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A new approach to asset investment optimization through simulation-based predictive analytics

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1. Introduction

Electrical transmission and distribution utilities manage increasingly complex networks composed of an ageing asset base under significant financial pressures because of demanding tariff controls. Coupled with uncertainty around future energy scenarios and the challenges of implementing successful maintenance and renewal strategies, network operators across Europe are seeking to better understand the impact of investment and maintenance decisions on their businesses. In the context of a rapidly approaching investment wall, then, the demand for effective asset investment planning is more critical than ever.

Traditional investment planning methods are based on extended intuition, data analytics, or simple silo-centric simulations. These methods, however, cannot handle the increasing complexity and expectations of the modern utility's operating environment. Indeed, research has demonstrated that in complex systems consisting of many interacting agents and composed of heterogeneous parts which are strongly coupled, the emergent behavior at the scale of the whole system cannot be inferred from the behavior of its sub-systems taken separately [1]. As an example, to accurately predict consequence of equipment failures, it is mandatory to represent the interdependencies between assets that play a key role for equipment redundancies. Consequently, the only means to understand and optimize decision making in such systems is through a whole-of-enterprise modelling approach.

Responding to these market needs, The CoSMo Company has developed an original model-driven approach for the development of applications for the study of complex systems.[1] This new approach has been tried and tested in the context of strategic asset investment optimization application for electrical transmission and distribution utilities. This work, conducted in partnership with one of the largest European TSOs, has led to the development of an application for Asset Investment Optimization (AIO).

This paper is presented in four main parts: i) a description to CoSMo approach for the development of applications and how it is relevant to face T&D utilities challenges; ii) a presentation of CoSMo asset investment planning model; iii) an explanation about how it can be used to optimize asset investment planning, and iv) an illustration of what benefits did early adopters observe.

[1] See www.thecosmocompany.com

2. CoSMo approach for Investment planning in utilities network

2.1 CoSMo for Complex System Modeling

Complex systems modelling is particularly relevant to describe and study real-life systems that present several of the following characteristics:

- they are composed of different heterogeneous parts;
- they include hierarchies, i.e. some parts of the system are composed of subsystems, which are themselves composed of subsystems, etc.;
- they are made of different parts coupled together, i.e. the behavior of one part depends on the condition of the other parts;
- they are made of different parts, which represent and/or evolve at different dimensions (space and time) scales.

The study of such models, whose description cannot be simplified since their behavior precisely emerges from the interaction between its different parts, requires numerical simulation. Indeed, numerical simulation enables to represent the evolution of the system step-by-step, and thus to study transitory trajectories, as well as identify multi-stationary states, or even chaotic behavior, in complex cases where analytical mathematical might be insufficient to provide all these answers [2].

What The CoSMo Company offers is an original methodology for complex system modelling, called Model Driven Simulation, a modelling language for the description and conception of complex system conceptual models, and relevant tools to automatically generate from the model description: i) a simulation software, i.e. the engine to launch computerized simulations, and ii) a data base to be fed with data to concretely represent the real-system and thus describe several scenarios to experiment though simulation. These components can be completed with a user interface making it an application, to ease the configuration of key parameters for scenario exploration and to create result dashboards for key performance indicators reporting.

2.2 Investment planning in utilities network as a complex system

Investment and maintenance in transport network utilities exhibit several of the properties reported above:

- The system presents heterogeneous parts, being the physical network and asset management, respectively, where asset management means investment and maintenance planning.
- It displays hierarchies: transport network is made of substations, themselves made of devices, and of lines, themselves made of lines segments. Asset management is based on technical policies, which define management strategies, composed by sustainment actions, themselves consisting in the execution of several unit tasks on assets.
- Interactions and coupling are crucial for the comprehension of the whole system: in transport network, some equipment impacts the ageing of others, acting as controllers; in addition, there is a strong interdependence for outage, as disconnecting some equipment would imply the disconnection of some others, while on the contrary the simultaneous disconnection of some network elements would have severe consequences, such as service interruption. Different sustainment actions or tasks might require the same resources (either financial, human, or material). Moreover, transport network and asset management sub-systems are strongly coupled, since equipment age and condition lead to sustainment actions, which in return act on equipment age and condition.
- Finally, the different parts of this system represent several levels of description, e.g., from network to device, and several time scales, from week or even day (tasks planning) to decades (technical policies definition).

