Is it possible to simulate an outage with the point of view of operation activities?

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Abstract: This paper discusses on the feasibility of automatically verifying an outage schedule based on IT information. The discussion starts from how to model outage concepts to request for different sources of data such as the schedule of tagout, the tagout and lineup database, the CAD drawings (mechanical, P&ID and electrical ones), *etc.*, and then proceed to the suggestions on the basis of an algorithm and tools that can assist the outage teams in verifying the schedule. The basic idea is to reuse existing software such as lineups visualization tools, P&ID and electrical drawings visualization tools, and impact propagation tools. Also a suggestion is made as to the new methodological proposals that can simplify outages preparation.
Keyword: plant operation; outage schedule; tagouts and lineups; maintenance activities

1 Introduction

Today, the control of quality and duration of outages becomes one of the major objectives of nuclear utilities. The aging of plants and their life extension up to sixty years (or more) implies the increase of maintenance works that require more activities during outages. The challenge is essentially to contain duration of outages for economical reasons with the high quality of maintenance.

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

Usually, the preparation of a specific outage starts six months before the D day, and simulations of all activities are manually performed by teams that prepare the outage (in charge of the schedule, in charge of tagouts, in charge of maintenance work, *etc.*). In average, overall simulations are performed every month (according to utilities).

These manual overall simulations can be run during several days, with the difficulty of tracking all the blocking situations such as a tagout that prevents a lineup. Data are usually manually extracted from different sources of data and then consolidated with each other.

This paper discusses on the feasibility of automatically verifying an outage schedule, before or during the outage, with faster time and better accuracy than at present.

It briefly describes an outage and the proposed concepts manipulated by its actors, methodological proposals, algorithms and tools that could be developed.

2 What is an outage?

2.1. IAEA definition [1]

According to the definition by IAEA, various terminologies of outage activities are defined as the following ways:

(1) Plant outages are shutdowns, in which various 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.

(2) Outage management is a complex task which involves in respect of the plant policy, the co-ordination of available resources, safety,

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regulatory and technical requirements and, all activities and work before and during the outage.

(3) 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.

(4) 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.

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. The respect of outages duration is an important criterion of assessment of utilities performance.

The outage duration of a pressurized water reactor (PWR) is usually between 7 and 60 days depending on the company, the type of reactor, and the constraints of national nuclear safety rules. Four types of outages can be distinguished by [2] such as:

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

The evaluation method of each duration time of those (a) to (d) may vary in country or operator. Those figures should be understood as the indicators or as the way to assess the evolution of sites performance.

For PWR, the above (a) of 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.*

The authors of this paper distinguish three main categories of schedules: long-term, medium and short term.

The long-term schedule should be established for 5 to 10 years. It should consider equipment aging, large maintenance activities, fuel optimization, and plant availability to the electric grid. It should estimate outages durations and budgets.

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

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

Companies who have large reactors fleets such as EDF should 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.

3. How to prepare for an outage?

3.1 Manipulation concept

3.1.1 Schedule slots

An outage schedule is composed of many time slots as shown in Fig.1. Each slot can cover one or several plant modes (cold or hot shutdown for example) and is specific to one plant circuit (boron water for example).

The authors of this paper distinguish four main types of slots:

(1) Operation slot which is dedicated to operational activities on the plant circuits such as restart or change of configuration,
(2) Unavailability of train A, for maintenance activities on train A, and
(3) Unavailability of train B, for maintenance activities on train B, and
(4) Unavailability of all trains (A + B in general).

3.1.2 Plant circuit

A plant circuit represents an elementary system or a subsystem. It can be defined as a set of components combined to achieve a plant function. The circuits of the plant can be visualized on P&ID drawings by highlighting their equipment.

3.1.3 Tasks

Tasks are the main elements of the schedule. They cover the main work to perform on a circuit, on one time slot. They are comprised by dates, resources and constraints.

