Increasing availability with Lean Outage Excellence: advance planning and execution optimization

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Abstract
GE Oil & Gas Global Services provides customers with a long-term partnership for reducing the cost of overall maintenance, repair and replacement parts, while improving the overall unit reliability and availability.

The effective implementation of planned maintenance and inspection provides direct benefits in reducing forced outages and increased starting reliability, which in turn can also reduce unscheduled repairs and downtime. Maximizing uptime means extending the mean time between maintenance, reducing unplanned shutdowns and shortening the duration of site activities. This paper is mainly focused on advance planning and optimization of execution for outages. It describes the new processes and technical solutions provided through Contractual Services to reduce risks, improve quality and EHS compliance, optimize maintenance activities and increase availability and production.

The case addressed in this paper concentrates on the major inspection of heavy duty gas turbines. This new outage planning and execution methodology was implemented for a power generation machine at the MLNG plant in Bintulu (Sarawak, Malaysia).

After this first implementation, MLNG and GE Oil & Gas agreed to adopt the Lean Outage Excellence planning methodology. As part of a new Contract Service Agreement valid for the next 10 years on the MLNG fleet, the outage duration will be progressively reduced, thereby increasing the MLNG fleet production.

Introduction
In recent years, the oil & gas industry has focused significant attention and resources on maintenance activities. GE Oil & Gas has concentrated significant effort on developing new processes and solutions for better outage planning and execution. Advance planning is a key element for the success of outage execution. It can help avoid rework, lost time and quality issues. Execution optimization reduces the number and extent of quality and EHS issues, increases uptime and guarantees extra production.

The Lean Outage Excellence (OE) process adopted by GE Oil & Gas applies to all major and critical inspections. The OE process defines a set of operations to be performed prior, during and after the shutdown, following a specific tollgate process and Lean methodology.

Gas turbine scheduled maintenance
Scheduled maintenance is performed with the machine (and the related portion of the plant) out of service. The unit, starting from the enclosure, has to be disassembled; then each component is inspected, cleaned, repaired or replaced, depending on the maintenance scope. The maintenance scope ends with the reassembly and the startup of the unit.
For heavy duty gas turbines, the inspection levels are:

- CI = Combustion Inspection
- LTPI/HGPI = Hot Gas Path Inspection
- MI = Major Inspection

The zones covered by these inspections are shown in the cross-sectional drawing of a gas turbine in Figure 1.

The complexity of the maintenance scope generally varies depending on the inspection level, application/configuration/operation of the machine (i.e., Power Generation, LNG production, etc.) and depending also on the total running hours (aging) of the units involved.

The main highlights are:

- Clear definition of deliverables, roles, and responsibilities
- Standardization of operating procedures
- Effective, proactive metrics
- Meeting established customer expectations

The hard deliverables of the process are outlined in the OE Handbook. The handbook contains all the documents related to the outage and is the guideline for the team involved in the activities. The project manager (PM) activates the process during the activities planning stage. Outages must be planned 18 months in advance in order to provide a timely capital spare forecast and ensure correct slotting. Failure to start early causes a delivery risk for the materials needed for the outage. The process start date is 18 months prior to the outage forecast date, and the first OE customer meeting is scheduled 12 months prior to the outage forecast date.

The OE planning milestones are:

**Definition and Procurement » 18-12 months before outage starts:**

GE Oil & Gas Global Services has developed a dedicated online system for the proactive forecasting and proposal of the maintenance date for units in service. The dates are defined based on the maintenance policy, service factor and contractual obligations. The system also provides the list of parts and personnel needed for the particular maintenance activity. The PM defines the main workscope using the suggested maintenance forecast. In addition to that, the PM will:

- Evaluate all the technical information letters and notes for applicability to the unit
- Evaluate and add to the hot-list per customer request
- Review any punch list items that might be open from the previous maintenance or installation
- Look at the operating history and trip reports to avoid major risks
- Review top issues and lessons learned
- Evaluate any potential upgrades for the system
• Take into consideration the contractual obligations of each outage

Detailed scheduling » 6-3 months: Together with the customer, the site organization is defined. The integrated EHS plan is built and validated. Manpower is committed and tools are identified.

Final review » 1 month: Final ready-to-go meeting for a last check of the availability of spare parts and resources, and to resolve any last minute issues.

Execution control » during outage execution: Starting from January 2010, daily monitoring and a special weekly operational review is scheduled to assess the status of all outages in progress.

Performance evaluation and lessons learned » post outage: Trip log and final report review; lessons learned discussion with customer.

Execution

In 2009, GE Oil & Gas launched a new program to optimize the outage duration in order to maximize the availability of customer units and to drive further improvements in quality and EHS. A Lean methodology was used for the analysis and the optimization.

