R&D proposals to improve outages operation: Methods, practices and tools

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Abstract: This paper deals with outage operation improvement. It offers a number of tracks on the interactions between the operation activities and maintenance, with a methodological perspective and proposals concerning the Information System. On the methodological point of view, a clever plant systems modeling may allow representing the needed characteristics in order to optimize tagouts, alignment procedures and the schedule. Tools must be taken n into account for new tagout practices such as tags sharing. It is possible to take advantage of 2D drawings integrated into the information system in order to improve the data controls and to visualize operation activities. An integrated set of mobile applications should allow field operators to join the information system for a better and safer performance.

Keyword: nuclear operation; outage, tag-out, alignment procedures

1 Introduction

The outages quality and duration control is now one of the major objectives for nuclear power utilities.

The plants aging and their life extension to 60 years (or more) implies an increase in maintenance, requiring more activities during outages. The challenge is to contain outages duration, essentially for economical reasons.

The international community has identified a large set of topics, such as precise scheduling of maintenance activities in long, medium and short-term, management of providers, outage plant operation (shutdown and restart), plant organization, nuclear safety management, plant activities monitoring, actors' coordination, *etc.* [1].

This paper is not focused on all these factors to be controlled for a successful outage. It does not take into account the organization of maintenance, monitoring operations, outage project management or human factor aspects. It offers a number of tracks on the interactions between the operation activities and maintenance, with a methodological perspective and proposals concerning the Information System (IS).

2 What's an outage?

2.1 IAEA definition

"Plant outages are shutdowns in which activities are carried out between disconnection and connection of the unit to the electrical grid. Therefore, outage is the period where significant resources are expended at the plant, while replacement power must be purchased to meet the utility's supply obligations.

Outage management is a complex task which involves in respect of the plant policy, the co-ordination of available resources, safety, regulatory and technical requirements and, all activities and work before and during the outage." [1].

"Each plant/utility develops its strategy for short term, middle term and long term outage planning. Extensive efforts are usually directed towards detailed and comprehensive preplanning to minimize outages, avoid outage extensions, ensure future safe and reliable plant operation and minimize personnel radiation exposures. All these elements are part of the plant outage strategy. Nevertheless, how the plant strategy is implemented is a key to the success of optimization of outage period.

Planning and preparation are important phases in the optimization of the outage duration which should ensure safe, timely and successful execution of all activities in the outage. The post outage review will provide important feedback for the optimization of the next outage planning, preparation and execution".

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2.2 A significant number of maintenance activities, with multiple constraints

The daily cost of unavailability of a nuclear unit is very high. That is one of the reasons why it is necessary to closely follow the schedule. Outages duration respect is an important criterion of assessment of utilities performance.

The outage duration of a pressurized water reactor (PWR) is between 7 and 60 days, depending on the company, the type of reactor and the constraints of national nuclear safety rules. We distinguish four main types of outages [2]:

- Refuelling only (in 7 to 10 days),
- Refuelling and standard maintenance (in 2 to 3 weeks),
- Refuelling and extended maintenance (up to one month),
- Specific outage for major backfittings or plant modernization (more than one month).

The duration evaluation methods may vary from one country or operator to another. We must understand these figures as indicators or as a way to assess the evolution of site's performance.

For a PWR refueling only outage, about 3000 / 4000 maintenance activities have an impact on operation.

2.3 The schedule is at the heart of the outage management

Outages are planned and prepared in advance, in order to limit risks. Schedule simulations can be performed to ensure that maintenance activities are consistent with the plant conditions, safety rules are followed, activities are all scheduled, contractors and spare parts are really available, radiation protection has been taken into account, tagouts are well defined, *etc.*

We distinguish three main categories of schedule: long-term, medium and short term.

The long-term schedule is established for 5 to 10 years. It considers equipment aging, large maintenance activities, fuel optimization, plant availability to the grid. It estimates outages durations and budgets.

The medium-term schedule verifies the adequacy between the objectives of long-term planning and the remaining time to implement the project. It integrates electricity market needs, human and material resources. It comprises a time period of 2 to 5 years.

The short term schedule secures all outage operations. This is the detailed schedule for the next outage.

Companies with large reactors fleets such as EDF develop generic outages schedules that plants must follow. These schedules are elaborated at the highest levels of the company and are adapted to each plant. The schedule tasks are either "national" or "local" when adjustments are needed.

