Experience from the outsourcing of the Cryogenic Operation & Maintenance at CERN

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Abstract. CERN operates and maintains several large cryogenic systems including those serving the LHC complex and its associated detectors, together with cryogenic Test Facilities and distribution services. Outsourcing of Operation and Maintenance to an industrial partner was implemented in 2016. It allows the cryogenics group to activate different level of services starting from basic technical support up to full delegation with result oriented obligations for availability and helium inventory management by means of dedicated contractual key performance indicators. After almost three years from the implementation of this complex service contract in a context of intensive Operation & Maintenance campaigns of CERN accelerators, detectors and test facilities, this paper will report on the obtained results, emphasizing on technical, organizational and economic performance. Additionally the paper intents to share lessons learned from the implementation and follow-up of such major outsourcing. Finally the paper will describe the expected evolution of specific needs with respect to the provided services during the Long Shutdown 2 (2019-2020) of the CERN accelerators, detectors and test facilities, including the phase of resuming operation of the cryogenic plants and ancillary infrastructure.

1. Introduction
The cryogenic Maintenance & Operation (M&O) contract was awarded 3 years ago to a joint venture of two specialized companies, associating an extended experience in facility management and general services on the one hand and technical expertise in gas industry on the other hand. Main activities and achievement are presented here below, the covered period includes two and a half years of the second run 2 2015-2018 inclusive and the very beginning of Long Shutdown 2 (LS2) for LHC, see Figure 1. As stated in [1] and [2] the scope of work for outsourcing of cryogenics M&O is structured in three different pillars. First one is Operation, divided in two modes, tasks oriented operation for LHC accelerator, ATLAS and CMS under CERN’s supervision, and results oriented operation cryogenics with full delegation of responsibility to the contractor for non-LHC plants including central helium distribution facility, other detectors and accelerators cryogenics, test area refrigerators and associated infrastructure and proximity cryogenic systems. Second pillar is maintenance of all cryogenic installations at CERN based on cryogenics group maintenance policy and requirements. And finally methodology pillar management and improvement of Computerized Maintenance Management System (CMMS), documentation and drawings management and spare parts management. In following chapters we will describe in details the results obtained for each pillar and the pros and cons of the two operation modes.
2. Obtained results after 3 years of contract

2.1. Development of Methodologies

2.1.1. Maintenance Procedures. The first priority was to address the development of methodology to consolidate the procedure system for maintenance tasks that includes work instructions, forms and checklists used on the field by technicians. All these documents have been reviewed by the contractor back office experts and CERN cryogenics group technical sections experts, also taking into account lesson learned from Long Shutdown 1 of the CERN accelerators complex [3]. Checklists have been applied on the field whenever possible during cryoplants technical stops to validate their applicability depending on effective asset configuration on site, the work sequence, the measurement points and the quality control thresholds. Thus, the cryogenics group has strongly increased the level of traceability on the CMMS database, standardised the required documentation attached to intervention work orders and formerly identified critical quality points for maintenance.

Table 1. Summary of maintenance reference documents revised since beginning of contract.

| Tasks          | Reviewed Work Instruction | Reviewed Forms | Comment               |
|----------------|----------------------------|----------------|-----------------------|
| Mechanical & Vacuum | 71                         | 71             | 174  Checklists       |
| Electrical & Instrumentation | 45                         | 32             | 14  Checklists        |
|                |                            |                | 8     Automated reports using calibration device |

For the LS2, in order to gain efficiency and avoid capture of errors we have transferred field checklists to electronic format, and technicians are now filling most documents directly on digital tablet using the online light version of the CERN CMMS, Infor® EAM Light created and developed internally.

In addition, after analysis of the previous calibration campaigns we purchased new instrumentation calibrators and developed a new calibration database and procedure to better track the sensors evolution and improve their maintenance plan.

2.1.2. Operation Procedures. For LHC cryogenic system the operation team had already developed a large set of about 300 operation procedures. They are presently undergoing a complete review managed by CERN cryogenics operation team in order to reduce their numbers and to homogenize the content.

A second set of operation procedure for result oriented cryoplants is structured in four different categories organizational, preparation, run and specific interventions has been gathered and is also under review, today 95 procedures are active, continuously updated by the contractor operation team and submitted to validation to CERN cryogenics operation experts.
2.1.3. Quality and reliability improvement of Condition-Based Maintenance (CBM). The adopted strategy for CBM was to keep advanced expertise within the Cryogenics group and to externalize measurements or samples taking on the field, together with a first level of expertise for task oriented facilities. For the other cryoplants under result-oriented contract the contractor shall apply the recommended CERN cryogenics CBM policy and is liable to undertake necessary action to ensure availability of the cryoplant.

