Abstract

This PhD thesis addresses early-phase decision support in space programmes, where mission-architecture choices, technology maturation, schedule, and cost are strongly coupled and affected by substantial uncertainty. It proposes an integrated methodology that connects architecture-centric modelling, knowledge-based integration of heterogeneous evidence, and uncertainty-aware planning in order to support the assessment and comparison of alternative development strategies.

The main contribution of the thesis is a traceable workflow for linking mission architectures, enabling technologies, and programme-level implications within a coherent decision-support process. At its core, the approach structures planning information around technologies, building blocks, operational capabilities, and mission concepts, and propagates uncertainty across technology-readiness transitions through data-driven time and cost characterisation combined with explicit modelling of risk-induced schedule delays and cost growth. A complementary budget-time analysis layer is also introduced to support what-if exploration of funding variations and their expected impact on schedule at TRL-transition level.

To improve consistency and make knowledge easier to reuse, the method combines model-based system overviews with a structured knowledge layer. This layer allows automatic collection of needed information, trackable searches, and clear links between requirements, system parts, tasks, and planning results. Overall, the workflow serves as a decision-support tool, not a prediction tool, with roadmaps and plans used as examples created using clear assumptions and limits.

The methodology is demonstrated through three complementary case studies representing different development contexts and mission classes: a bounded MicroLauncher validation benchmark, the SpaceHOME habitat framework as the main industrial demonstrator, and a Nuclear Electric Propulsion (NEP) Space Tug as a reference case characterised by high uncertainty and strong technological complexity. In all three applications, the workflow is used to generate both baseline and perturbed planning scenarios, allowing the comparison of readiness timelines, cumulative development costs, and key technological drivers under uncertain conditions.

Overall, the thesis contributes an evidence-informed, model- and data-centric framework that strengthens transparency, traceability, and consistency in early-phase architecture and technology-planning decisions for future space systems.