2.4 Units in infrequent operating states

A plant is running most of the time. Shutdown states are infrequent and some circuit configurations are therefore rarely operated.

Thus, the crews need to control a system in infrequent states, and sometimes modified by tagouts for maintenance.

The crews' concentration and attention are very high during these phases. Their workload is also particularly important.

2.5 Often a different organization, adapted to outage

Some utilities choose to implement specific organizations to manage their outages. A project can be set up for each outage, involving different plant departments.

In addition, most utilities implement strategies to deal with unexpected events, often with dedicated rapid response teams ("Fix It Now Team" for example).

For operations, modifications of working hours or teams organization may occur. According to national laws, operations can move to 2x12 hours shifts.

Sites must also accommodate a large number of contractors' employees to perform maintenance work. These workers must be trained, managed and assisted.

3 Research paths in terms of method

From the operation point of view, some methodological or theoretical barriers still need to be overcome. The following chapters are a a proposal of topics to work on.

3.1 A schedule modeled from plant operational constraints

An outage schedule integrates constraints of work orders, duration of work, required equipment, security, plant modes, availability of backup circuits to comply with safety rules, *etc.*

Today the schedule is established by experts who formalize their experience directly in the organization of tasks.

However, we can identify main rules that organize the major phases of the schedule. Examples include the plant mode, reactor water movements, nuclear safety rules that specify the dynamics of operation or redundancy of systems, *etc.*

But we don't find, either on sites or on research programs of major organizations, proposals for constraints formalization imposed by the plant operation on the schedule. These constraints such as the availability of circuits (and therefore the modeling of possible configurations), specific rules of safety, operation time are not formalized as rules to integrate into the schedule.

Today, the strategies consist in toughening the schedule. They do not allow you to manage easily hazards in an optimized way.

The formalization of such constraints could secure the schedule during construction, but also allow adapting it in case of problem.

A project modeling these constraints and standardizing their representation would allow utilities to develop outage schedules with embedded logic traceability and with clear adaptation limits due to operation constraints.

Among other things, the formalization of the reactor physical and regulatory constraints enables better coordination (depending on the organization set up on site) between the team in charge of the outage schedule and the operation teams.

3.2 Areas of work that doesn't slow down systems' restart (well adapted areas)

The different work areas of an outage are prepared for maintenance activities. The operation teams have the responsibility to secure them with tagouts. The result of this engineering process is a work order.

In many organizations, a work order includes several chapters; one of them is dedicated to tagouts.

Tagouts consist in isolating the equipments on which a work is expected. All risks to workers such as electrical hazards; steam, *etc.* must be taken into account. Practically, it consists in isolating part of plant circuits to provide safe work areas for maintenance.

A tagout may require the opening or closing of various types of equipments such as electric breakers, valves, *etc*, under the responsibility of various departments of the plant.

A work area may be close to another work area, so that it becomes possible to create a common safety zone. It has the advantage of limiting the number of equipments to tagout, but the disadvantage of making a greater area of unavailable systems. In other words, the same tagout can secure several work areas described in several work orders.

One sees here the issue of tagouts size coming up, with a direct impact on the work comfort, but also on the availability of plant systems, that consequently implies strong constraints on the schedule.

So far, the tagout strategy is discussed within the team in charge of schedule preparation. This team integrates, of course, operation teams' members. The process converges on the one hand by the previous outages feedbacks and in the other hand by simulation exercises, by highlighting the sequences of maneuvers on P&ID drawings, according to schedule tasks dealing with operation. This simulation can show conflicts between tagouts and operation maneuvers.

Models, or ways to represent different grouping strategies of work areas, based on functional criteria, schedule, safety, plant modes, *etc.* would be particularly useful. They would allow teams to prepare tagouts (tag-in - tagout) with a good understanding of theirs choices on the outage performance.

It is necessary to produce simple and effective models for tagout implementation.

3.3 Optimized alignment procedures

Tagouts production does not on only consist in making field work secure, according to functional, safety, and schedule constraints. The tagouts removal has to be taken into account if we want to optimize the restart of plant circuits.

The classical approach consists in separating tagout removal and alignment activities. In practice, a first field operator removes tagout tags and chains that secure work areas, and position equipments in their default position, according to the operation management database. The target position is generally conservative. A second field operator then performs the alignment procedure to prepare the circuit to be filled in or restarted.

