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To cite this article: L Serio *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **278** 012115

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Outsourcing strategy and tendering methodology for the operation and maintenance of CERN's cryogenic facilities

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Abstract. CERN operates and maintains the world largest cryogenic infrastructure ranging from ageing but well maintained installations feeding detectors, test facilities and general services, to the state-of-the-art cryogenic system serving the flagship LHC machine complex. A study was conducted and a methodology proposed to outsource to industry the operation and maintenance of the whole cryogenic infrastructure. The cryogenic installations coupled to non LHC-detectors, test facilities and general services infrastructure have been fully outsourced for operation and maintenance on the basis of performance obligations. The contractor is responsible for the operational performance of the installations based on a yearly operation schedule provided by CERN. The maintenance of the cryogenic system serving the LHC machine and its detectors has been outsourced on the basis of tasks oriented obligations, monitored by key performance indicators. CERN operation team, with the support of the contractor operation team, remains responsible for the operational strategy and performances. We report the analysis, strategy, definition of the requirements and technical specifications as well as the achieved technical and economic performances after one year of operation.

1. Introduction

CERN has been operating cryogenic installations for several decades adapting and improving since then the operation, maintenance and performances [1, 2, and 3]. Today more than 160 kW @ 4.5 K are produced and distributed over a 5 km radius across the French – Swiss border near Geneva, Switzerland.

The largest installation and equipment are part of the flagship accelerator, the Large Hadron Collider (LHC), providing cooling at superfluid helium temperature with eight pairs of cryogenic plants of 18 kW @ 4.5 K and 2.4 kW @ 1.9 K, serving each 3.3 km long sectors via compound cryogenic distribution lines as well as the associated infrastructure to manage an inventory of more than 150 t of helium and a distribution of more than 10'000 t of nitrogen per year. The LHC has also three large superconducting magnets for the detectors, ATLAS and CMS, with 3 dedicated helium refrigerators for a total capacity of 10.3 kW @ 4.5 K as well as a nitrogen refrigerator. There are more than 20 cryogenic installations or facilities around the CERN site and a total of about 40'000 inventoried parts divided in 4 classes of components (mechanical, electrical, instrumentation and vacuum) and 25 main types of equipment (adsorber, filters, turbines, valves, motors, measurement devices, pumps, etc.).

We have recently reviewed, streamlined and optimized the operation and maintenance activities to prepare for the forthcoming phases of the machines exploitation. Maintenance and operation methodologies, processes and procedures, have been progressively reviewed and optimized to allow the outsourcing of the activities to industry, with the objective to efficiently and economically run the



installations while staff resources are dedicated to core activities of the Organization for the forthcoming upgrade toward higher luminosity.

2. Maintenance and operation requirements and methodology

CERN's installations are continuously operated over the year with only few short technical stops for critical corrective maintenance interventions. The preventive maintenance plans are optimized to match with the yearly shutdowns of the accelerators and their duration of about two months. The activities requiring more time, such as the major overhauls of rotating machineries, are scheduled during the major year-long shutdowns (LS) every four to five years.

Operation is performed during normal working hours for test facilities and experimental areas while a full shift crew is dedicated for monitoring and intervention of the installations serving the LHC machine due to the complexity, size, and impact of the downtime on the Organization scientific program. On-call interventions by operation and maintenance teams ensure the support to re-establish nominal operating conditions or troubleshoot of all the installations.

Due to the large size and complexity of the installations all maintenance activities are implemented via a Computer Aided Maintenance Management System (CAMMS) based on Infor EAM™ [4]. Over the past years we have implemented and documented the operation and maintenance methodology. The results are stored in an Oracle™ database together with the machines physical parameters allowing to efficiently monitor and manage all operation and maintenance activities according to plans and available budget.

The management of the activities is organized and implemented across the following tasks:

- Assets inventory and management;
- Maintenance and Operation Procedures;
- Documentation management;
- Spare parts analysis and management;
- Work management and administration;
- Work control and optimization;
- Implementation and analysis of Key Performance Indicators (KPIs).

