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SCHEDULE MANAGEMENT FOR LARGE SCALE PROJECTS: THE EXAMPLE OF HL-LHC AT CERN

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Abstract

The High Luminosity Large Hadron Collider (HL-LHC) project seeks to significantly enhance the performance of the LHC to deliver ten times more data to the LHC Experiments. The project relies on cutting-edge systems and technologies deployed in the new facilities constructed to the HL-LHC requisites and replacing large existing equipment and systems in the LHC tunnel. The project complexity lies in the production and installation of innovative systems with strong interdependencies.

A methodological schedule management approach is essential to ensure timely equipment delivery, anticipate potential risks and implement mitigation actions. This paper describes the schedule management aspects of the HL-LHC project, providing a robust framework adaptable to any large-scale project. It encompasses the management of the baseline changes, the monitoring of milestones, the planning and coordination of the new facilities installation, and the integration of the HL-LHC installations within the regular LHC maintenance programme. Emphasizing the significance of key performance indicators, the paper highlights the critical role of metrics as indicators of schedule robustness.

INTRODUCTION

CERN particle accelerators require a specific and dedicated project management structure due to their complex nature. OpenSE [1] is a system engineering framework suited to intricated technological systems projects arranging a common understanding of their lifecycle. OpenSE encompasses all the phases, describing the expected milestones to be achieved, results and documentation (Fig. 1).

Figure 1: OpenSE project lifecycle.

This paper describes the methodological schedule management approach applied to the High-Luminosity LHC (HL-LHC) project, framed on OpenSE, based on the experience and know-how of previous CERN projects.

HIGH-LUMINOSITY LHC (HL-LHC)

The HL-LHC project seeks to increase the Large Hadron Collider (LHC) performance, delivering 10 times more data to the experiments. CERN established the following targets to fully exploit the LHC [2]:

- A peak luminosity of 5×10^{34} $cm^{-2}s^{-1}$ with luminosity levelling,
- An integrated luminosity of 250 fb^{-1} per year,
- The goal of 3000 fb^{-1} for ATLAS and CMS.

The HL-LHC project is divided into 20 Work Packages (WP), most of them overseeing the lifecycle of a system or equipment from the design up to the installation and commissioning phase.

Due to the strong interdependency among the systems/equipment and the major upgrade of the LHC infrastructure, a comprehensive coordination is critical to ensure the completion of the WPs delivery, installation and commissioning.

SCHEDULE MANAGEMENT

The schedule management of the HL-LHC project relies on a consolidated CERN methodology. A coherent set of data, collected in a unique single source of truth (MS Project) and validated by WP leaders (WPL) and CERN department heads, provides a robust tool for decision taking.

The approach for schedule management is divided into two pillars:

Pillar 1: Installation Readiness and Milestones Follow-up

Built upon the OpenSE framework, each WP has sub-WPs structured in a Product Breakdown Structure (PBS) looking for the equipment/system deliverables. Data is stored in a single MS Project file, which allows the generation of a Master Schedule of each WP (Fig. 2) [3]. It provides a top-level view of the WP lifecycle, showing the timeline of the phases and deliverables.

The Master Schedule includes the milestones established for the different phases described in OpenSE. They are constituted by milestones and deliverables to be achieved. The WPs are interlinked via these milestones: inputs (those coming from other WPs) and outputs (those that the WP delivers, either to another WP or to the LHC installation).

The Master Schedule helps ensure resource availability and avoid incompatible co-activities. A dedicated analysis is required for those WPs with a high risk of being impacted by these two factors.

For instance, WP16 oversees the installation and commissioning of the Inner Triplet (IT) String in a dedicated CERN surface building. The IT String will serve as a test bed to validate the entire system before the LHC tunnel installation [4]. Figure 3 shows the installation resource loaded for the IT String in blue and yellow versus the main programmed stops of the LHC in red. These two inputs provide a general picture of the resource demand for HL-LHC and LHC.