All these considerations led CoSMo to consider investment and maintenance in transport network utilities as a complex system, for the study of which our complex system modelling approach would be the best avenue.

3. Asset investment planning model

The model proposed by CoSMo for asset investment planning describes the structure and behavior of the T&D system, and how the user can observe and manipulate the simulated system. As any model, it is a simplified representation of the real-life system, which excludes any properties considered as irrelevant to the challenges being addressed.

3.1 Conceptual model

The model is composed of several sub-models, as depicted in Figure 1, that correspond to individual subsystems with their own behaviors and properties. These sub-systems are interconnected and interact with the other sub-systems. The three primary sub-models are the electrical transport network model, the asset management model, and the resources model.

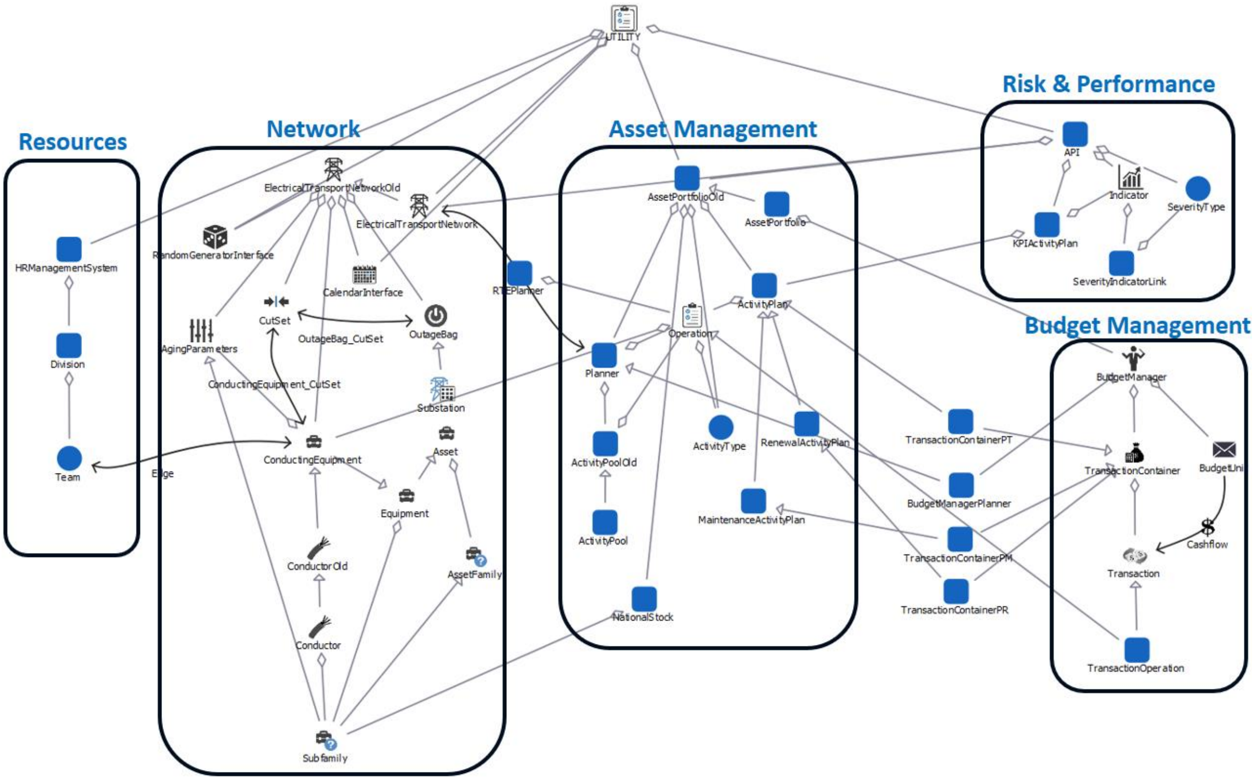

Figure 1. The Model is composed of individual interconnected sub-models.

