Finding the needle in the haystack

In the course of our engineering work on mining and metallurgical plants we are often called upon to evaluate the merits of different choices in process flowsheets, operating parameters and philosophies, raw material selection, and many others. The phenomenological complexity of the minerals industry usually means that each of these aspects is parameterised by a large number of variables, and there are also strong coupling effects between them – one changes a feed-rate setting *here*, and even though it fixes the immediate production problem over *here*, it also affects several other things over *there* in ways that one did not expect.

In the digital age we have access to powerful process and systems models, which can create virtual analogues (or "digital twins" if one prefers catchy jargon) of our real-world plants, which can make decision-making easier. However, in the pursuit of improved accuracy these models often start to become as impenetrable and confusing a black box as the actual thing they are trying to simulate. This is especially true when data-centric artificial intelligence and machine learning methods are included in the mix. Manually exploring such systems models by making basic changes using oversimplified fundamental principles, can very quickly turn into an endless game of whack-a-mole to mitigate the cascade of unintended consequences.

To better manage this problem, two formal mathematical concepts are becoming increasingly useful as interface layers over complex systems models. **Uncertainty quantification** tracks the propagation of errors through a system from inputs to outputs, and **sensitivity analysis** identifies how strongly outputs are affected by changes in the inputs. In combination, these tools can help guide design or process optimisation studies to find small changes that yield large improvements while minimising undesirable side effects. They are well worth investigating to help us find the needles in our metallurgical haystacks.

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