The services outsourced to the contractor consist in:

- Operation of the installation according to the procedures and agreed schedule;
- Regular inspections of the plant(s) according to the inspection plan;
- Corrective maintenance triggered by the operation teams;
- Preventive maintenance according to the maintenance plan and agreed schedule;
- Asset management comprising: management of the maintenance documentation, management of the equipment database, updates and elaboration of inspection and maintenance plans;
- Work order management to track all activities performed by the contractor;
- Spare part management comprising: management of the existing spare part stock, management of consumables, spare part procurement;
- Quality Assurance and Control;
- Monitoring of the performance of maintenance activities to optimize plants availability, reliability and cost.

CERN oversees and inspects the activities and, reviewing the Key Performance Indicators agreed with the contractor, provides general guidance, implements strategic decisions, requests and approves modification of the maintenance plans and spare parts stocks.

3. Analysis and definition of the operation and maintenance activities

CERN has accumulated over the years a significant amount of data and expertise in the maintenance and operation activities of the installations. The CAMMS has been a valuable source of information to perform the analysis of needs and prepare the requirements to outsource to and industrial contract the

activities with well-defined performance goals. The implementation strategy and the definition of the activities were based on the optimisation of the preventive maintenance plans according to the statistics of the corrective interventions and a parametric analysis based on Key Performance Indicators to meet performance and budget targets.

The maintenance and operation performances of the LHC cryogenic equipment commissioned in the last decade were optimized under CERN responsibility [3] and guidance to reach target values satisfying both the accelerator scientific program and the organization budget. For a target availability above 95 %, and a Corrective over Preventive ratio (defined as the ratio between the cost of corrective and preventive maintenance interventions) of about 15 %, the cost of maintenance activities was evaluated to about 0.6 % of the Replacement Assets Values (RAV, defined as the monetary value that would be required to replace the production capability of the present assets in the plant). The required spares to guarantee the operational performances were selected drawing a criticality matrix based on frequency, number and type, procurement delays, detectability of faults, installed quantities and cost. The required budget for the corresponding spares was set to 0.2 % of the Replacement Assets Value.

In 2016 CERN, having reached the required maturity in the documentation, procedure and performances, decided to implement the full outsourcing of the operation and maintenance activities under performance or task obligations. A task-oriented obligation refers to the performance of tasks requested by CERN, foreseen under a maintenance plan or required to re-establish the nominal performance of an equipment. A performance obligation relates to the actual maintenance and operation of an installation where a target performance level is defined by CERN and shall be achieved by the contractor.

The scope of work has been identified and detailed through several contractual documents that were part of the call for tender and implemented as contractual obligations. The contractual documents are:

- The functional specification providing the details of the services required, the requested performances and the constraints to perform the activities;
- The list and detailed information of all installations to be serviced;
- The localization, number and types, equipment and components;
- An excel spreadsheet identifying all tasks to be performed by the contractor and the types and number of equipment to be serviced, the expected quantities, periodicities, frequency of occurrence of interventions (with statistics from previous year, references to maintenance plans and operating hours), see Table 1;
- A precise estimate of work load for the contractor based on operating scenario, maintenance plan and full cycle statistics of the installations;
- A list of required performance indicators with bonus, malus and penalties.

Table 1. Summary of the Scope of Work, equipment and activities.

Type	Quantity	Units
Tasks	207	u
Maintenance plans	4'400	u
Assets	2'600	u
Equipment	40'000	u
Spare parts references	7'000	u
Average Mean Time Between Failures	140	days
Min / Max Mean Time To Preventive	8'000 / 40'000	hours
Average Mean Time To Preventive	24'000	hours

Industry has provided, via a call for tender and an adjudication based on the best value for money (parametric assessment of cost and quality of service), a detailed list of unit prices per operating hours of the installations or for the individual tasks performed.

The contract was awarded and implemented in July 2016 and it has been operating since then successfully. It is managed using Infor EAM™ to initiate, review and approve all activities via work order and work packages as well as handling the stores and spare parts. It also allows the automatic issue of work packages for the preventive maintenance activities and the invoicing based on the unit price list defined with the tender. Pentaho™ is used to report contractual performance indicators and operational statistics.