Another example is the dedicated resource loaded schedule in terms of CERN facility and manpower for the production, assembly, and test of the Insertion Region Magnets (WP3) and Cold Powering (WP6A) [5].

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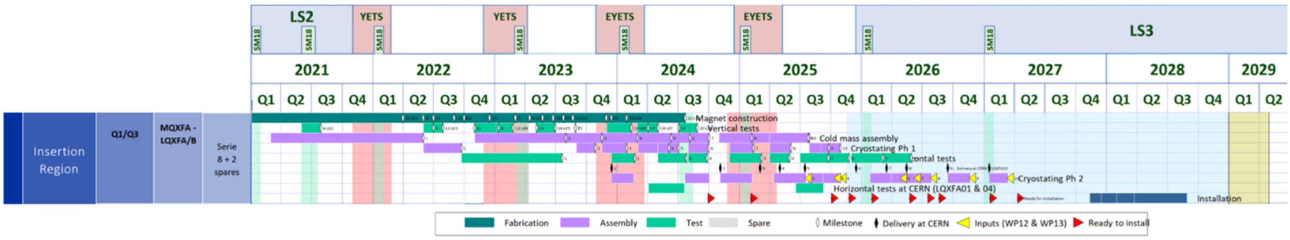

Figure 2: Extraction of Master Schedule of WP3: Magnet for Insertion Regions.

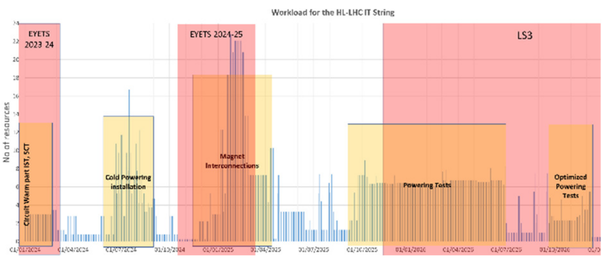

Figure 3: IT String (WP16) installation resource load.

Four reporting tools are set up as fundamental support for project analysis as a reliable source for strategic decision making. Following the one single source of truth principle, the tools are based on the Master Schedules data:

The milestones tracking table stores in a spreadsheet the evolution of the milestones throughout the HL-LHC management reporting.

The trend analysis (Fig. 4) follows the output installation readiness for a given equipment/system evolution.

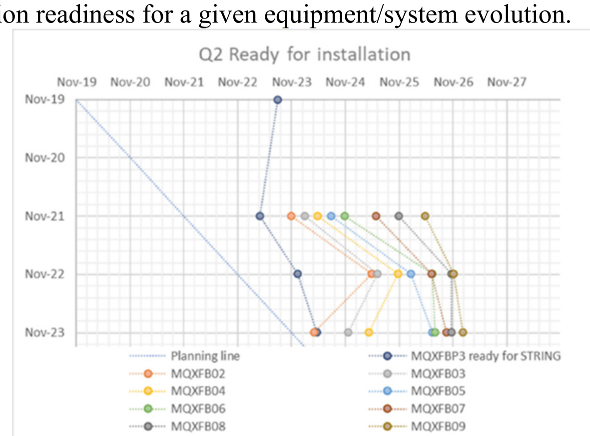

Figure 4: Extraction of HL-LHC milestones trend analysis for Q2 magnet.

The float schedule (Fig. 5) relates the equipment/system installation readiness to the scheduled installation date.

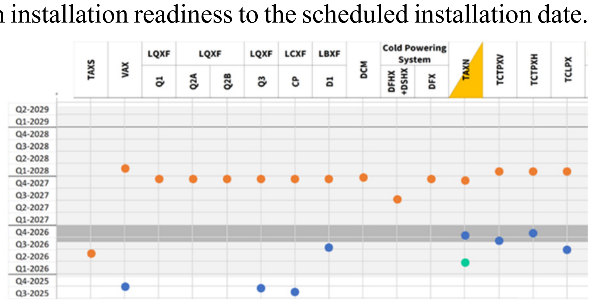

Figure 5: Extraction of HL-LHC float schedule.

