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AN APPLICATION OF THE MODEL OF MARGIN

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1 CONTEXT AND MOTIVATION

Context

- Uncertainties are generated all along the design process of large industrial systems.
- In some collaborative context, probabilistic methods (e.g Uncertainty Quantification) are not available or shared among the stakeholders.
- Margins are still used by engineers to mitigate (prevent) the risks.

Margin definition (informal): an amount of something included so as to be sure of success or safety (Oxford Dictionary).

Problem The information on margins is not widely shared during the design process. This leads to a "local" treatment of the margins instead of a global approach. They are too often hidden or implicit, and thus leads to the overdesign of the product [1]. The goal is to reduce the irrelevant margins without impacting the reliability and the safety of the system.

2 GENERAL APPROACH

1. Describe mathematically the object "margin" to unify the concept among engineers (proposed in [3]).
2. Model how and why the margins are taken in an industrial process.
3. Rigorously formulate and solve some margin-based problems, guided by the use-cases. *Examples:*
   - Margin accumulation during the design of a cranking battery.
   - Margin sensitivity on the sizing of the battery of an electric vehicle.
   - Multi-disciplinary margin trade-off on the mass of a space system.
4. Generalize the approach and infer the methodological aspects. Thus, the margin issues are categorized, and a solution can be proposed for each case.

A possible industrial output of these works can be in the form of softwares to handle margins in industrial processes or a set of best practices to manage margin in some more specific contexts.

3 MODEL OF MARGIN

The mathematical generic formulation of a margin
Model of margin:

State space E
Physical equations $\mathscr{C}$
Acceptance set $\mathscr{A}$
Probing set $\mathscr{G}_U$
Distance $d_{\mathbb{S}}$
Margin variables ϕ_U $\mathbb{S}$

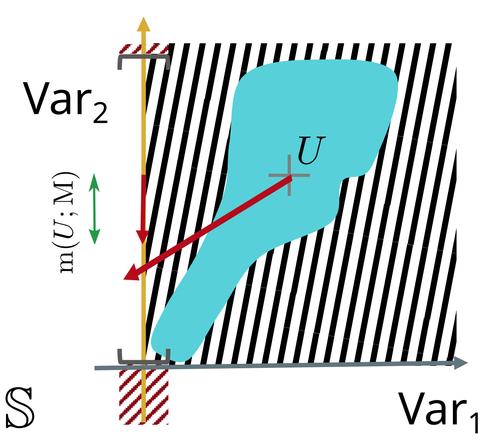

Figure 1: The effective margin at the point U on the variable Var_2 in a specific direction. It is one choice among a wide range of possibility.

In [3], we define the model of margin:

$$\mathsf{M} = (\mathrm{E}, \mathscr{C}, \mathscr{A}, (\mathscr{G}_u)_{u\in\mathscr{C}}, \mathbf{S}, d_{\mathbf{S}}, (\phi_u)_{u\in\mathscr{C}}) \tag{1}$$

and margin at the point $U \in \mathscr{A} \cap \mathscr{C}$ is:

$$\mathsf{m}\left(U;\mathsf{M}\right) = d_{\mathbf{S}}\left(\phi_U(U), \phi_U(\mathscr{A}^c \cap \mathscr{G}_{U|\mathscr{C}})\right). \tag{2}$$

Two different concepts for a given model of margin M:

- **Effective margin** the real value $\mathsf{m}\left(U;\mathsf{M}\right)$ for a given U.
- **Demanded margin** the requirement $m_{\mathrm{req}} \in \mathbb{R}$ that defines the "marged" acceptance set $\{U \in \mathscr{C} | \mathsf{m}\left(U;\mathsf{M}\right) \geq m_{\mathrm{req}}\}$.

4 USE CASE: STARTER BATTERY SIZING

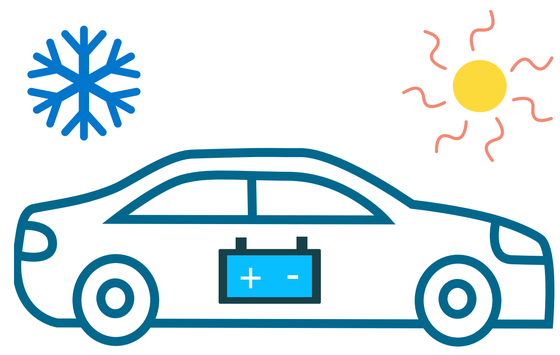

Figure 2: Sizing the starter battery so as to tolerate two mutually exclusive conditions.