Lean manufacturing or Lean production, which is often known simply as “Lean”, is a production practice. Lean manufacturing is a generic process management philosophy derived mostly from the Toyota Production System (TPS) (hence the term Toyotism is also prevalent) and identified as “Lean” in the 1990s. It is renowned for its focus on the reduction of the original Toyota seven wastes in order to improve overall customer value. Basically, Lean is centered on creating more value for the customer by eliminating process waste. The 5 principles of the Lean approach are: Value, Value Stream, Flow, Pull, and Perfection.

Value is defined as any action or process that a customer would be willing to pay for. The starting point for a Lean analysis is the identification of all the types of waste. The seven kinds of waste are:

• Transportation (the moving of products that is not actually required for execution)
• Inventory (all components, work-in-progress and finished products not being processed)
• Motion (people or equipment moving more than is required for execution)
• Waiting (waiting for the next production step)
• Overproduction (production ahead of demand)
• Over Processing (activity resulting due to poor tool or product design)
• Defects (the effort involved in inspecting for and fixing defects)

Value Stream Mapping allows the team to see the waste and potential solutions, and highlights value added and non-value added activities. The VSM highlights the Time and Sequenced Map of all activities required to bring a product/service from a customer request to customer satisfaction. The VSM shows the linkage between the information and material/document flows.

Lean manufacturing can also be seen as a variation on the theme of efficiency based on optimizing Flow. A flow-based process, where activities follow each other without any accumulation of waste is critical for applications in which process time is a key metric.

Wherever a flow process cannot be executed, the Pull system approach is required. Each step pulls the product/transaction when needed from the preceding step. The Just-In-Time approach, leveraging the Kanban techniques, is the most common tool for implementing a pull process.

The aim of Lean implementation is to obtain, step-by-step, a better process through the implementation of small Kaizen actions (Japanese term for small systematic improvements). Continuous analysis and Kaizen implementation is fundamental in striving for Perfection.
The methodology, used by the OE team to optimize outage execution consists of the following steps shown in Figure 3:

- Outage observation
- Lean Action Work Out
- Kaizen action development
- Application to site
- Final validation
- Standardization and implementation
- Continuous optimization starting again with observation

A Lean Black Belt leads the AWO team through the Value Stream Map (Figure 4). Once the “As Is” process is defined the AWO team builds the “To be” process trying to eliminate all process waste. The final purpose of the AWO is to identify and prioritize all the short, medium and long term actions that allow reaching the ideal “To be” process.

**FIGURE 3 The cyclic paradigm**

During observation, a dedicated resource or team (depending on the complexity of the outage) performs a survey of the activities. The resources are skilled field service engineers. They use a standard template to document the activity they are observing. The document includes: sequence of activities, relationship between activities, duration of activities, utilization of resources, utilization of tools, touch time, wait time, other kinds of waste, EHS and quality issues and customer interfaces.

The observation is then analyzed during the Lean Action Work Out (AWO).

The AWO is performed on site right after the outage execution. The team (10-12 people) includes the crew that performed the outage, the customer representative, a selection of the outage personnel and other key resources (engineers, project managers, technical experts, etc.).

**FIGURE 4 Value stream map built during AWO**

After having developed the Kaizen actions proposed during the AWO (i.e., new tool development), the selected solutions are applied to the site in subsequent outages. If it is possible or if it is required by EHS procedures, the new solutions are validated in the manufacturing testing area before application to the site.

The final step is standardization involving training of all personnel involved in the execution of activities (project managers and field service engineers) in order to implement the new execution procedures all across the fleet, as appropriate.

The improvement areas for outage execution can be classified as follows:

**Planning:**
- Guarantee that the advance planning includes the customer. Optimize the schedule of activities to maximize capacity utilization.
- Define a standard template and methods.

**Execution:**
- Definition of the site layout and logistics; manpower coordination and skill set segmentation; tools management; configuration of shifts.

**Tooling:**
- Customized smart outage tooling design and development.

**Customer interface (Figure 5):**
- Simultaneous activity agreement. Hold point and permitting procedure definitions.
The site AWOs are continuously integrated with Headquarter activities. The Lean Outage Excellence team periodically runs a series of Action Work Outs. The aim is to bring together the cross-functional resources of GE Oil & Gas to come up with new ideas. The testing and packaging areas in manufacturing are also used to identify new technical opportunities and to prove them during the disassembly or re-assembly phase.

GE’s Repair and Technology Center of Excellence (RT CoE) makes a fundamental contribution to the Lean OE process. Collaboration between the Lean OE in Florence, Italy and the RT CoE in Greenville, South Carolina began in early 2009. The Customer Outage Engineering Department of the RT CoE operates from the Repair Development Center (RDC), which is housed in a 1400m² building and is dedicated to the development and industrialization of innovative repair solutions for the GE Infrastructure Businesses. Leveraging from a broad base of knowledge across the global infrastructure, the RDC and Customer Outage team delivers state-of-the-art solutions around a wide range of processes including: thermal spray and diffusion coatings, adaptive machining, laser welding, elevated temperature gas tungsten arc welding, RenewAlloy™ brazing and rejuvenation heat treating, electro-discharge machining, material testing and inspection, as well as tooling and field outage support for the global services network. The dedicated GE Oil & Gas tooling and field outage support team delivered several new tools in 2009 (see below for some examples).