3.1.1 Electrical Transport Network Model

The electrical transport network model describes the physical assets used to transport electricity. These include, but are not limited to, overhead lines and line segments, power transformers, circuit breakers, and towers. These assets are characterized by their physical properties such as their voltage caption, their ageing parameters and failure laws, and by the connection between assets (i.e. the structure of the network) which introduces constraints around asset outages.

3.1.2 Asset Management Model

The asset management model describes the management of assets based on the rules and intervention plans determined by the user. These rules and technical policies determine the

planning and execution of preventive and curative maintenance actions for the T&D utility's assets.
The interface between the electrical transport network model and the asset management model is via the concept of assets, a term that covers all equipment in the electrical transport network model. Maintenance actions planned and executed in the asset management model impact equipment condition and ageing, and thus any failures that occur in the power system.

3.1.3 Resources Model

The resources model includes several sub-models such as a human resources model, a budget model, and a stock model. Human resources model includes intervention teams requested to execute actions on assets. Budget model represent financial constraints and calculates expenses over the simulation. Stock model defines the material constraint for replacement actions on assets and how this stock is managed. These sub-models all act as constraints for the asset management model; for example, before any maintenance action is planned, the availability of the resources necessary to complete the action on the planned date is assessed and, if these resources are not available, the maintenance action is postponed.

3.2 Model algorithm to describe system behavior

The general behavior of the system, as simulated when a user runs a scenario, is as follows:

- In the absence of any external action on the power system ("do nothing" scenario), equipment ages and fails accordingly to the ageing and failure probability parameters set by the user;
- Different technical policies set parameters and represent a set of rules for the creation, planning, and execution of asset maintenance and renewal actions. These actions reduce the speed of assets ageing and thus decrease the probability that failures occur[2];
- The planning of maintenance actions is sequential and begins with preventive maintenance (renewal actions, predetermined and condition-based maintenance actions). Then, after the simulation begins and some equipment fails, curative actions to repair or replace the out-of-order asset are planned with highest priority, and already planned preventive actions might be postponed or canceled;
- Updates on different elements of the model are done at relevant time scales, e.g., every year for budget resource limit and every week for asset ageing or stock supply.

The possibility of an asset outage related to maintenance actions and the availability of resources (financial, human or material in stock) are checked at both the planning and execution stage. The fact that an action requires or does not require an asset outage, as well as the financial and human resource costs, are parameters set by the user.

Moreover, sustainment actions planning is done following relevant rules to be optimal. Indeed, the order in which the different types of actions are handled is defined to be consistent with real-life system. In addition, a priority value is attributed to each action, based on calculation over various criteria, such as the importance of the asset in the network, its age or the criticality of its condition. This priority value is used in model algorithm to plan actions of highest priority first.

3.3 Key Performance indicators

[2] For example, renewal policies might define at what age assets of a specific class should be replaced. Upon replacement and with the condition of the asset reset to 'new', the age of the asset is concurrently set to zero.

Simulations based on this model are meant to be run over a period of several decades. Key performance indicators (KPIs) including operating expenses (OPEX) and capital or investment expenses (CAPEX), the number of failures in the power system, the number and type of maintenance actions executed or postponed, and some specific business values that relate to financial impact or to the impact asset's bad condition has on the environment, are calculated in the model. These KPIs are aggregated dependent on various dimensions such as asset class and the simulated year. In CoSMo AIO application, all KPIs can be visualized on custom dashboards (see Figure 2) thanks to the integration of a business intelligence tool.