3.1.4. Activities

The details of activities are the content of the tasks. They are the basic components of the schedule. For example, a master tagout will be described as a task. The elementary tagouts linked “under” the master tagout are the single tagouts, the fill-in procedures, the venting procedures, work requests, alignment procedures, *etc.*

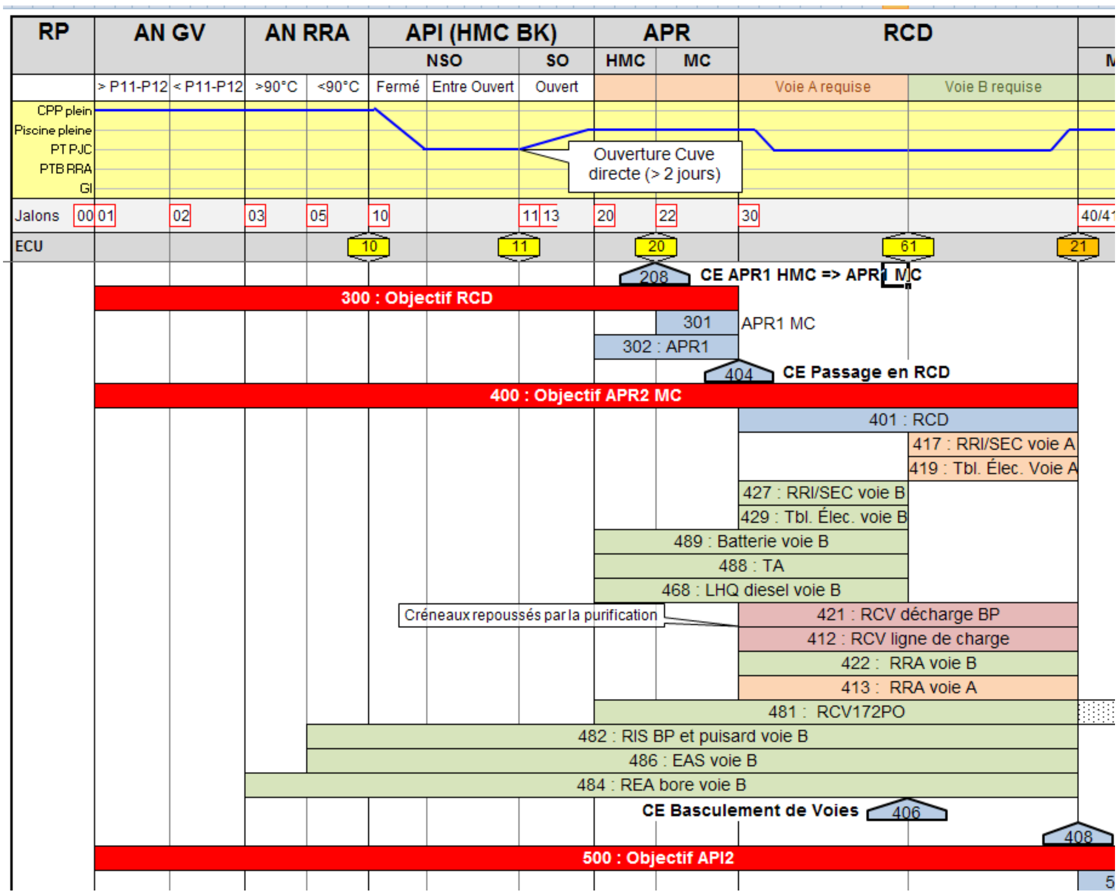

Fig. 1 Example of slots.

3.1.5. The nuclear Technical Specifications

The "Tech. Specs" can be described by tables, where columns represent the plant modes, rows the functional objectives covered by plant circuits, while cells the requirement corresponding to a schedule slot or set of slots. Clearly, the spine of the schedule relies on the Tech. Specs requirements.

3.2 Main activities of outage preparation

3.2.1. Feasibility of the strategy according to the Tech. Specs.

The first phase of the outage preparation will analyze the feasibility of the strategy according to the Tech Specs. It consists in verifying that all the slots of unavailability (for train A or Train B) of the different circuits comply with the Tech Specs.

Sometimes, the Tech Specs require more than one system or circuit and authorize different configurations. These alternatives must be studied and "projected" on the different circuits.

At this stage of focusing on the overall strategy, water movements are also checked, for example, for verifying whether or not drains and fillings will be feasible.

