ROADEF Challenge RTE: Grid operation-based outage maintenance planning

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1 Introduction

Réseau de Transport d'Électricité (Electricity Transmission Network), usually known as RTE, is the electricity transmission system operator of France. It is responsible for the operation, maintenance and development of the French high-voltage transmission system, which with approximately 100,000 kilometres, is the largest of Europe.

Guaranteeing both electricity delivery and supply is one of the most important mission of a transmission system operator such as RTE. But such an objective can be carried out only if the grid is correctly maintained. In particular, some maintenance operations on the overhead power lines are live-line works while others require to shut the power down. When this happens, both electricity delivery and supply have to be guaranteed, meaning that maintenance operations have to be planned carefully. When there is not any maintenance operation, the network is resilient enough to endure an unexpected contingency. However, if several breakdowns occur, the grid might face major blackouts. In this context, planned outages due to maintenance work have to be scheduled with extreme caution.

Alongside with this very operational aspect, anticipating what maintenance plannings will look like in the years to come helps in designing efficient network design strategies. If future maintenance operations appear to be unfeasible due to an aging network, new generation and consumption plans or even the energy transition, RTE has to anticipate these changes and adapt its current maintenance practices and design strategies as of today. In particular, the increasing integration of renewable energies in the electricity network leads to important changes in its operation, resulting in new grid constraints. Maintenance interventions requiring a planned outage may not be feasible with a renewable-driven grid operation.

Figure 1: A maintenance team performing an intervention on overhead power lines

To tackle this issue, RTE decided to implement a three-step approach. First, risk values corresponding to different future scenarios are computed. Second, these computed values are included in several optimisation approaches in order to find a good schedule. Eventually, a third step validates the obtained planning.

This challenge focuses on the second step of this approach: given the risk values, the goal is to find an optimal planning regarding a risk-based objective. Moreover, this planning must be consistent with all job-related restrictions such as resource constraints.

2 Inputs and notations

This section describes the problem settings, inputs and notations.

2.1 Planning horizon

The schedule has to be established over a one-year period. Nevertheless, the time step of the schedule can either be a day or a week, depending on the needed precision.

Formally, the number of time steps is denoted by $T \in \mathbb{N}$ and the discrete time horizon is $H = \{1, ..., T\}$. For instance $T = 365$ for a day by day schedule and $T = 53$ for a week by week one.

2.2 Resources

To carry out the different tasks (or interventions), some workforce is necessary, and is split in teams (or resources) with different sizes. Each team has different specific skills and can potentially be required on any intervention. C denotes the set of resources.

Maximum resources (u_t^c) The available resources are always limited and therefore there is a maximum value for each resource that cannot be exceeded. Moreover, the available workforce varies over time. So for every resource $c \in C$ and every time step $t \in H$, u_t^c denotes the upper limit that cannot be exceeded.

Minimum resources (l_t^c) For operational reasons, there is also a lower bound on the resources consumption. In order to prevent workforce from not being used at all, there exists thresholds indicating the minimum required value of consumed resources. Such a threshold is denoted by l_t^c and represents the minimum value for resource $c \in C$ at time $t \in H$.

2.3 Interventions

Interventions are tasks that have to be planned in the coming year. They are not equal in terms of duration nor in terms of resource requirement. The set of interventions is denoted by I.

Time Duration ($\Delta_{i,t}$) Because of days off (weekends, public holidays), the duration of a given intervention is not fixed in time, and depends on when it starts. Therefore, $\Delta_{i,t} \in \mathbb{N}$ denotes the actual duration of intervention $i \in I$ if it starts at time $t \in H$.

Resource workload ($r_{i,t'}^{c,t}$) Every intervention requires specific skills to be correctly carried out. Consequently there is a resource workload which depends on the considered resource but also on time. This is because the duration of an intervention depends on time, but also because more resources are generally needed at the beginning and the end of the intervention for specific purposes (bringing and removing equipment, finishing touches). Therefore, the workload requiered for resource $c \in C$ at time $t \in H$ by intervention $i \in I$ if i begins at time $t' \in H$ is denoted by $r_{i,t'}^{c,t} \in \mathbb{R}^+$.

We have a tradeoff of interest.