**MLNG case**

In March 2009, the first site observation was conducted in Bintulu (Sarawak, Malaysia) for an MS5001PA DLN Major Inspection. This unit is one of five identical power generation units at that site. The reason for choosing this unit as the pilot is that in 15 months, all five of the MS5001 machines would need a major inspection. Therefore it was possible to apply the cyclic Observation-AWO-Actions-Application-Validation-Training paradigm.

A field service engineer, an engineer from RT CoE and two Lean Black Belts constituted the observation team. During the Action Work Out, the team found opportunities to reduce the duration of the major inspections of the power generation units by 20%.

Continuous improvement is the essence of the Kaizen methodology and enhancements (e.g., methods, design and production of new tools, etc.) were incorporated into the process in three steps corresponding to the subsequent three major inspections scheduled in July ‘09 (10% reduction), October ‘09 (15% reduction) and March ‘10 (20% reduction) (Figure 6).

The MLNG site AWO proved to be a great success as it gave to the process an additional “real site” perception with the team generating more than 100 ideas to be implemented during the subsequent outages.

In July ‘09, implementing the first ideas for improvement, the major inspection was successfully completed. The key factors
contributing to success in this first implementation were: tooling improvements (in terms of quality and number), standardization of methods, advance and shared planning (through more detailed activities Gantt charts) and better integration with the customer during critical phases of the outage.

In October ‘09 the second step was a greater challenge given that the additional scope included the generator rotor inspection in the schedule, and that there was limited overhead crane and lay-down area availability. In part, thanks to the prototype of the new tooling (made available by the RT CoE), the outage cycle time reduction target was successfully reached.

Finally, a 20% reduction target is planned for the last major inspection in March 2010 (see Figure 6) and key improvements will focus on manpower team segmentation and the introduction of additional new tooling.

Combustion liner installation (RT CoE)
Combustion liners require precise circumferential alignment and significant installation force to compress the transition piece hula seal. With a half-inch ratchet and a lightweight combustion liner installation tool that utilizes a bearing-mounted central ACME screw, accurate assembly of each combustion chamber is achieved within minutes (Figure 9).

Turbine shroud pin removal (RT CoE)
Turbine shroud retaining pin plugs may shear off inside the turbine case during disassembly. This tool kit features a special expanding collet assembly that is inserted into the associated turbine case counterbore (Figure 10). A drill guide bushing is then mounted central to the collet to allow the operator to remain precisely on center while drilling through the sheared plug.

Body bound bolt removal (RT CoE)
A suite of hydraulic body bound bolt removal tools is now available to fit within the casing counter-bore diameter. Similar to the other tools, the body bound bolt removal kit includes everything needed to perform the job and comes in a single heavy-duty steel tool chest.
Rotor alignment guides
Rotor radial guides have been developed to ensure that during removal/assembly of the rotor, axial compressor blades do not come into contact with the turbine casings. The new tool assures the proper quality during lifting/assembly of the rotor (Figure 11).

New combustion casing bolting
Silver coated bolts will be used to connect the combustion casings to the turbine. This new type of bolt will reduce the potential for seizing during disassembly, decreasing the time required to remove them.

Dry ice axial compressor cleaning
Dry ice blasting is a relatively new cleaning process using solid CO₂ pellets (dry ice). Dry ice pellets sublime once they hit the surface being cleaned, leaving a clean, dry surface with no residue (Figure 12). GE Oil & Gas decided to extend this process to the on site cleaning of axial compressors. It has resulted in minimizing waste and saving time, and it is an Eco-friendly process.

The Lean OE project for Power Generation units has been the pilot for implementation on LNG trains starting with the next set of major inspections for LNG machinery. Additionally, MLNG and GE have agreed to adopt the Lean Outage Excellence reduction planning methodology. As part of the new Contractual Service Agreement for the next 10 years on the MLNG fleet, the duration of outages will be progressively reduced from the first set to the third set of major inspections on all the LNG trains through site AWO execution and improvements applied at each of the three steps agreed to.

Conclusions
The introduction of the Lean Outage Excellence initiative resulted in a new level of outage planning. Outages for Global Contracts planned in less than 6 months, and consequently with high execution risk, have been eliminated, while 90% of outages are now planned at least 12-18 months in advance. In 2010, the new planning process will cover 100% of GE Oil & Gas Global Services contracts.

Many opportunities to reduce the outage duration by up to 20% have been identified. Lean methodologies are now the norm for applying Lean Outage Excellence to reduce the disruption of production in our customers’ plants during outages.
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