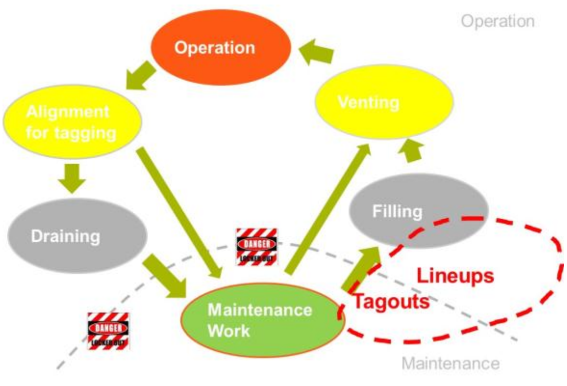

Fig.2 Activities between operation and maintenance.

3.2.2. Grouping maintenance work into the slots of the schedule

The next phase consists in organizing the maintenance work in the different available slots. Personnel in charge of the preparation should verify the following items:

(1) Compatibly of duration between the slots and the activities to perform,
(2) Assignment of tasks / activities on the circuits, without concurrent work,
(3) Human and material resources,
(4) Impact on wastes (nuclear effluents),
(5) Integration of previous outages feedback,
(6) Good timing between shutdown, tag-in, drainage, maintenance work, tagout, alignment, *etc.*

3.2.3. Tagouts definition

Tagouts consist in securing a work area as illustrated in Fig.3 Practically, electrical power is removed, pressurized air is also removed and all fluids are blocked by "on/off" valves.

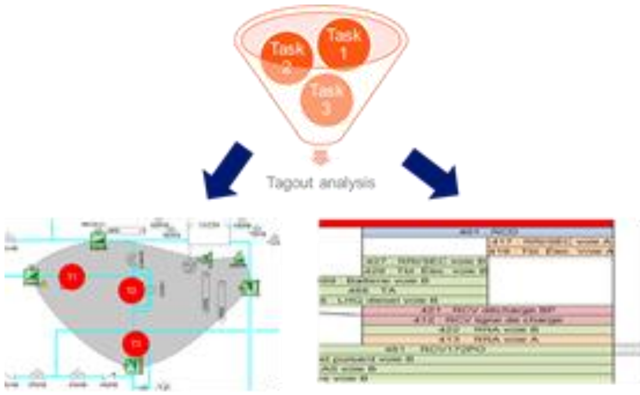

Fig.3 Tagouts are based on the analysis of maintenance tasks to perform.

Tagouts are defined in accordance with the maintenance tasks to perform on a circuit. They are also driven by slots constraints, capability of filling the circuits, and restarting them quickly. Defining huge areas of tagouts allows to make grouping a large set of tasks, despite of the capability of reusing parts of the circuit for operation, while defining small areas of tagouts allows high maneuverability of the circuits, despite intense work of tag-in-tagout, alignment, drain, *etc.*

A good tagout definition is a balance between large and small areas of work. Today, master tagouts have been established, and they are used as models.

The diagram as shown in Fig. 4 summarizes the main phases of outages preparation.

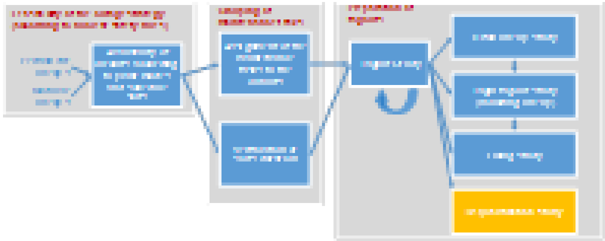

Fig.4 The main phases of outages preparation

4 Methodological proposals

4.1 Removing tagouts and aligning the equipment in the same task

Tagouts design does not only consist in making field work secure in accordance with functionality, safety, and schedule constraints. The tagouts removal has to be taken into account, if you want to optimize the restart of plant circuits.

The classical approach of tagout design consists in separating tagout removal and alignment activities. In practice, a first field operator removes tagout tags and chains that will secure work areas, and places each equipment in its default position, according to the operation management database. The way of target positioning is generally conservative. When all maintenance work is finished (this can be several days after the first tagout removal), a second field operator then performs the alignment procedure to prepare for the circuit to be filled in or restarted.

A more efficient approach consists in tagging-out each equipment in its standard alignment position (or 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 by using easy to use functional models which will allow taggers (or operation managers) optimizing these joint activities.