A more efficient approach consists in tagging-out in the alignment position, adapted to its refilling and/or restart. Alignment activities depend on the state of the circuit. Indeed, an alignment will be different depending on whether we must fill in a circuit, vent it, restart it or turn it off.

As for tagouts, the tagout removal and its associated alignments strategy should be modeled, using easy to use functional models, that will allow taggers (or operation managers) optimizing these joint activities.

The potential gains are very important. Indeed, the classical approach tends to postpone alignments as late as possible, when all tagouts are removed. The optimized approach limits this postponement effect, by removing alignments from the schedule critical path. Such a method has been implemented on the EDF Penly and Nogent 1300 MWP NPPs, with very good results.

Here again, tools and methods that can propose strategies according to restart constraints, would produce important gains, especially in case of unforeseen events.

3.4 Outage replay and simulation

The proposed outage simulation is not based on chronological time as for engineering or training simulators. It follows, here, the logical sequence of schedule activities.

Some utilities use to simulate their schedule before each outage. The main check points are the availability of resources (human and material) and the projection of activities on the plant circuits to verify all constraints. Such tools must include copies of the plant equipments database, the outage schedule, operation procedures, tagouts, alignments, functional models of the circuits and operation and safety rules.

To be easily understood, the simulation results should be visualized on P&ID drawings or on functional representation of the circuits.

In practice, the outage simulation must be able to highlight conflicts between tagouts and alignment procedures, impact of tagouts on circuits' availability, the result of the execution of a procedure on circuits.

These functionalities should allow the verification of the schedule technical applicability on the plant circuits. They also should allow the optimization of tagouts, safety, alignment and circuits restart. In addition, outage logical simulation should allow the definition of a strategy in case of unforeseen event.

In the outage monitoring team, the tool could help at explaining and discussing the new strategy.

The outage logical simulation can be smoothly introduced. At first, it is possible to implement a "log system" in order to replay the past outage and identify possible improvements for the next one.

3.5 A support to the definition of configurations

The previous proposals are all based on a functional modeling of plant circuits. This functional modeling is at the heart of the research activity to carry out. Here are some features:

– It must consider the main operating situations on normal operation. It is not necessary to detail all the possible configurations (because too complex to manage in a behavior point of view). It must be capable to discern the main functions to be implemented.
– Some functions, in particular due to systems' redundancy, may have various operation configurations that must be clearly identified. This is the case for trains filtration, for an alternative mean of pumping, *etc.*
– It must be able to distinguish forbidden operation configurations. For example, it is generally prohibited to fill a tank by two different pumping means, in order to be able to precisely monitor the injected volume of liquid.
– In order to take into account out of operation circuits and maintenance conditions, functions must contain all their equipments. Thus, if a drain or a vent is not correctly closed, we cannot consider the system as available, for its conditioning and restart.
– Functions are managed by alignment, fill in, conditioning start and stop procedures. It is necessary to be able to identify the impact of procedures on functions' equipments.

For utilities, this means that:

– Functions must be identified as such in their network of functions (of a plant system). It is necessary to indicate their mechanisms of collaboration or exclusion.
– Each function must be represented (or projected) on a P&ID drawing (or several), with each

involved equipment and its state(s) (open, close, set, released, tagged, *etc.*).

In other words, operations need to have a clear vision of plant systems with a representation of their functions, of their associated structures and of the logical behavior that characterizes them. For an easy understanding, it is necessary to easily project the behavior or the functions on structures (P&ID for example).

In conclusion, a clever plant systems modeling may allow representing the needed characteristics in order to optimize tagouts, alignment procedures and the schedule.

4 Research paths in terms of tools

From the operation point of view, new information system tools may provide significant improvements.

4.1 The use of 2D technologies

Paper based P&ID are essential to prepare operation activities, to perform them and to verify them by all team members.

Plan circuits are highlighted and equipments' positions are manually defined.

We can imagine a transition from a paper based world to a digital world, with 2D drawings automatically highlighted and animated by IS data. It is even possible to consider updating IS data using P&ID drawings as a digital interface.

2D drawings have the particularity, if they are well done, to manage links between the equipments. For example, a pipe links two valves through a relationship that contains the direction of the flow between the two valves.

If they follow advanced construction rules, 2D drawings may realize treatments and controls that are not permeated in classical IS implementations (usually relational databases). Then, the need to merge information system data and 2D CAD data appears, in order to add semantic to the IS model, and then more advanced control data rules.