Requirements: the battery should store and supply enough energy to crank the engine running in tough conditions.

- The battery must handle at least 6 months of storage in warm, temperate and cold countries.
- To ensure that the engine actually start, there must be enough power to perform three cranking.

Choose C_{req} s.t for all the temperature $\theta^-_{\mathrm{cool}} \leq \theta_{\mathrm{cool}} \leq \theta^+_{\mathrm{cool}} | \ \theta^-_{\mathrm{start}} \leq \theta_{\mathrm{start}} \leq \theta^+_{\mathrm{start}} | \theta^-_{\mathrm{dis}} \leq \theta_{\mathrm{dis}} \leq \theta^+_{\mathrm{dis}}$:

$$C_{\mathrm{req}} \geq C_{\mathrm{batt}}(\theta_{\mathrm{cool}}, \theta_{\mathrm{start}}, \theta_{\mathrm{dis}}) \tag{3}$$

5 MARGIN ACCUMULATION

Observation Starting from a nominal design in temperate condition:

- A margin on $\theta^-_{\mathrm{start}}$ is taken for the cold countries ($0\,^\circ\mathrm{C} \rightarrow -18\,^\circ\mathrm{C}$).
- A margin on $\theta^+_{\mathrm{dis}}, \theta^+_{\mathrm{cool}}$ is taken for the warm countries. ($(20, 65)^\circ\mathrm{C} \rightarrow (35, 80)^\circ\mathrm{C}$)

If not enough care is taken, the accumulation leads to the design of a battery that must withstand both a cold country on $\theta^-_{\mathrm{start}}$ and a warm country on $\theta^+_{\mathrm{dis}}, \theta^+_{\mathrm{cool}}$ *at the same time* . This margin accumulation is a worst-case design.

Margin modeling There are two ways to mathematically accumulate (add-up) demanded margins [2]:

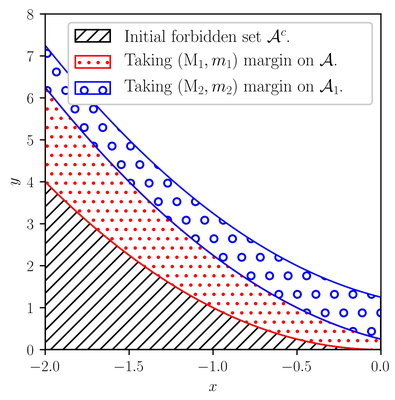

Figure 3: Sequential accumulation

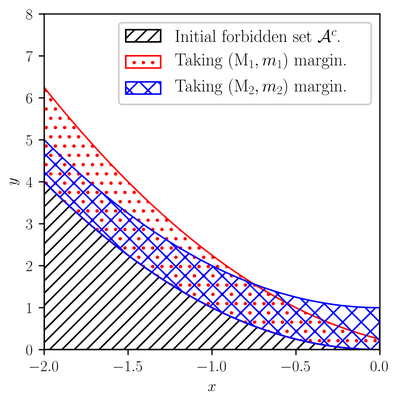

Figure 4: Mutual margin accumulation

Explicit margin accumulation (General rule): When two risks are mutually exclusive (i.e they cannot occur at the same time), the related margins must accumulate in a mutual way. Otherwise, they must accumulate in a sequential way.
A (software) library has been developed to implement this rule automatically.

Method	Worst-case	Probabilistic (with $p = 1$)	Explicit margin accumulation
C_{req}	92 A h	69 A h	69 A h

Table 1: Comparison of the explicit margin approach with two other classic approaches.

Conclusion and future works

A proof of concept of the relevance of the model of margin in the analysis of industrial design process has been provided. In order to reach a wider applicability, some directions are currently under investigation:

- Include the multi-disciplinary aspect, with nested simulations and requirement cascading.
- Linking the model of margin with the topic of robust optimization.
- Developing the tools (theorical and numerical) to perform some analysis with margins more easily.
- Exhibit other relevant industrial problems that can be expressed as margin problems.

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References

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