The potential gains of the tagout removal and its associated alignments strategy are very important. The classical approach tends to postpone alignments as late as possible, when all tagouts are removed. The optimized approach will limit this postponement more effectively by removing alignments from the critical path of the schedule. Such a method has been implemented on both Penly and Nogent 1300 MWP NPPs of the EDF with very good results.

A specific animated flowchart as shown in Fig.5 has been developed, in order to show, in real time, the automatic alignment of the circuits when tagouts are removed, where each flowchart page is associated with one plant mode.

Fig.5 Animated lineups flowchart

4.2 Using different views of the same circuit (a set of equipment)

As shown in Fig.6, the analysis of different definitions such as the definition of the functions in the Tech Specs, the definition of outage circuits, the content of the master tagouts, the content of the standard lineups, *etc.* will show that they all rely on the same set of equipment in the same structure. In other words, those different operation concepts can be seen as different views of the same circuit.
By using the IT system, it becomes possible to link different operating concepts with the equipment they are built on.

Thus, the engineering of an outage could consist in evaluating the impact of work to perform on a set of equipment and to calculate which circuit is affected. The impacted circuits can then be analyzed in terms of slots, lineups, tagouts, drains, safety functions, *etc.*

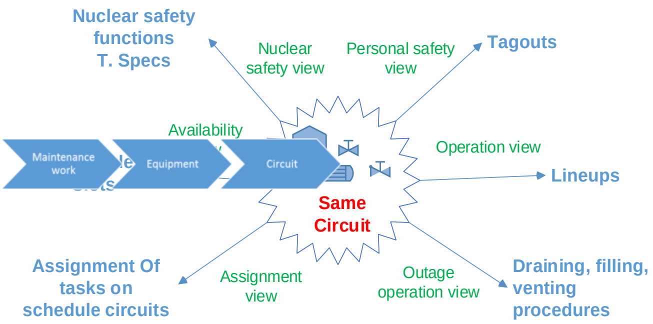

Fig.6 The different views of the same circuit.

4.3 Implementing integrated packages

As described in chapter 3.2.3, the tagout preparation consists in finding a good balance between tagouts, lineups, drains, ventings and requalification procedures.

A new proposal here is how to create integrated packages based on standardized circuits that can be reused for each outage on which feedback can be integrated.

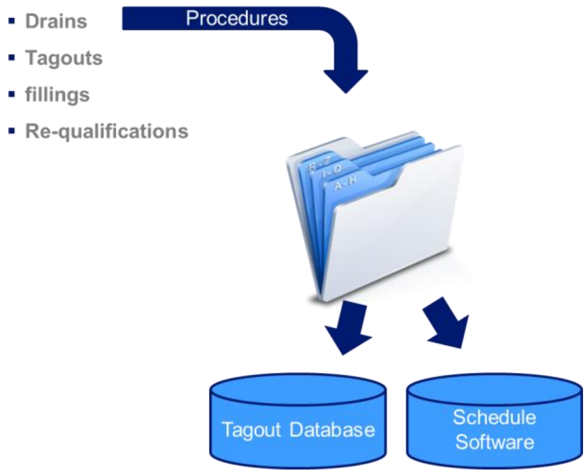

Fig.7 Implementing work packages into the plant database.

These packages must include the operation procedures and standardized tasks. They have to be split into the IT system in coherent way, for example, into the tagout database and into the schedule database as shown in Fig.7.

4.4. Evaluating the accessibility of equipment

An important part of an outage preparation is devoted to the identification of potential "aggressors" of each schedule task.
Accessibility of equipment means the capacity of operators to perform their activities on field. Aggressors can block activities. They can be gamma radiography controls, red or orange radiological zones, hydraulic test zones, scaffolds, tagged equipment, or painting areas.

To set the physical accessibility of equipment, it is necessary to know the following items:

(1) The list of equipment of each room,
(2) The rooms in which the tasks will be carried out, and
(3) The nature of the intervention.

4.5. Evaluating the availability of equipment

Functional unavailability of an equipment depends on its overall condition (full thermal insulation in place, cleanliness), physical integrity (manual remote control operable), the availability of supplies necessary for its operation (electricity, air), the availability of its I&C.