For this, the use of rich 2D data formats and easy to implement is required. Such models already exist; unfortunately, they are not sufficiently integrated in information systems architectures.

4.2 Less dosimetry and less field maneuvers

In older informtion systems each tagout placed on an equipment generates a tag. As a result, several tagouts on the same equipment generate several tags to be placed on it.

US utilities have now, in a large majority, adopted a different organization; only one tag is hung, even if many tagouts impact the same equipment. The first tagout generates the placement of the tag, the last one its removal.

The decrease of tagouts to be hanged or removed limits field operator's radiation exposure and save operation time.

In practice, each tag has a chronological number, automatically generated by the tagout software that manages relationships between the tagouts and the tags.

Tag sharing allows easy changes of tagouts borders, with a second effect of limiting field maneuvers. For example, the US eSOMS software allows to copy and paste tagouts with tag management. Tagouts borders modifications often use this mechanism during restart.

4.3 The use of 2D technologies

3D technology can also improve outage performance. Here are some examples.

3D training modules can help contractors to better understand work situations. Enhanced reality could bring useful additional information during work performance.

During outage, some plant areas, such as the reactor and the auxiliary buildings are often crowded. In some cases, moving equipments, spare parts, containers, *etc.* becomes a nightmare.

Based on 3D models, it is now possible to manage scenes of these buildings. And by coupling these 3D scenes with the outage schedule, it is possible to verify the feasibility of easy handling during all the outage duration.

Severe radiation exposures due to zoning mistakes are a major risk. 3D technologies (or enhanced 2D) should also allow verifying the complete zoning of radio shoots.

The technological barriers consist in recreating 3D models of existing buildings at low cost from laser shoots. An integration work of this modules into the information system is also needed.

4.4 Quality assurance of the IS system

The proposed optimizations for tagouts and alignments impose up to date and validated information. Operations must be confident that the IS information is reflecting the plant components state.

This means that traceability mechanisms, electronic signatures must be implemented, in order to ensure the position of unmonitored equipments or to understand the cause of wrong position in case of mismatch.

This implies a rigorous operation where any unregistered information (for example a change of valve position) is prohibited.

It is possible to go further in data quality assurance, in comparing IS data to process data, provided by the I&C system and/or the monitoring systems. This control can be automatically performed or manually carried out by comparison of IS and process data on the same 2D drawing, for example during pre-job briefings.

Beyond the controls, the mix of IS and process data can help operations for their rounds, periodic tests and pre-job activities.

4.5 The need of an integrated mobile solution

Field operators are often the poor relation, with only a pen and a piece of paper in hand (in complement of badges, keys, security equipments, *etc.*).

However, during an outage, their activity may be positioned on the critical path, without any modern mean to communicate data with the rest of the operations.

At EDF, human factor studies have shown that field operators routinely perform several activities in parallel, such as alignments and observations, due to requests from main control room operators.

We have established their need to be able, on an unique PDA, to manage alignment procedures, tagouts, rounds, observations, periodic tests and to access the IS in order to reed P&ID, access I&C or IS data, access user manuals or pedagogic documents, *etc.*

As for the IS, each equipment data can be utilized and updated by different modules (rounds, tagouts, *etc.*). This implies a dedicated architecture, implemented into the PDA in order to fulfill the requirements of data exchange between modules. A database must be implemented into the device.

The software architecture must integrate generic modules, reusable by other modules, such as QR-Code recognition, pictures, video recording, audio recording and login / logout.

The gains are potentially important:

- Fast data update thanks to direct data upload from field,
- Parallel execution of procedures by field operators,
- Equipment recognition to limit equipment errors,
- Electronic signature.

For mobile solutions, a field of research is the implementation of multi-activities architectures, allowing vendors to propose new modules that can be implemented and securely linked to the IS system.

5 Conclusion

The improvement of outage operation requires a number of research items on the interactions between the operation activities and maintenance, with a methodological perspective and proposals concerning the Information System.

On the methodological point of view, a clever plant systems modeling may allow representing the needed characteristics in order to optimize tagouts, alignment procedures and the schedule.

Tools must be taken into account for new tagout practices such as tags sharing. It is possible to take advantage of 2D drawings integrated into the information system in order to improve the data controls and to visualize operation activities. An integrated set of mobile applications should allow field operators to join the information system for a better and safer performance.

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