At the beginning of the contractual year, using the unit price list, a detailed estimate of the work to be performed (based on the operating hours of the machines, the maintenance plan for preventive tasks, the statistics from previous years on the potential corrective activities likely to be performed and the required methods tasks) is drawn and contractually communicated to the contractor.

The activities are entered in Infor EAM™ and the work is planned with details of resources and cost.

During the year the activities are initiated either automatically (work packages for preventive maintenance) or manually (operators, technician request for repairs for corrective maintenance). Once initiated the activities become a work order or a group of work orders (work packages for grouped preventive maintenance on an installation), are verified by the contractor technically and resource wise and then sent to CERN for acceptance (CERN can in this case review the need to perform the activities). Once validated by CERN technical officers (various technical responsible depending on the category of the work, i.e. operation, mechanical, electrical, methods, etc.) the activities are performed by the contractor technicians and validated as completed with the information on time spent, resources used, spares used, start and end date, cost. The work order goes then to the contractor maintenance or operation engineer for validation before being sent to CERN for final validation and payment. All the way during this process several KPIs are used to follow up the activities of the contractor.

4. Technical and economic performances

The following figures present the operational results and performances of the industrial service contract to which the operation and maintenance activities have been outsourced since July 2016.

The results are given for typical cryogenic installations and equipment servicing:

- The LHC machine accelerator complex [1], in operation since 2008, operated under task obligation by the contractor and requiring the highest level of availability and reliability in order to fulfil the Organization scientific program;
- One of the test facilities, the SM18 [5], the main cryogenic test benches facility for magnets and radio-frequency superconducting devices, operated under performance obligation.

Table 2 describes the time periods (past and present performances against target specifications) used to assess Operation and Maintenance (O&M) cost performances during a full operation cycle.

The Operation and Maintenance costs include:

- Internal and external manpower to perform standard Operation and Maintenance tasks
- Spare parts and consumables required for each maintenance tasks
- Vibration monitoring and analysis
- Major Overhaul costs when required outside the planned long shut down windows

Table 2. Reference operating periods of the installations.

		NEW CONTRACT							
		Past performance	Present performance	Target specification					
		2013	2014	2015	2016	2017	2018	2019	2020
LHC, ATLAS & CMS	Long Shut Down 1	Long Shut Down 1	RUN	RUN	RUN	RUN	Long Shut Down 2	Long Shut Down 2	
	SM18 Test Facility	RUN	RUN	RUN	RUN	RUN	RUN	RUN	

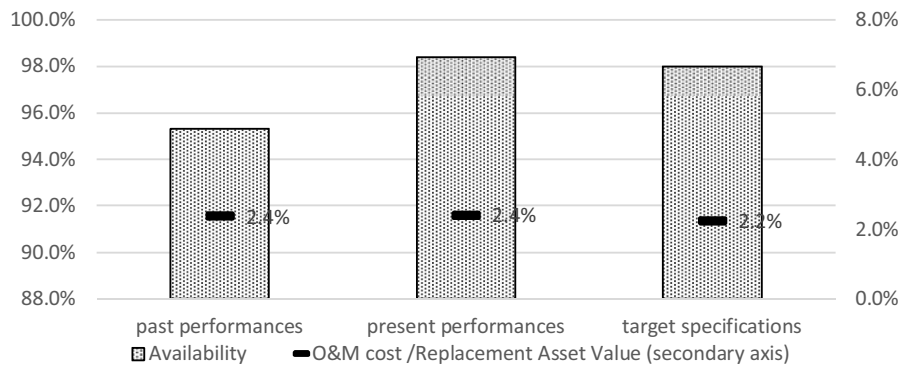


Figure 1. Operational performances and O&M relative cost for the LHC machine.