4.6. Evaluating the filling of circuit

It is important to know if a circuit is full or empty, and if it has to be drained or filled, especially during the preparation in to estimate the impact on integrated packages and to evaluate the volumes of fluids to transfer.

It is possible to tag a circuit as full or empty according to drain procedures or to vent or drain valves that have been maneuvered in any operation procedure / task.

Today, 2D CAD tools allow to show graphically the limits of a tagout, and the color of the pipes can indicate their state of filling.

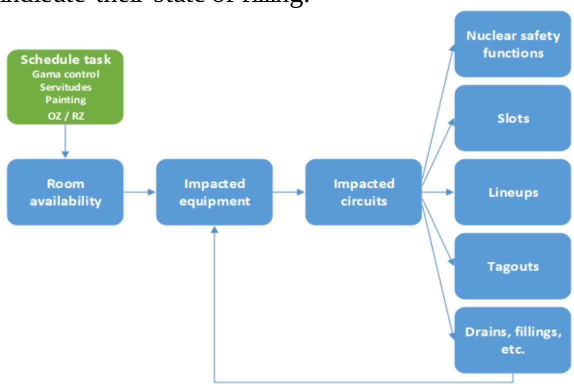

Fig.8 Outage preparation activities that drive end user's questions.

5 Typical questions to answer

Before modelling the concepts to integrate into the simulation system, the authors of this paper have prepared for the end users about the typical questions to answer during the outage preparation. The number of questions is huge but to summarize the kinds questions given, they mainly deal with room availability, equipment involved, equipment availability and accessibility, circuit availability, distribution boards availability, date of tagouts, detailed information on each maintenance or operation activity (content, schedule, date of maintenance work and operation activities), date of requalification, date of work order delivery, *etc*.

The schematic diagram in Fig.8 shows the process of the schedule validation that drives all the questions mentioned above.

6 First proposal class diagram of the domain

The diagram as shown in Fig.9 is the first proposal of organization of the concepts used to prepare an outage, in the form of an UML class diagram.

This diagram is not exhaustive yet. It aims to identify key information that may be implemented into a simulation database. It has to be refined and completed to produce the conceptual data model underlying the simulation.

Each schedule task impacts a circuit, covers equipment and can generate an aggressor which itself impacts other equipment and circuits.

An aggressor may be defined as the state of availability or accessibility of an equipment, discordant for multiple tasks at the same time.