The broken line (Fig. 6) is the indicator used to follow up on the status of the Master Schedule using the "In Work" Master Schedule at a given date.

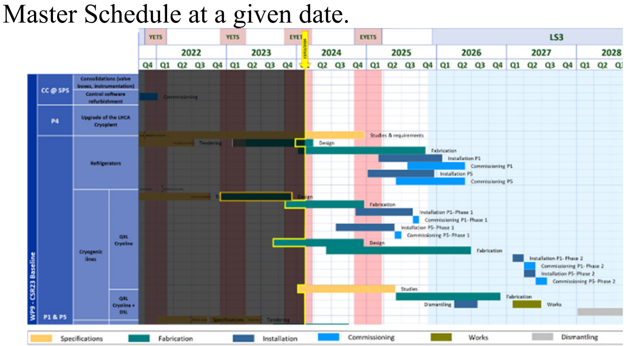

Figure 6: WP9 (Cryogenics) broken line in Sept. 2023.

Pillar 2: Installation Schedule and Follow-up

The main LHC upgrade impacts the equipment and layout of the 600 m Long Straight Sections (LSS) of LHC Point 1 (ATLAS) and Point 5 (CMS). However, other sections of the LHC will be modified [6]. Furthermore, the HL-LHC requires new civil engineering facilities (additional technical galleries, underground areas, and surface buildings) to host the new components and the corresponding technical infrastructure.

The LHC, as the rest of the CERN accelerator complex alternates operation and programmed stop periods, the time windows dedicated to preventive and corrective maintenance and/or upgrades. The interventions required in the machine are carried out during these so-called programmed stops. Most of the changes (dismantling of current LSS and reinstallation with HL-LHC equipment) occur during the Long Shutdown 3 (LS3) of the LHC, currently foreseen from the end of 2025 to 2029. Nonetheless, some modifications have been already completed in previous programmed stops [7]. Works taking place outside the LHC tunnel (i.e., new civil engineering infrastructure and its equipment installation) are executed outside the programmed stop periods, with no interference with accelerators operation, except for resource availability aspects. Figure 7 shows the integrated view of the HL-LHC installation from 2022 up to the end of the LS3, divided into three different geographical areas. The HL-LHC in the LHC tunnel: interventions are allowed only during the programmed stops. Run3 stands for the beam operation period, followed by the LS3. The LS3 integrates the so-called LHC frame (i.e., the standard sequence from the LHC beam shutdown

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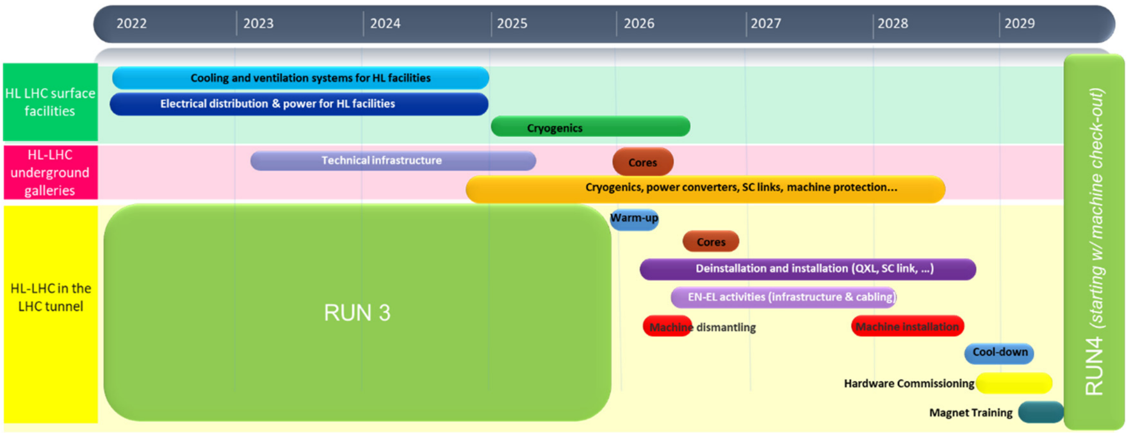