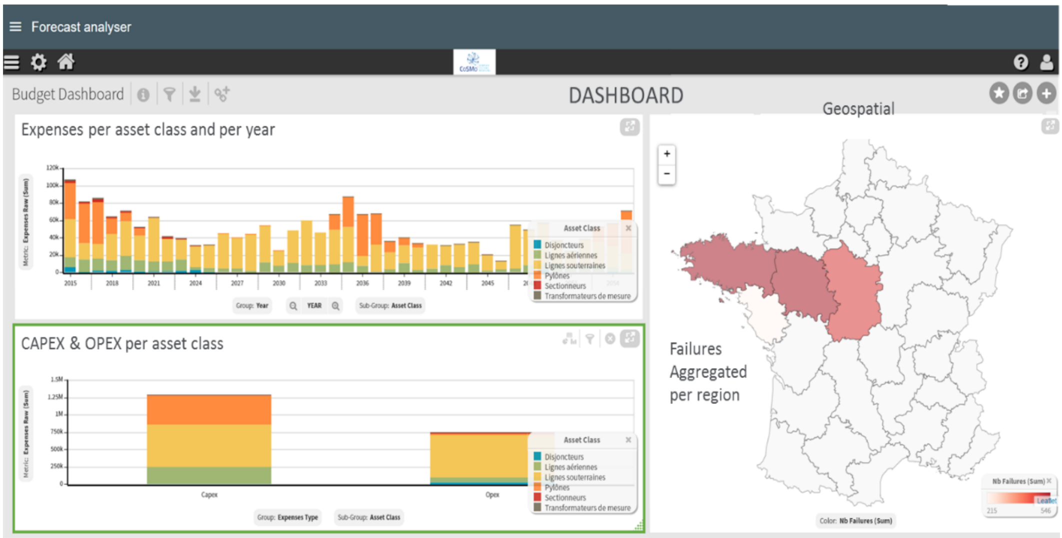

Figure 2. Example of configurable dashboard by an end-user via the CoSMo AIO application interface.

4. Numerical experimentation, model exploitation and optimization

4.1 Scenarios comparison

All data used to feed the data base automatically generated from the model description are loaded with input data files provided by the user utility, including the list of all assets making up electricity transport network and their properties. Part of these data are intrinsic to the system, such as equipment ageing and failure parameters in transport network sub-model or maintenance action cost and impact, while others correspond to the description of a strategy the user wants to evaluate. This is for example the case for application dates for the implementation of technical policies, values for annual budget limits, and the restocking parameters in resources models. The KPIs described in section 3.3 enable to evaluate the performance of different strategies, corresponding to the configuration of different scenarios. Specific dashboards for scenario comparison can be created in application to confront results obtained with different strategies.

4.2 Parameters exploration

In addition, CoSMo provides protocols, which are sets of simulations based on a same model, for parameters exploration. This approach allows to explore a given range of values defined for several parameters, to identify the optimal scenario.

Figure 3: Example dashboards tracking failure evolution (top) and budget evolution (bottom) for a utility.

4.3 Optimization

An algorithm for optimization is currently in development, to allow to determine the scenario configuration, which leads to minimal expenses or risks. In mathematical terms, the optimization problem can be expressed as:

given a function F(X), we seek an input X_0 such that $F(X_0)$ is the minimum value of the function

Considering the nature of complex systems, which have extremely high complexity, the most efficient approach to solve this problem in the case of CoSMo models without meeting unsurmountable performance issues is surrogate-based optimization [3, 4](Queipo et al., 2005; Han et al., 2012).

CoSMo proposes surrogate optimization based on machine learning techniques and using basin-hopping algorithm. This implies some constraints for the choice of variables X to leverage and of the function F to optimize. First, the existence of an optimum is ensured by X having closed boundaries, according to the extreme value theorem. This condition is also required by surrogate algorithms, design experiment needing finite sample space. Second, machine learning techniques require X to be validated by feature engineering. Finally, basin-hopping algorithm applies if X is a vector of continuous variables and F(X) is a real number [5].

In the use case we propose, we will consider F(X) as the total expenditure (OPEX+CAPEX) obtained over the whole simulation, and X as a vector of several variables, some defining renewal strategies (age at which equipment are candidates for replacement) and others defining preventive maintenance strategies (frequency of maintenance actions). The result of this optimization will be the identification of the best strategies, i.e., the best combination of renewal and preventive maintenance strategies values, and the total expenditure value corresponding to this scenario, which should be minimal.

5. Benefits of a model-driven simulation approach for investment strategy optimization

5.1 Challenges faced by T&D utilities

CoSMo application for asset investment optimization has been developed in partnership with one of the largest European TSOs, RTE, to find out optimal intervention plans, i.e. determine the most efficient, least conflictual, and lowest risk decisions to proceed, in a context of huge challenges faced by all T&D utilities.