The following costs are excluded:

- Liquid Nitrogen for precooling and Helium consumption [2]
- Energy costs and other utilities such as water cooling and compressed air supply
- Capitalized technical modifications or consolidations of the cryoplants
- Maintenance costs of the cryogenic distribution lines and tunnel instrumentation

Figure 1 shows that the cryogenic availability reached by the LHC installations during the first year of operation, excluding utilities faults, is well above the target figures and in line with the planned costs. Operation and Maintenance costs remained stable over the last 2 years despite the significant increase in availability and the implemented outsourcing strategy based on a task oriented approach. The LHC target availability of 98 % for the forthcoming years takes into account savings in the required resources after the implementation period required to obtain a smooth transition in order not to impact the scientific program. The extrapolated costs during the long shutdown periods every four to five years is estimated to go up to 3 %. Figure 2 shows the cryogenic availability reached by the SM18 test facility during the first year of operation. O&M costs increased due to the first year overlap between CERN and contractor staff to ensure the smooth handover of the installation but are expected to return to an average of 5.7 %. Figure 3 summarizes the Corrective over Preventive Maintenance ratios for the contractor maintenance tasks of the LHC inclusive of the ATLAS and CMS cryoplants, but excluding major overhauling. It shows an increase in the past year due to planned tasks performed during the winter 2016-2017 extended shutdown. Figure 4 shows that the C/P ratio for SM18 is stable. Figures 5 and 6 detail the preventive and overall maintenance costs for the installations. The share of corrective interventions is distributed almost equally between mechanical and instrumentation/electrical activities.

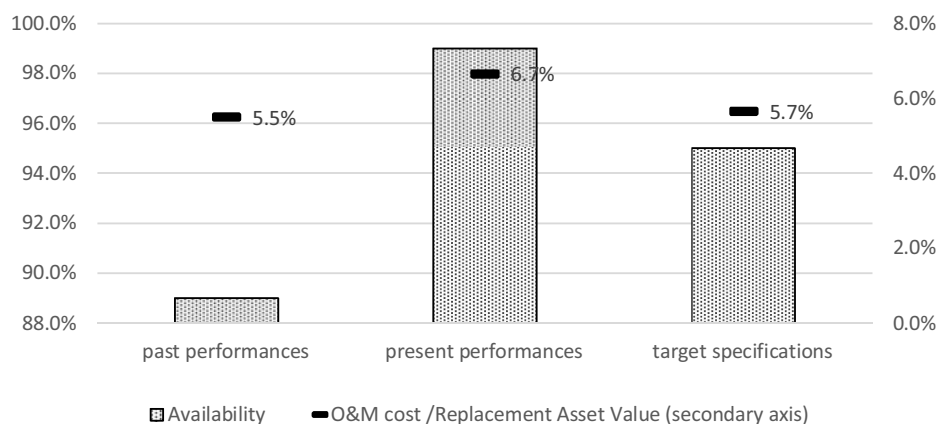


Figure 2. Operational performances and relative cost of the SM18 test facility.

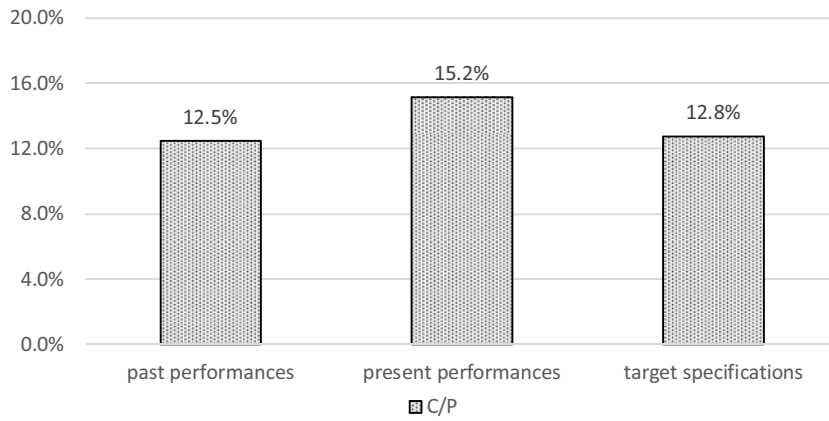


Figure 3. LHC machine Corrective over Preventive maintenance ratio.

