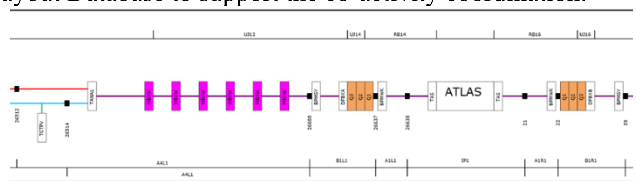

Figure 6: LSS Schematic View.

Time & Space View (Fig. 7): automatic representation via Python scripts of the activities foreseen for a given date and location.

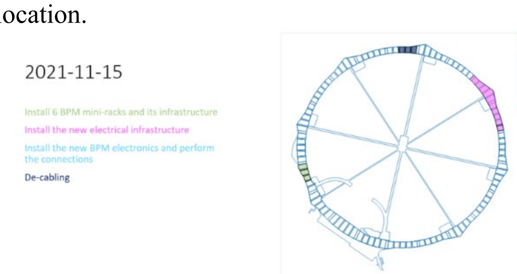

Figure 7: Time & Space View for the PS.

Equipment readiness dashboard and resource load analysis created via VBA for Excel or Python scrips, since MS Project was not fulfilling the needs for these assessments.

OUTCOMES AND CONCLUSIONS

Unexpected events, mainly due to the COVID-19 crisis, brought an LS2 delay of almost 3 months for the Injectors. In the case of LHC, non-conformities delayed the beam commissioning following the LS2 by 14 months. This time shift caused a lack of the beam run between the end of LS2 and the beginning of YETS 21-22. For this reason, the Operation team has scheduled a pilot beam to verify the correct status of the machine. A post-mortem process has been developed to collect the feedback of all the parts involved, to improve the methodology and tools [1].

The LS2 could not have been realized without a strong methodical approach to managing, planning, and coordinating the activities, keeping flexibility and adaptability to unexpected changes. A big effort has been put in place to migrate the planning to an open-source database and to consolidate the scheduling tools to successfully manage the LS2 and be ready for the next CERN Programmed Stops.

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