Table 2. Summary of condition based maintenance evolution for LHC and detectors.

|                      | July 2016 to June 2017 | July 2017 to June 2018 | July 2018 to June 2019 | Unit                      |
|----------------------|------------------------|------------------------|------------------------|--------------------------|
| Vibration measurement| 1215                   | 1270                   | 946                    | Measurement point x,y,z   |
| Oil analysis         | 81                     | 44                     | 62                     | Samples                  |
| IR Thermography      | 85                     | 96                     | 94                     | Electrical cabinets      |

Vibration monitoring measurements on the field were performed by the contractor from the beginning of the contract. The rapid knowledge transfer of this task was made possible thanks to the cryogenics group industrial vibration tools that includes a spectrum collector and a shared database made available to all stakeholders. The externalization of first level of expertise took more than a year to reach the expected quality level, and remains carefully followed with the support from third party expert. It has to be noted than in 2018, two major warnings raised by the contractor on high pressure compressors for two different cryoplants of the LHC enabled us to anticipate the stop of these assets before breakdown and avoided operational impact on the LHC availability.

Oil samples are taken every year by the local maintenance contractor for analysis in order to anticipate potential breakdown if the oil quality is degrading. The samples are then sent to a specialized laboratory and analyzed. In the last 3 years efforts have been put to improve the measurements repeatability and quality modifying sampling the point and standardizing the sampling procedures.

Finally, in order to reduce potentially damaging connection tightness check campaigns, the Infra-Red thermographic controls of each and every electrical cabinet are executed by the contractor at the end of the running period before the annual technical shutdown.

2.2. Operation tool and achievement

2.2.1. Operation electronic logbook. The contractors have been fully integrated in the elaboration of the requirements for the electronic operation logbook [4] which captures and tracks all activities occurring on cryoplants at a specific time. From March 2018, support team migrated it to use the same database as the CMMS. This evolution was a real improvement for the communication between the operation and support teams when interventions are required. It increased the possibilities of cross functionalities between operation activities and maintenance intervention and logging for further analysis. Table 3 gives a first overview of the quantity of events logged into this new database.
A rapid analysis of this initial content showed that the two teams are not using the logbook in the same way, a common review involving the stakeholders will have to be conducted to assess the differences and propose evolutions if necessary. Nevertheless as the electronic logbook will be key element to ensure traceability of operation and historical data in the future we plan to develop the automated availability tracking functionalities.

2.3. Operational achievements

2.3.1. Availability of the LHC cryogenics. Average availability for the LHC cryogenics calculated for the total duration of the run 2 from April 2015 to December 2018 amount to 97.2%, the best results were achieved in 2016 with 98.6% [5] and [6]. The present M&O service contract provides a third of the LHC and detectors operation resources, two operation stand by duty services, and also maintenance interventions since mid-2016 and play an essential role in the operation continuity as the CERN operators are mostly working in shifts.

2.3.2. Availability of the other cryogenics plants. Other cryogenics plants at CERN, so called non-LHC, are providing cryogenics to users at testing facilities, in the Cryolab, or for other accelerators (ISOLDE) or experiments. They are fully operated by the contractor who is responsible to maintain availability of each cryoplant above 95% and helium losses below the average losses for the last 3 years, incentives being associated to achievement of these performances.

Each cryoplant availability is calculated individually depending of user requirements for refrigerators and experiments, and effective liquid helium production for liquefiers. Table 4, presents an overview of annual operating time for each plant since the beginning of contract and yearly availability.

Table 3. Events recorded in new Logbook since March 1st 2018.

| Events subcategories | LHC and Detectors cryogenics | Non-LHC cryogenics |
|----------------------|-------------------------------|--------------------|
|                      | 6026                          | 1381               |
| Report               | 13%                           | 39%                |
| Ongoing operation    | 0%                            | 20%                |
| Fault                | 4%                            | 12%                |
| Information          | 30%                           | 17%                |
| Instructions         | 51%                           | 3%                 |
| Others               | 1%                            | 1%                 |

| Generated Work Orders | 45 | 84 |

| Events subcategories | Non-LHC cryogenics |
|----------------------|--------------------|
|                      | 1381               |
| Report               | 39%                |
| Ongoing operation    | 20%                |
| Fault                | 12%                |
| Information          | 17%                |
| Instructions         | 3%                 |
| Others               | 1%                 |
Table 4. Summary of non-LHC Cryogenics running hours and availability over the last 3 years.

