Uncertainty based Multidisciplinary Design Optimisation of UxVs with Operability Objectives and Constraints

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Keywords: maximum of 5 entries. The first entry must quote one of the Event (Research Symposium, Specialist Meeting or Workshop) areas.

ABSTRACT

It is well known that any choice taken at the early stages of the design process have a huge impact on the final performance and operability (including running costs) of any engineering system. Therefore, it is crucial to develop, implement and use design approaches that consider both engineering performances and operability requirements since the preliminary design phase. Moreover, since early in the design process the knowledge about system models and operational conditions is limited, the design approach must include and appropriate way to treat the uncertainties associated with simplified models, as well as non-well known or intrinsically aleatory operative conditions. Some attempts to include operational processes into the design have been based on Markov processes, and Petri Nets. In a previous work, Petri Nets have been used to model the operation activities within the preliminary design process of a conventional launch vehicle, where the problem was formulated to minimise the expected cost per launch, considering engineering and operational constraints, as well as uncertainties on modelling parameters. Petri nets have already been used for applications such as safety assessment of UAVs , and mission planning. This summary discusses the extension of the previous work to the design of UxVs.

1.0 BACKGROUND

The use of civil and military drones has been steadily increasing over past years and decades. Moreover, also the complexity of the vehicles and the infrastructure systems, and the operational impact of their failures have also risen sharply in the recent years. These developments have implicated a growing need for efficient operation and maintenance of UxVs. One of the approaches to cope with these challenges has been the introduction of modular maintenance, and in particular condition-based maintenance strategies that can be implemented to meet the strategic goals of the operator in terms of reliability, availability and cost. Selecting optimal maintenance strategies is becoming a must for every operator and suitable tools to analyse, compare and optimize different maintenance strategies are required.

Because it is well known that any choice taken at the early stages of the design process have a huge impact on the final performance and operability (including running costs) of any engineering system, it is crucial to develop, implement and use design approaches that consider both engineering performances and operability requirements since the preliminary design phase. Moreover, since early in the design process the knowledge about system models and operational conditions is limited, the design approach must include and appropriate way to treat the epistemic uncertainties associated with simplified models, as well as non-well known or intrinsically aleatory operative conditions.

Petri nets have been increasingly applied to model and simulate operational and maintenance strategies [1]. Petri nets present an approach to mathematically describe processes based on basic set theory, and given their flexibility, they can be used for general maintenance engineering and planning. Petri net enable the modelling of the different maintenance process steps and are able to model the failure and degradation behaviour based on defined stochastic behaviour.

In a previous work ([2]), Petri Nets have been used to model the operation activities within the preliminary design process of a conventional launch vehicle, where the problem was formulated to minimise the expected cost per launch, considering engineering and operational constraints (such as the minimum number of launches per year), as well as uncertainties on modelling parameters.

2.0 IDEA AND NEEDS

The idea is to extend the previous work to the design of UxVs. In particular, Petri Nets can be used to model maintenance operations and the preliminary design optimisation can be formulated considering, for example, responsiveness objectives for diverse services and missions, such as deliveries, surveillance and reconnaissance. A successful implementation will require appropriate modelling approaches that should be supported by available data and data that will be obtained through the operations in a way that exploits the concept of digital twinning. This notion implies that for an object/system in the physical world there exists a digital representation that holds all the information that accumulate during its lifetime.

The modelling and approach to design should definitely shift forward to not only consider the engineering performance, such us range and payload, but also operating cost and maintenance, in a way that analysts and designers should not only see one aspect or one performance, but the entire life cycle of the system. In the same way, a full set of data, containing both classical performance and maintenance procedures and times, should allow for the implementation and update of an integrated digital twin system vehicle+mission+maintenance.

A practical and promising modular and scalable approach to digital twinning has been presented recently [3]. Here the vision is to consider the maintenance operations as a sub-system/component that is modelled via Petri Net and included in a library of component-based models from multi-fidelity simulations and available data, which can then be used to build the digital twins. As for the other models, Petri Nets are constantly updated in terms of structures and transition parameters through the interaction with the operating physical twins. In this context, the Learning Petri Nets [4], where machine learning approaches are integrated for updating/learning, could be better used. The updating process let reduce the epistemic part of the uncertainties and better model the intrinsically aleatory ones associated with the maintenance processes, as well as identify the need for different, additional models. One of the main challenges of the modular library based approach is the data-driven model identification and use. In [5] the authors propose the use of interpretable machine learning classification methods to those models in the model library are the best candidates for the updated digital twin. Here we can think to expand the use of the classification to consider also the case when no one of the Petri Net models can fit, meaning that likely a different model has to be implemented and included in the library. Naturally, the classification introduces additional uncertainty in the updating process and related design process that must be considered as well.

To proceed in this direction, the needs are both technical and human/social. The modelling approach should be able to integrate all the recorded info/data and should be able to chain and interface engineering and operational aspects, such that engineering parameters affect the operational performance and operation parameters affect the engineering performance also for low fidelity and relatively not expensive models. Moreover, the above mentioned modularity that will let handle different variants of vehicles or operational scenarios without requiring totally different models will need well planned and coordinated I/O. From a design point of view, methods for multidisciplinary design optimisation under uncertainty have to be used able to treat multiple heterogeneous variables and uncertainty parameters have to be considered. In particular, the inclusion of Petri Net based models in the simulation process will require to work with mixed aleatory-epistemic uncertainties.

When interacting with complex systems, the human element cannot be neglected. Of the two primary forms, human inconsistency, both deliberate and accidental, in following rules, processes, and procedures and a lack of sense-making, i.e., the ability to make sense out of the inputs and stimuli that are being presented to the human, especially the former must be considered when modelling maintenance. Moreover, the social factors must be considered as well and the following has to be facilitated:

- electro-mechanical and aerospace engineers have to communicate with management engineers, life cycle management experts, and operators;

- UxVs operators have to understand the need to share data about any aspect of the operations, including maintenance; this has to take into account both privacy/confidentiality aspects and possible associated costs.

3.0 CONCLUSIONS

The proposed integrated design approach is already possible with the current technology and the future advancements in information technology, including data acquisition (sensors and protocols), data transmission (bandwidth and protocols), and data processing (computing capability and methods/models), will make its use more and more affordable, even considering the worst case scenario with heavy Monte Carlo based simulations to manage some uncertainties. However, models and computational methods will have to be implemented considering the human and socio-cultural elements.

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