2.4 Risk

When an intervention is being performed, the considered lines have to be disconnected, causing the electricity network to be weakened at this time. This implies a certain risk for RTE, which is highly linked to the grid operation: if another close site is to break down (due to extreme weather for example), the network may not be able to handle correctly the electricity demand. Even if such events have an extreme low probability to occur, they have to be taken into account in the schedule. In order to financially quantify these risks, RTE already conducted simulations for different scenarios for different time steps. Let S_t be the set of scenarios at time $t \in H$. They correspond to a certain grid operation, and therefore do not depend on interventions.

Risk $(risk_{i,t'}^{s,t})$ The risk value itself, however, depends on the considered intervention. It also depends on time, as it is often much less risky to perform interventions in summer (when the electricity network is not much solicited) rather than in winter. So the risk value (in euros) is denoted by $risk_{i,t'}^{s,t} \in \mathbb{R}$ for time period $t \in H$, scenario $s \in S_t$ and intervention $i \in I$ when i starts at time $t' \in H$.

The risk under the high scenario for 12/6 if you start intervention 1 on 12/8.

3 Solution

Scenario only seems to matter with respect to the risk and risk only shows up in the objective function.

A schedule (or solution) is a list L of pairs $(i, t) \in I \times H$, where t is the starting time of intervention i. Let $start_i$ denotes the starting time of intervention $i \in I$, and $I_t \subseteq I$ the set of interventions in process at time $t \in H$.

A planning is said **feasible** if additionally all constraints presented below hold.

These are the decision variables and seems to be confirmed by the other document which shows you the solution format ingested by python.

4 Constraints

4.1 Schedule constraints

4.1.1 Non-preemptive scheduling

Interventions have to start at the beginning of a period. Moreover, as interventions require to shut down some lines of the electricity network, once an intervention starts, it cannot be interrupted (except for the non-worked days). More precisely, if intervention $i \in I$ starts at time $t \in H$, then it has to end at $t + \Delta_{i,t}$.

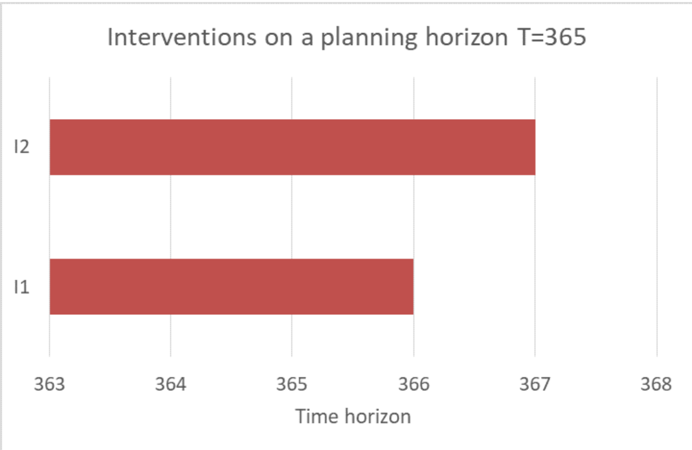
4.1.2 Interventions are scheduled once

All interventions have to be executed.

Covering constraint.

4.1.3 No work left

All interventions must be completed no later than the end of the horizon. If intervention $i \in I$ starts at time $t \in H$, then $t + \Delta_{i,t} \leq T + 1$. In Figure 2, I_2 is not correctly scheduled.



Almost like a time window constraint. This could also eliminate useless decision variables.

Figure 2: Example of an intervention terminating before the end of the horizon (I_1) and after (I_2) when $T = 365$

4.2 Resource constraints

Given a solution, the workload due to intervention i for resource c at time t is $r^{c,t}_{i,start_i}$.

Then the total resource workload for c at time t is $r^{c,t} = \sum_{i \in I_t} r^{c,t}_{i,start_i}$.

The needed resources cannot exceed the resources capacity but have to be at least equal to the minimum workload, and hence the resource constraints are:

$$l^c_t \leq r_{tot}(c,t) \leq u^c_t \quad \forall c \in C, t \in H \tag{1}$$

4.3 Disjonctive constraints

Some lines where maintenance operations have to be performed are sometimes too close to each other to carry out the corresponding interventions at the same time. This would weaken the network too much, and would be dramatic in case another close line is disconnected during the interventions. While the risk values are computed independently for each intervention, exclusions take into account dependencies between them. Moreover, these exclusions also vary in time. For instance in summer, it is much less risky to weaken the network because the overall demand is much less than in winter, and so the network can handle the disconnection of another close line.