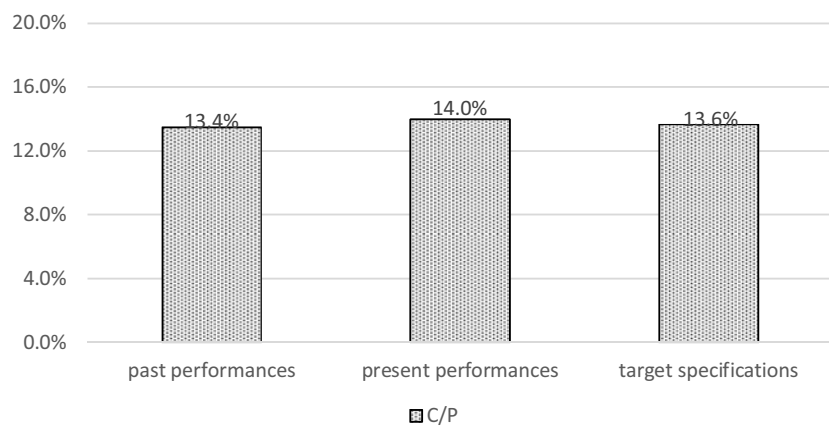


Figure 4. SM18 Test Facility Corrective over Preventive maintenance ratio.

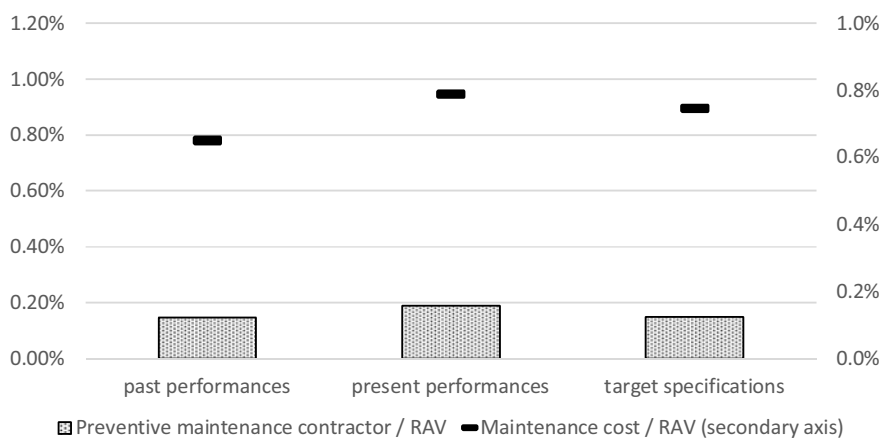


Figure 5. LHC machine Preventive maintenance and maintenance relative cost.

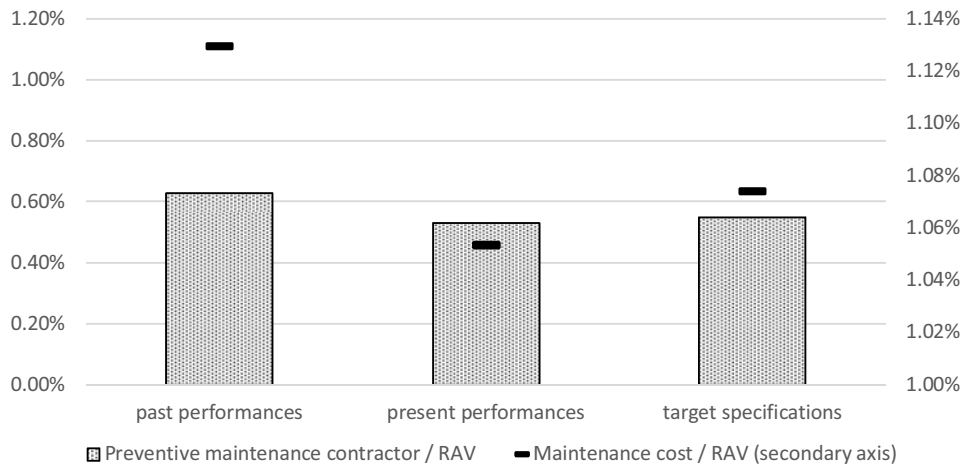


Figure 6. SM18 Test Facility Preventive maintenance and maintenance relative cost.