| Meyrin | July 2016 - June 2017 | July 2017 - June 2018 | July 2018 - June 2019 |
|--------|----------------------|----------------------|----------------------|
| Central Liquefier 165 | 7,755 h | 99.5% | 7,954 h | 100.0% | 6,023 h | 98.8% |
| LHe Liquefier | 7,755 h | 99.5% | 7,954 h | 100.0% | 6,023 h | 98.8% |
| SM18 | 7,630 h | 99.4% | 6,969 h | 99.3% | 5,763 h | 99.6% |
| Testing Facility | 7,630 h | 99.4% | 6,969 h | 99.3% | 5,763 h | 99.6% |
| North Area | | | | | |
| NA61.1 | 4,384 h | 97.9% | 4,115 h | 99.5% | 3,972 h | 91.9% |
| LHe Refrigerator | 4,384 h | 97.9% | 4,115 h | 99.5% | 3,972 h | 91.9% |
| NA61.2 | 6,057 h | 99.7% | 5,106 h | 99.6% | 4,668 h | 96.4% |
| LHe Refrigerator | 6,057 h | 99.7% | 5,106 h | 99.6% | 4,668 h | 96.4% |
| ATLAS HB | 6,256 h | 99.9% | 6,110 h | 99.9% | 5,985 h | 99.9% |
| LHe Refrigerator | 6,256 h | 99.9% | 6,110 h | 99.9% | 5,985 h | 99.9% |
| COMPASS | 6,682 h | 100.0% | 6,339 h | 99.9% | 5,994 h | 99.9% |
| LHe Refrigerator | 6,682 h | 100.0% | 6,339 h | 99.9% | 5,994 h | 99.9% |
| CMS RD5 | 4,499 h | 98.8% | 3,735 h | 92.8% | 2,920 h | 91.9% |
| LHe Refrigerator | 4,499 h | 98.8% | 3,735 h | 92.8% | 2,920 h | 91.9% |
| NA62 | 4,760 h | 99.9% | 4,760 h | 100.0% | 6,760 h | 100.0% |
| LKr Calorimeter | 4,760 h | 99.9% | 4,760 h | 100.0% | 6,760 h | 100.0% |
| Ilsole accelerator | 4,287 h | 99.6% | 4,287 h | 99.6% | 4,287 h | 99.6% |
| HIE-Isolde | 4,287 h | 99.6% | 4,287 h | 99.6% | 4,287 h | 99.6% |
| SPS accelerator | | | | | |
| BA4 Coldex | 1,660 h | 94.8% | 1,660 h | 94.8% | 1,660 h | 94.8% |
| LHe Refrigerator | 1,660 h | 94.8% | 1,660 h | 94.8% | 1,660 h | 94.8% |
| BA6 RF Cavity test | 2,046 h | 100.0% | 2,046 h | 100.0% | 2,046 h | 100.0% |
| LHe Refrigerator | 2,046 h | 100.0% | 2,046 h | 100.0% | 2,046 h | 100.0% |
| LHC Point 8 | 3,708 h | 97.3% | 3,708 h | 97.3% | 3,708 h | 97.3% |
| CAST | 3,708 h | 97.3% | 3,708 h | 97.3% | 3,708 h | 97.3% |
| LHe Refrigerator | 3,708 h | 97.3% | 3,708 h | 97.3% | 3,708 h | 97.3% |
| Neutrino | | | | | |
| NP04 | 6,168 h | | | | |
| LAr Calorimeter | 6,168 h | | | | |
| NP02 | | | | | |
| LAr Calorimeter | | | | | |

The distribution of non-LHC downtime responsibility over the last 3 years is shared between CERN with 62% of the time, mainly due to utility fault or obsolescence, and the contractor with 38% of the time. The main events impacting availability cryoplants under responsibility on the contractor in the last 3 years are related to compressor breakdown, instrumentation issue, turbine breakdowns, clogging of water circuit or recovery time too long after user events.

For each failure mode, the contractor raised cases in the logbook, submitted them to CERN cryogenics group to reduce the risk of new occurrence. The action plans taken may include modifications of operation or maintenance procedures, consolidation of the installations, modifications of the system control logic.

2.3.3. Nitrogen logistics. From the first year of the contract we have included the management of the LN2 delivery in the contract scope for a lump sum price. This has proved to be very efficient and successfully saved CERN resources.

2.4. Maintenance results. From the contract effective starting date the contractor maintenance team has accumulated experience for the LHC and associated detectors with seven technical stops with 2 to 4 days maintenance and two yearly end technical stops of 2 to 4 weeks maintenance windows for each cryoplants. For the non-LHC facilities the yearly facility Shut-Down with maintenance windows from 1 to 8 weeks and last but not least the curative maintenance interventions during the operation period under the end-user pressure.

The volume of Work Orders that required rework by the contractor after interventions closing are very low, below 0.2% in the last 2 years. Work orders not validated directly by CERN represented 5.9% in the second year of contract and have decreased to 4.4% during the last year. In most cases the claim is related to missing information in the report or in the task list of the maintenance, in that cases the correction is directly treated by the contractor quality officer.