The set of exclusions is denoted by Exc. It is a set of triplets (i_1, i_2, t) where $i_1, i_2 \in I$ and $t \in H$. The exclusion constraints can formally be written as:

$$i_1 \in I_t \Rightarrow i_2 \notin I_t \quad \forall (i_1, i_2, t) \in Exc \tag{2}$$

This is whether the intervention is in progress, not just about whether they start at the same time.

5 Objective

The score evaluation of a feasible planning only depends on the risk distribution. Firstly, only the mean risk was taken into consideration (over time and scenarios). In addition of being intuitive, an average risk sums up an entire planning in a single value expressed as a monetary cost. If an arbitration had to be made in a few seconds between two plannings, the mean risk would definitely be the indicator to look at.

But if the scheduler had several minutes, he or she would want to know more than just an average, and would look at the distribution over the year: is the risk higher in summer, when a lot of interventions are generally carried out but the grid is less solicited? Or is it in winter, when a few - but risky - interventions have to be performed? Then a decision would be made.

Eventually, if the scheduler had hours, he or she would want to know even more, by diving precisely into each period: for this particular week, what is possibly the worst scenario? The average one? Is it likely that the financial costs go higher than expected?

RTE conducted studies driven by the current scheduling methods to find which indicator best represents all these interventions-related nuances. The overall mean cost appeared quickly as an excellent candidate, but it was not enough for taking into account specific behaviours of the risk distribution. In the end, RTE found another indicator, when in combination with the mean cost, is able to capture some of the above described job realities.

Therefore, one can now quantify the quality of a given planning by looking at two criteria: the mean cost and the expected excess. Both of them are risk-related and are quantified in euros.

As mentioned before, the first one is simply the mean risk over the year. With everything else being equal, the goal is to reach the lowest possible value. In addition to this first metric, planning quality is also determined by looking at the expected excess. It helps quantifying the cost variability by controlling a certain quantile of the distributions.

5.1 Mean cost

Given a solution, the cumulative planning risk at $t \in H$ for a scenario $s \in S_t$, denoted by $risk^{s,t}$, is the sum of risk in scenario s over the in-process interventions at t : $risk^{s,t} = \sum_{i \in I_t} risk^{s,t}_{i,start_i}$. This is a first order approximation, as the risk values are assumed to be independent.

Notice that this is based on what is active, not just what was started. You keep incurring risk while the intervention is in play.

For a given time step, what is the risk?

The mean cumulative planning risk at $t \in H$ is $\overline{risk^t} = \frac{1}{|S_t|} \sum_{s \in S_t} risk^{s,t}$.

Then the overall planning risk (or mean cost) is

$$obj_1 = \frac{1}{T} \sum_{t \in H} \overline{risk^t} \tag{3}$$

The mean cost is then an average in two ways: regarding the scenarios and regarding the time horizon.

5.2 Expected excess

As mentioned before, the planning quality also takes into account the cost variability. Indeed, by computing the mean risk over all scenarios, some information is lost. In particular, critical scenarios inducing extremely high costs may not be captured enough by the mean. To prevent this kind of events from happening, a metric exists to quantify the variability of the scenarios.

5.2.1 Reminder

Let $E \subset \mathbb{R}$ be a non-empty finite set and $\tau \in]0,1]$. The τ quantile of E, denoted $Q_\tau(E)$ is:

$$Q_\tau(E) = min\{q \in \mathbb{R} : \exists X \subseteq E : |X| \geq \tau \times |E| \text{ and } \forall x \in X, x \leq q\} \tag{4}$$

5.2.2 Definition

The expected excess indicator relies on the τ quantile values. For every time period t, we define the quantile value Q_τ^t as follow :

Can we approximate this? Do we have a transformation for maximization? Do we have tools for dealing with quantiles? Would dynamic programming be effective here? Was there something ugly and nonlinear in the reassignment problems and how did people

Can you have multiple interventions at the same time?

$$Q_\tau^t = Q_\tau(\{risk^{s,t}\}_{s \in S_t}) \tag{5}$$

The expected excess at time $t \in H$ is then defined as:

$$Excess_\tau(t) = \max(0, Q_\tau^t - risk^t) \tag{6}$$

Figures 3 and 4 show an illustration of the variability cost for $\tau = 0.9$. Let I_1, I_2 and I_3 be three interventions planned at time $t = 1$. Their individual risk values over 10 scenarios are as follows:

