SCHEDULE EVOLUTION DURING THE LIFE-TIME OF THE LHC PROJECT

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Abstract

The Large Hadron Collider Project was approved by the CERN Council in December 1994.

The CERN management opted from the beginning of the project for a very aggressive installation planning based on a just-in-time sequencing of all activities.

This paper aims to draw how different factors (technical development, procurement, logistics and organization) have impacted on the schedule evolution through the lifetime of the project. It describes the cause effect analysis of the major rescheduling that occurred during the installation of the LHC and presents some general conclusions potentially applicable in other projects.

INTRODUCTION

The LHC machine is being built in the existing ex-LEP tunnel. The tunnel is divided into 8 equal length sectors. The installation has been treated as if there were 8 different machines, each sector independently, and it was subdivided in five main phases, corresponding to the principal project milestones:

- Civil engineering works,
- Installation of general services,
- Installation of the cryogenic line,
- Installation of the machine elements,
- Hardware commissioning.

These five phases were defined in detail and duration was estimated based on experience with other machines (by the system "owners"). Different times were given to different sectors due to the characterization of each sector and taking into account a training curve for the works that have to be repeated from one sector to another. Once the times were defined the five phases were scheduled in sequence giving the critical path for each sector. The schedule defined activities to be carried out in sequence and in parallel in the different sectors based on availability of resources and technical constraints with no contingency..

During the life time of the project, a number of changes were made and problems arose in areas such as technical developments, procurement of components, logistics. The baseline of the first general co-ordination schedule had to be changed in order to minimize the impact on the final milestones given by the management. These changes in some cases represented an increase in the level of risk of the project.

Figure 1: Summary Installation Schedule – March 2001

HISTORY AND MAJOR EVENTS

First General and Coordination Schedule

The first general co-ordination schedule was issued in March 2001. Most of the civil engineering works were underway, as well as installation of general services in the different surface buildings and tunnel integration studies. The general schedule was based on the following [2]:

- general services installation in two years, working in four sectors in parallel,
- cryogenic line installation in two years, starting in January 2003 and working in parallel in two sectors,
- machine installation (the magnets are located in front of the cryogenic line and block access to the line) in 28 months, 3 fronts working in 2 sectors in parallel.
- Commissioning in 3 months.

Integration and General Services

The second general co-ordination schedule was issued in April 2002 [1].

While project execution had to be carried out from civil engineering to machine installation, the integration studies (spatial integration of components in the tunnel, suing 3D computer design software) was carried out in the inverse order.

In consequence, some changes and new activities had to be added and the installation of general services had to be delayed. As an example, at point 7 (narrow tunnel), all the cables which were already installed had to be revamped, in order to take into account the high radiation level announced by the collimation sub-project. In addition there were procurements delays and a shortage of resources to perform the work around the machine.

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With hindsight, the schedule for the general services installation was very tight. But the groups in charge and the coordination team worked in close collaboration to take the adequate corrective measures.

Figure 2 shows the resulting schedule issued in April 2002:

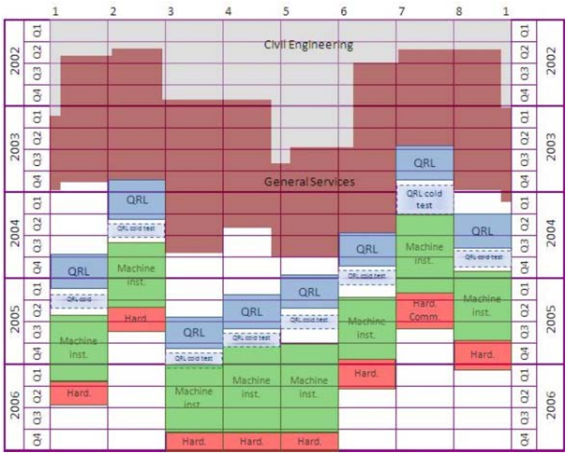

Figure 2: Summary Installation Schedule – April 2002

Cryogenic Line Installation (QRL)

The QRL feeds the superconducting magnets with liquid helium [3].

The installation contract was awarded in December 2001. Following the award of the contract, the firm asked for a delay of 6 months to the start of installation. As a result, general services installation was rescheduled in order to optimize the use of resources and avoid co-activities clashes in the tunnel.

In June 2003 the cryogenic line started to be installed in sector 7-8. The rate of delivery of the components to CERN was far below the one expected. After few months of installation, serious technical and quality problems arose (faulty components and poor weld quality). The manufacture and the installation were stopped on several occasions, during periods of negotiations that took altogether about a year. During this interruption the manufacturing procedures were revised by the firm in close collaboration with CERN. The restart of the fabrication was accompanied by stringent quality control. In order to avoid, interferences with the new production, CERN took the decision to repair and re-install the faulty elements that were already at CERN. The contractor finally resumed the installation of the cryogenic line in November 2004, about a year and a half after the original start date of the contract [4].

Consequences of the Cryogenic Line Installation Delays

Technical impact: Technical changes had to be implemented. However, in order to make up for the delays encountered it was decided to cold-test only the first sector installed by the contractor, and to skip QRL cold commissioning in the others sectors.

Logistic impact: During the interruption of QRL installation, the cryo-magnets production was going on and CERN had to face a serious problem of storage. Around 750 cryo-magnets were to be stored on surface. Additional outdoor storage areas were created, and surface transport resources had to be more than doubled.