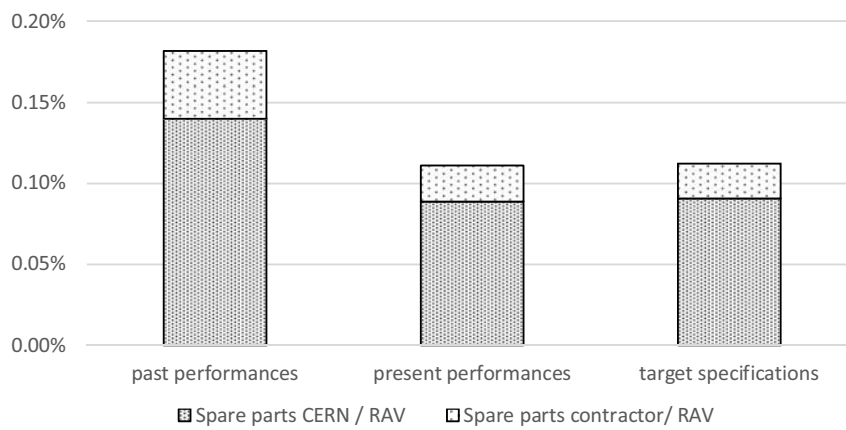


Figure 7. LHC machine spare parts relative cost.

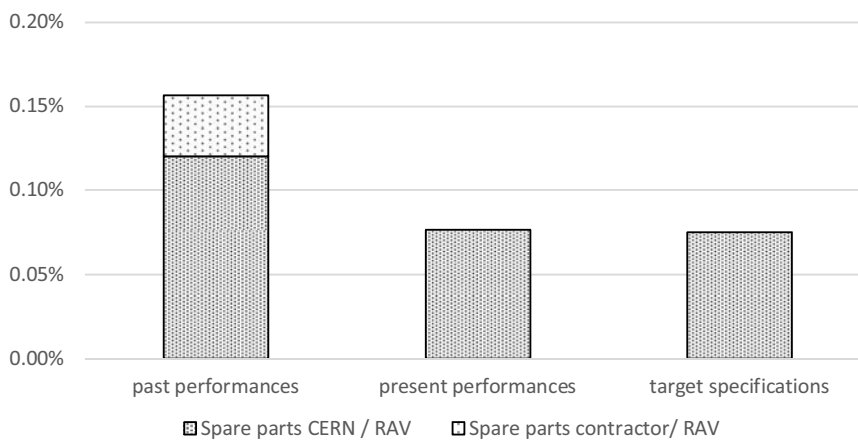


Figure 8. SM18 Test Facility spare parts relative cost.

Figures 7 and 8 detail the amounts spent for maintenance spare parts and consumables. Stock increase or spares above a defined cost threshold are purchased directly from CERN in order to reduce the risk and therefore cost of the contract. Otherwise the spare parts and consumables costs are included in maintenance task price of the contract.

5. Conclusions

CERN has successfully analyzed, specified and outsourced the operation and maintenance activities of the cryogenic installations for its test facilities and the LHC machine complex.

The experience accumulated over the years has permitted to specify in detail the activities and implement standard industrial maintenance methodologies to reach corrective over preventive maintenance ratios and maintenance costs in line with industrial best practices [6].

A continuous and iterative process guarantees that the target performances and costs are reached or even improved over the years via regular adaptation of the maintenance plans and spare parts.

The CAMMS and key performance indicators allow a continuous monitoring and optimization of the activities in order to guarantee the highest level of availability at reasonable costs.

The challenge for the coming years will be to confirm over the long term the achieved performances and keep the highest level of availability and cost targets despite the ageing of the installations.

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