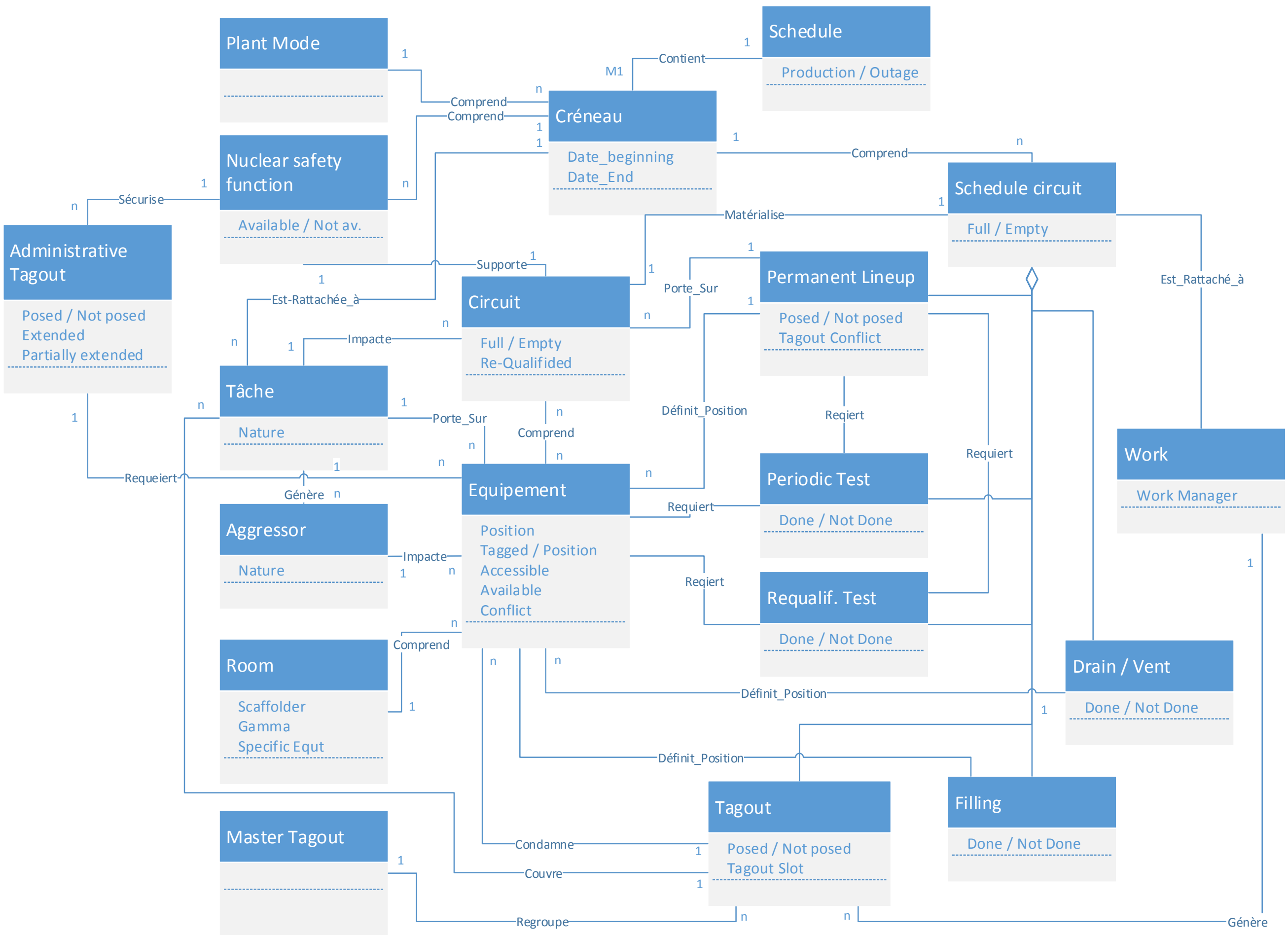

Fig.9 First proposal of class diagram.

7 Principals of the algorithm

7.1. Tagout preparation support

For each new activity (work request or new task), the first analysis will check if there is a need of tagouts to secure the work on field.

The second level of analysis will be to verify that the work can be covered by a master tagout with its associated tagout package.

The third level of analysis will focus on tagouts modifications. If the activity impacts equipment out of the secured area or on the tagout “border”, it will be necessary to adjust the reference package. For this, the algorithm will be proposed tagout extensions based on mechanical links in P&ID drawings on the analysis of nearby other master tagouts and on a feasibility analysis of drains and fillings.

7.2. Slots verification

The objective is to detect if the activities of the schedule are correctly positioned with their associated tagouts, in the unavailability slots.

For each activity, it is necessary to develop the following algorithms that can
-Identify the associated tagouts,
-Identify the impact on permanent lineups (which serve as a reference to the "circuits"), and
-Verify the functional impact on slots associated with the permanent lineups as are discussed in chapter 4.1.2.

At the present stage of the algorithm development it is possible to check the proper timing of activities in slots but not their contents. The future release of the algorithm could challenge the duration of slots.

7.3. Schedule activities verification

7.3.1 Master tagouts verification

The algorithm to be developed will perform those functions that can

- Identify incomplete master tagouts for which a task of pose, maintenance an depose is missing,
- Verify that the logical and chronological sequence (drain, tagout, maintenance work, lineup, filling) is properly conducted,
- Identify the master tagouts for which no work is planned, and
- Check their positioning in the right slot.

7.3.2 Tagouts conflicts verification

Sometimes, the same equipment can be involved in more than one tagout. Different cases of conflicts will be tested, for example, when this equipment is at the border of two tagouts, when the maintenance equipment has to be performed, and when it is also involved into a lineup, *etc*.

7.3.3 Equipment accessibility verification

The algorithm to be developed will check, for each slot, any task that limits access to equipment by the following aspects:

- gamma radiography controls,
- red or orange radiological zones,
- hydraulic test zones,
- scaffolds,
- tagged equipment, and
- painting areas.