Organizational impact:

- The sequence of the sectors was changed in order to ease the underground logistic of cryo-magnets installation (as an example, a cryo-dipole transport and installation cycle for sector 6-7 took 24h).
- The transport and interconnection of the cryo-magnets in the tunnel needed to be squeezed into 20 months instead of 36 months foreseen in March 2003.

  Negotiations took part between CERN and the contractor in charge of the interconnections, to increase the resources (equipment and personnel) to work in three sectors in parallel, instead of two (when the contract was signed).

  The schedule had to provide separate time slots for magnet transport and interconnection work.
- The time window dedicated to the hardware commissioning was drastically reduced from 20 months to 13 months, and the strategy was changed. In the original plan it was foreseen to power test one sector at once, the reduction of time made it necessary to power test two adjacent sectors in parallel. As a consequence the resources available spread in the relevant groups had to be increased [5].

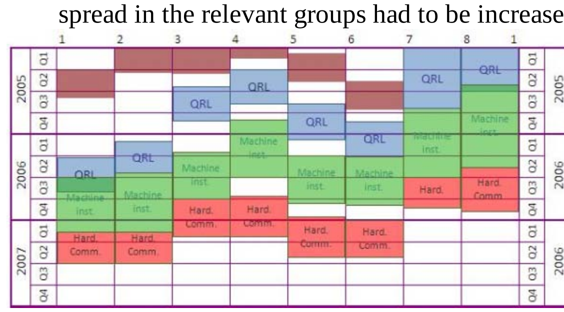

Figure 3: Summary Installation Schedule – Apr. 2005

2005-2006: Start of the Machine Element Installation

A new schedule was produced in October 2006 [1] reflecting the situation explained below.

Magnet transport: the first cryo-magnet was lowered in March 2005. As already mentioned, the rate of transport needed to be increased by a factor three. This has been a difficult task due to co-activity with other operation that were not foreseen and some delays in the production of the magnets, especially with the short straight sections whose numerous types limited exchangeability [6].

Magnets interconnection works: The interconnection works started in June 2005. It was slowed down at the beginning by missing magnets, co-activity with transport and lack of resources.

A large effort was applied to the fragmentation of the interconnection tasks to reduce the critical path of the activity itself, and to create specialized teams that could be deployed elsewhere before completing a given sector.

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This allowed interconnection work to advance in more than 3 sectors in parallel.

The decrease in time between the end of the interconnection work and the end of hardware commissioning, changed the baseline of the planning:

- The decision was taken to divide the Beam Commissioning into two phases. The first one being at 450GeV [1] which permitted planning of partial powering tests, for 5 of the eight sectors. And a second phase at 7 TeV after a shutdown of the machine.
- In order to gain experience with the hardware commissioning as soon as possible and in the maximum number of sectors, decoupling of adjacent sectors, in terms of cryogenics was needed.

Figure 4 shows the summary of the revised version of the schedule.

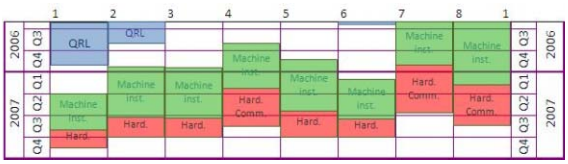

Figure 4: Summary Installation Schedule – Oct. 2006

Inner Triplets Crisis

The inner triplet system [3] provides the final focusing of the proton beams before collision at four locations in the machine: interaction regions located at point 1, 5, 2 and 8.

In November 2006 the heat exchanger tube of the Inner Triplets magnets failed during the pressure test of the sector 78. It was then decided to isolate this assembly from the cryogenic line (QRL), and go on with the cool-down of this sector. The replacement of the heat exchanger was done in the triplet of point 5Left in February and March 2007; unfortunately, the pressure test of the repaired assembly failed revealing some weak points in the design. A dedicated task force was quickly created in order to review the technical design of the assembly. Today, the technical solution for the necessary repairs has been selected, and the repair will be validated at the beginning of July (pressure test of Inner Triplet at point 8Right).

Inner Triplets Crisis Impact

In order to deal with the delays induced, the General Schedule is being reviewed based on the following approach:

- Split the hardware commissioning in two phases (1^{st} phase without the Inner Triplets if necessary, and 2^{nd} phase with the entire sector), in order to gain experience of powering tests as soon as possible,
- Increase of number of sectors being commissioned in parallel from 2 to a maximum of 6.
- Commission the beam in one phase, directly up to nominal current (for 7TeV).

CONCLUSIONS

During the course of the LHC installation, the strategy defined by the general co-ordination schedule has been modified several times in response to key events and problems encountered during this large long-term project. The lessons learned are that the following actions are necessary in order to succeed with the installation and coordination of a large scale research project:

- To perform spatial integration studies before starting installation
- To split the major contract on the critical path between at least two concurrent firms whatever the financial situation is
- To set-up internal "rescue" teams in order to react quickly to technical problems
- To define and record as early as possible, and in as much details as possible the different activities in order to avoid co-activities clashes
- To set up storage areas in key positions, in order to ease logistics ("just in time" is not suited to research projects)
- To provide flexibility during the installation and commissioning by creating individual and independent sub-projects
- To allocate contingency time for consolidation of each phase.

We are now at the cornerstone of the last installation phases, finishing the installation of machine components and starting the hardware commissioning; there are just a few months to go before the first circulating beam.

ACKNOWLEDGMENTS

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