Figure 7: HL-LHC installations during the Run3 and the LS3.

to the cryogenic lockout, and from the cryogenic unlockout to the LHC recommissioning), the HL-LHC installation and all the other interventions non-related to HL-LHC. On the other hand, the interventions on the HL-LHC surface facilities and underground galleries are not impacted by the programmed stops until the end of the excavation of 16 vertical cores (two blocks in brown in Fig. 7), connecting the new infrastructure with the LHC, allowing the passage of specific hardware, such as radiofrequency equipment for the crab cavities, superconducting links, and cryogenic distribution lines.

These three areas have dedicated installation plannings. They follow the methodology implemented during the LHC installation [8], which has been proven and consolidated during the previous programmed stops as LS1 and LS2 [7, 9, 10]. The equipment ready-to-install milestones serve as a trigger for the installation planning construction process. Coordination meetings with the stakeholders and resource analysis form an iterative process to optimize the time required for the installation completion. In the case of the LHC LS3 installation planning, the main challenge is to introduce HL-LHC inside the current LHC infrastructure. The LS3 frame has been established around the HL-LHC installation planning, thus generating the minimal duration of the LS3. This exercise acts as groundwork to include all the interventions not related to HL-LHC during the LS3. Figure 8 shows the LHC-LS3 installation linear planning, where each block corresponds to an intervention to be performed in the tunnel at a given location and time.

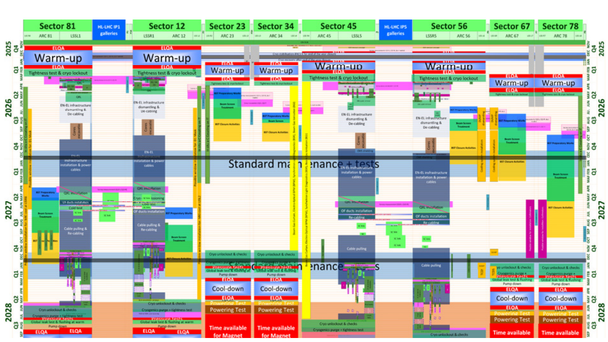

Figure 8: Extraction of the LHC-LS3 installation linear planning (January 2024 version).

This process has helped to identify installation uncertainties and to prepare mitigation actions. The installation planning has no contingency allocated; therefore, a non-conformity strategy will be defined. Many interventions and projects are not yet approved and defined; this may affect the HL-LHC activities.

Change Management Process

The HL-LHC and CERN management must control the schedule and manage changes. This requires a methodical schedule change process. The baseline collects all the inputs described previously and converge in a resource and time optimised schedule. Any deviation from this baseline is followed by a change management process settled by the project. This constitutes an iterative process where the schedule modifications are described in a Schedule Change Requested (SCR), with a special focus on the changes of milestones. The report and analysis indicators are modified, and an in-work planning is developed. The output of this process is discussed in dedicated Project Steering Meetings (PSM) organized regularly, typically every three months for each WP. Finally, a new baseline is presented and accepted by all the stakeholders in a yearly HL-LHC Cost & Schedule review.

OUTCOME AND CONCLUSION

The next big challenge is the integration of all the activities foreseen for the LS3 together with the HL-LHC installation planning. The LS3 preparation, the flexibility and adaptability of the schedule management process and the tools put in place are crucial for ensuring an optimised and successful LS3. A consolidated methodology has been implemented for the schedule management aspects of the HL-LHC project, providing a robust framework adaptable to any large-scale project.

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