7.3.4 Equipment availability verification

In the first version of the algorithm, it will detect the following items:

- The absence of tagout,
- The presence of electric power sources and control means (125V),
- The presence of auxiliary sources (compressed air), and
- Physical integrity (if it can be calculate.)

The related calculation is performed task by task, and from or impacted standard circuits.

7.3.5 Draining and filling verification

The calculation of the filling state (full / empty) of the circuits will rely on:

- Positions of the drains and vents, and
- Procedures already performed.

It should allow the first analysis of feasibility or filling.

7.3.6 Feasibility verification of requalification tests

The feasibility of requalification tests is calculated from the availability of all equipment used in the requalification procedure including the mentioned supplementary means.

7.4. Resources availability verification

A future release will integrate the availability of the associated resources (human, means).

8 IT architecture proposals

The proposed IT architecture should rely on the following four levels.

The first level comprises the existing databases, such as the schedule database, the tagout / lineups database, the radio-protection database, *etc*.

The second level consists in a repository of aggregated data that requests periodically the first level. This architecture allows to limit access to the existing IT systems (for maintaining the guaranty of performances) and facilitates access to any concurrent simulation tool.

The third level is devoted to the treatment that can implement the algorithm. The authors of this paper are designing it so that it can make it as flexible as possible in order to easily add new controls.

The last level will reuse the existing IT tools such as animated P&ID, animated lineups flowcharts, simplified Gantt diagrams, and lists.

9 Concluding remarks - the first mock-up in 2016?

The proposal of an outage simulation tool presented in this paper has been under discussion of development, where the potential gains have to be estimated, although they seem to be significant in term of the reduction of the duration of plant outage. The authors of this paper have a good hope to conduct on experimenting the presented proposals in the coming year of 2016.

Acknowledgement

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References

[1] IAEA – Nuclear power plant outage optimization strategy – IAEA Tecdoc-1315 – October 2002.

[2] IAEA Nuclear Security Series No. 17 - Computer Security at Nuclear Facilities, Vienna, 2011.

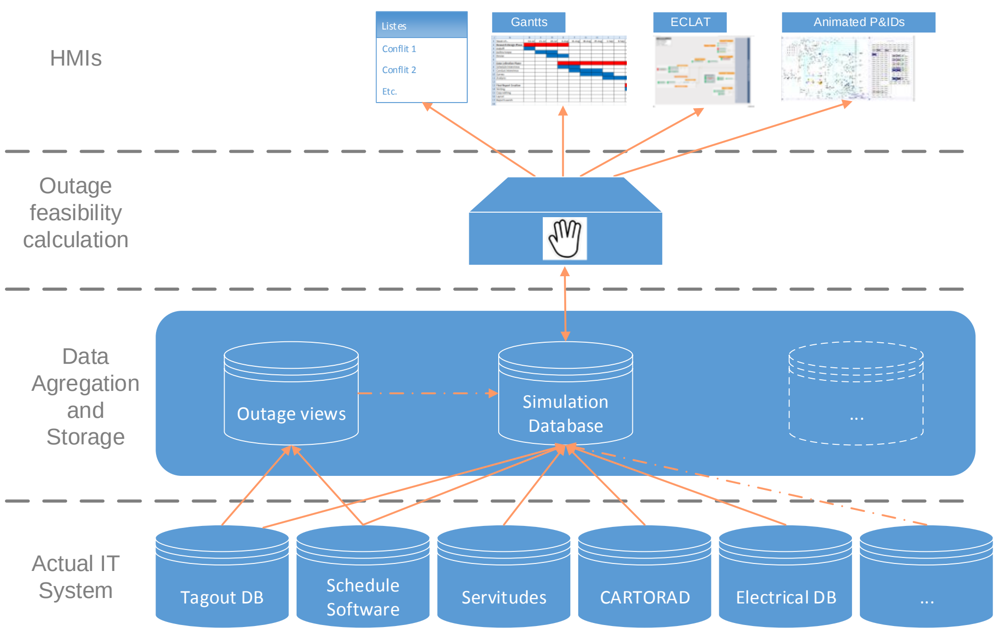

Fig.10 First IT architecture proposal.