5.1.1 A Wall of Investment

The French electrical transmission network was constructed in a short period of time some fifty to seventy years ago. This fast expansion and significant investment post-World War II was a great aid in helping France expand economically in the second half of the twentieth century. However, with electrical transmission assets from this period of expansion now approaching the end of their useful life, RTE is faced with making enormous investments in assets and infrastructure in a relatively short period. This is known colloquially as a ‘wall of investment’ and is a major challenge for TSOs across many advanced economies and most OECD countries.

5.1.2 Collaboration Between Silos

Like most large companies, RTE is managed by dividing its business and operations into various departments who have their own objectives but are not always able to collaborate to find out the global optimal plan. Decisions about asset maintenance, network development, and asset renewals are made by leaders and managers working in separate divisions with different performance indicators, different goals, and silo-specific objectives. RTE is faced with the challenge of encouraging collaboration across silos while managing, planning, and implementing a company-wide asset investment strategy.

5.1.3 Reporting to Regulators and Stakeholders
RTE's executive team is responsible to stakeholders as well as answerable to regulators who set the tariff that RTE relies on to generate revenue. Any asset investment strategy must be supported with an argument that is acceptable to both corporate stakeholders and convincing to regulators. In this latter case, it is important that any asset investment strategy is auditable and repeatable, and that calculations and assumptions are transparent where a tariff increase is sought.

5.2 Scenarios comparison

5.2.1 Data loading by utility: network characteristics
The data set provided by RTE to enable the testing and comparison of scenarios within the AIO application includes their electrical transmission network in France. This totals more than 105,000 km of power lines (both overhead lines and underground lines), 300,000 towers, 1,300 power transformers, more than 50,000 circuit breakers and disconnectors, and 55,000 transformers. These assets are connected to substations which define the cut sets used by the application as outage constraints. All RTE's assets must be maintained and some of them renewed. The global asset management budget allocated to predetermined maintenance and renewal is over €260 million annually. Scenarios for RTE are run over 40 years, this equates to around €15 billion in total maintenance and renewal.

5.2.2 Strategic leverages
Scenarios to be evaluated and compared are defined through the configuration of key parameters: e.g., dates for replacement in the context of renewal, inspection or sustainment actions frequency for preventive maintenance, budget limits or restocking strategy. For example, user can compare a baseline scenario (the current strategy, or 'business as usual' scenario) with a scenario that reallocates a part of the overhead lines renewal budget to the circuit breakers and disconnectors renewal budget.
The comparison of these two scenarios will provide insight on which provides the optimal outcome based on the primary optimization indicators: capital expenditure (CAPEX), operational expenditure (OPEX), annual number of failures, number of postponed preventive maintenance action, and financial losses due to non-delivered energy.

5.2.2 Benefits
By adopting this approach, RTE has identified significant improvements over the baseline or 'business as usual' scenarios, potentially leading to a reduction in OPEX and CAPEX by 14.5% and a reduction in operational conflicts by more than 20%, while maintaining a high quality of service.

Moreover, this approach enables them to create an investment plan which is globally optimized. Existing and competing solutions most often consider the electrical utility sector separately, limiting the different teams involved in the project to the study of their specific asset categories, and within the boundaries of their static view. In contrast, CoSMo approach promotes a "breaking the silos" vision, by easing for managers of budgets, human resources, stock assessment, and the company's transport network to work collaboratively and embrace a holistic and company-wide decision management solution.

6. Conclusion

CoSMo's technology allowed RTE to optimize their maintenance strategies and investment programs over the short, medium and long term by integrating existing organizational and operational constraints in a single model. Additionally, RTE could connect disparate information, break out of enterprise silos, test 'what-if' scenarios for maintenance and investment, deliver interconnected insights to key internal and external stakeholders, and optimize the entire network operation.

While originally developed and customized to the RTE use cases, CoSMo's AIO application is being used outside of the electrical transmission and distribution utility sector. Any industry that is asset-intensive or composes a highly-networked environment can benefit from CoSMo's complex systems approach, and CoSMo clients have expanded to include, for example, other utilities (gas distribution, water distribution) and the transport sector (rail freight, urban transport networks).

Following the improvements to network operation and investment planning at RTE, CoSMo is now establishing new partnerships to expand the scope of the AIO application to cover the specific needs of electricity distributors, too. As utility networks become only more complex and interconnected, it seems clear that applications that not only accounts for but embrace and extract value from that complexity are going to become industry standard in the very near future.

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