3. Lesson Learned from outsourcing of operation and maintenance activities

3.1. Performance and flexibility. The portfolio of mixed activities included in this service contract associated to the critical size increased significantly the contract flexibility, and allow us to manage smoothly the transition from LHC run period to LHC long shutdown. The maintenance team, has been strengthen by personnel coming from operation team together with temporary staff hired to cope with the increasing workload. Average headcount during run period of the LHC was 46 people, now increased to 58 people and should remain stable till the end of the LS2.
Yearly budget remains relatively stable between running and maintenance period, peak year will be in 2020 when we will cumulate maintenance activities and several cryoplant restarts on the same year, but the increase should remain under 10% compared to 2018. Cost share detailed in Figure 4 illustrates evolutions of the budget structure between LHC run and shutdown periods. It has to be noted that we maintain a significant level of activities on our testing facilities cryoplants with one third of the budget.

3.2. Maintenance shutdown management
To improve and integrate the lessons learned, common sessions with CERN and contractor have been organized after maintenance shutdown and interventions resulting in the following sequence:

1. Preparation and scheduling before intervention
2. Cryoplant transfer from operation to maintenance team with work authorization opening
3. Local coordination of maintenance work to avoid co-activities
4. Cryoplant return from maintenance to operation team with work authorization closing
5. Reviewing and closing of work orders and reports to validate the work performed

The main action developed to improve this activity was to develop a standardized work authorization in order for the operation team to authorize and monitor maintenance interventions. It includes a better planning and scheduling structure, improved associated communication, the review of existing safety documents including risk analysis before intervention and a study of the necessary action to ensure the safety of the maintenance team. Its application has been generalized with more than 300 work authorizations signed since beginning LS2, and proved to be efficient and appreciated by the involved teams.

3.3. Limitation of M&O subcontracting
M&O service contract can be efficiently implemented only if you own a significant amount of data and expertise cumulated over the years in your organisation. Outsourcing this type of services requires a high level of standardization of the subcontracted tasks and highly performant electronic interface to ensure a good level of follow-up with the contractor.

From the last years, we have noted some limitations that we would recommend to consider.

Responsibility matter:
- Technical knowhow and expertise for automation and functional analysis, advanced cryogenic instrumentation, together with maintenance expertise on critical assets (screw compressors, cold compressors, or HV motors) shall remain within the cryogenics group.
- Consolidations and obsolescence management cannot be delegated to the M&O contractor.
- For central services delivering helium to users without a dedicated cryogenic plant using thermally transportable containers, you should develop the tracking of delivery to include

Figure 2. Cost sharing of M&O activities during LHC run and LS2.
within the contractor obligation the responsibility of the entire supply chain, from request to the effective delivery of required quantities and gas recovery, purification and re-liquefaction.

Cost matters:
- Methodology deliverables shall be detailed initially but also during the contract lifetime in defined work packages with associated planning, pricing and paid according to effective delivery.
- Establishing prices for the exploitation of new installations can become difficult if the rules are not defined within the contract. We would advise to include figures that allow validation of additional operation costs, billing of commissioning and standard risk factor for maintenance and operation.
- Integration of new facilities such as HL-LHC test bench for crab cavities [7] since August 2018, or Neutrino platform proto-DUNE since November 2018 is not always straightforward. Depending on the technical documentation available for the handover, it may increase the duration for the responsibility transfer depending on the willingness of the contractor.
- We have noted that the participation of the contractor staff to projects of new cryoplants facilitate the onsite commissioning but can hardly be standardized with the present term of the contract.
- We are continuously investing resource and capital expense to streamline cryoplants operation to adapt capacities to provide better availability for users, and developed computerized M&O solutions. Expected returns for these investments and their associated optimization on the service prices shall be agreed with the contractor at the beginning of the project.

Review of the contract technical specification, as well as the price list structure is under study by the cryogenics group in order to go beyond these limitations in future service contracts.

4. Conclusions and perspectives
The M&O service contract implemented at CERN over the last 3 years has demonstrated that it can provide adapted support to sustain continuous improvement of LHC availability, and maintain a very good level of availability for a significant number of cryoplants serving multiple users at CERN. In addition it can adapt to the requirements evolution between run and shutdown periods.

The contract structure also allows joint developments of M&O methodologies between CERN and its industrial partners.

Feedback after LHC run 2 is positive and the work organization is now centered on long shutdown requirements. It shall confirm in the next two years the capability to deliver the maintenance scope of work and support CERN cryogenics group to resume LHC operation at nominal capacity for the third run.

5. References
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