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# Evidence-Based Robust and Reliable Optimisation of Dynamic Complex Systems

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**ABSTRACT**

This paper will present a new approach for the Optimisation for Robustness and Reliability of Dynamic Complex Systems when they are affected by epistemic uncertainty.

Commonly, approaches for the design of Complex Systems, like safe margins approach, lack robust procedures for the design, test and redefinition of the system prior to large economical investments. Often, indeed, drawbacks are identified after a lot of money have been already spent for prototyping or after the design has already reached a mature stage. When this happens, engineers has to take a difficult decision: whether to continue and try to minimise the negative impact of this gap, or to abandon part or all of the work for a better design with consequent loss of time and money. Both decisions lead to negative consequences.

There are three main reasons why this occurs with traditional approaches. They don't proper model uncertainty that comes from different sources and manifests itself in different ways. They don't adequately deal with the interaction between sub-systems which form the Complex System and are usually studied by different design teams. Also, they don't consider the evolution in time of the system during its operational life.

About the first point, it is largely accepted to divide uncertainty in in aleatory and epistemic: the former can not be reduced and it is basically due to randomness of nature and it can be captured with a frequentist approach, while the second comes from lack of knowledge and/or subjective probability and it can be reduced to aleatory uncertainty as information increases. Aleatory uncertainty is used, for example for measurement errors; epistemic uncertainty, instead, is always present in the early design phases when experts are used to express their opinions and models are low fidelity; there is epistemic uncertainty also when data is incomplete or has poor quality. To rigorously deal with both types of uncertainty, then, we use Evidence Theory [Shafer, 1976,

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Alicino and Vasile, 2014, Croisard et al., 2010] because it is a promising mathematical tool and it is a generalisation of the classical Probability Theory.

About the second point, we model *Complex Systems* using *Graph Theory* [Boccaletti et al., 2006]: they are represented as networks where each node is a sub-system and each link an information pathway. To each node it is associated a value of the quantity of interest and a measure of uncertainty. Given that we use *Evidence Theory*, the probability measure is generalised by the measures of *Belief* and *Plausibility* and the network is called *Evidence Network Model* (ENM). The graph-structure of the ENM allows also to solve the NP-hard problem - given by the uncertainty propagation with the use of Evidence Theory - drastically reducing the computational cost from exponential to linear with the problem dimention .

The approach of ENM for *Evidence-Based Robust Optimisation* was introduced in [Vasile, et al., 2017, Filippi, et al., WCCI, 2018, Filippi et al., SECESA, (2018), Filippi et al., IAC, (2018)]. Here we are focused in the optimisation for *Robustness* and *Reliability* and in particular the work presents an innovative method for the propagation of uncertainty for the reliability analysis: degradation of the sub-systems' state is modelled, differently from the literature, as a continuous function of time.

Finally an example demonstrates that ENM is a valid tool for the preliminary design of dynamic complex space systems that are affected by epistemic uncertainty: the method is applied to the design of a cube-sat, where the quantity of interest is the overall mass.

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