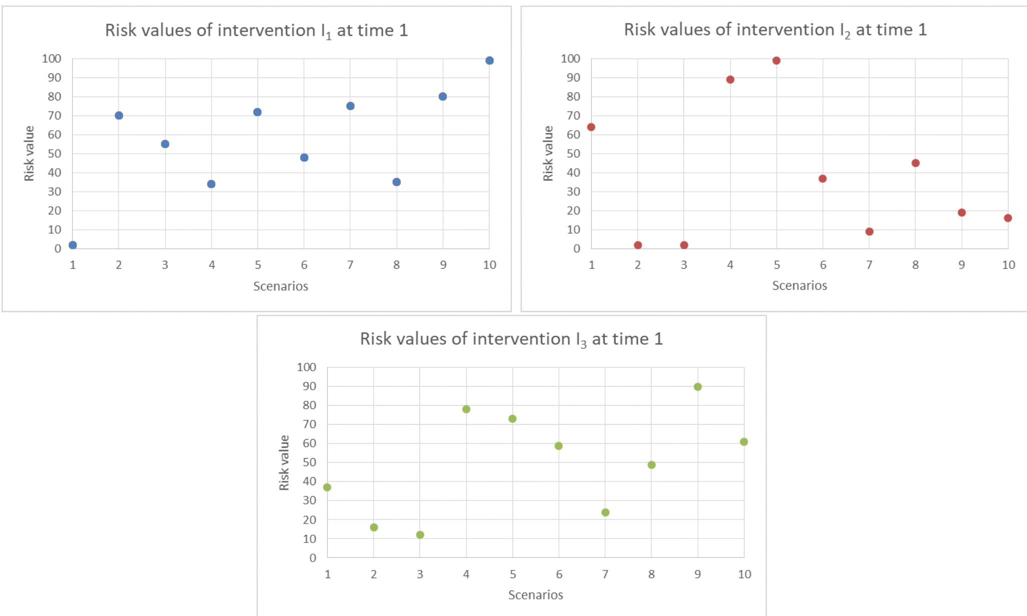
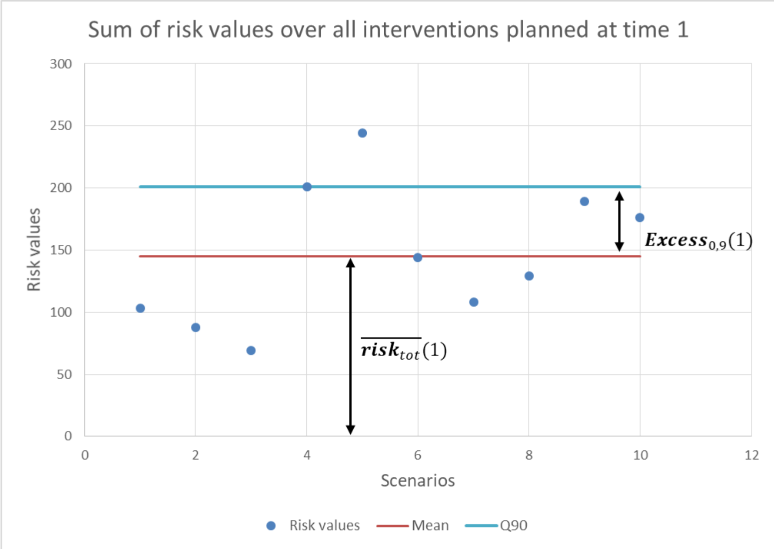


Figure 3: Risk values for 10 scenarios

Then one may compute the mean risk, the $Q_{0.9}$ quantile and then the expected excess.



Excess is the didstance between the mean and some quantile

Figure 4: Sum of risk values for 10 scenarios

The expected excess of a planning is:

$$obj_2(\tau) = \frac{1}{T} \sum_{t \in H} Excess_\tau(t) \tag{7}$$

5.3 Planning ranking

The two metrics described above are in euros. However, they cannot necessarily be compared directly, as they depend on risk aversion (or risk policies). That is why a scaling factor $\alpha \in [0, 1]$ is needed. Then the final score of a planning is :

$$obj(\tau) = \alpha \times obj_1 + (1 - \alpha) \times obj_2(\tau) \tag{8}$$

The goal is to find a feasible planning with the lowest possible score regarding this objective.