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Design for Affordability in Complex Systems and Programs Using Tradespace-based Affordability Analysis

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Abstract

With growing emphasis on affordability, the conceptual design of complex systems and programs is no longer confined to maximizing technical performance, but also to minimizing cost and schedule related attributes. By defining affordability as the property of becoming or remaining feasible relative to resource needs and resource constraints over time, Multi-Attribute Tradespace Exploration and Epoch-Era Analysis can be used to find affordable solutions. Single-epoch, multi-epoch and single-era analysis were conducted for a Space Tug program case study to demonstrate the application of these tradespace-based methods and a design with the best tradeoffs among performance, cost and schedule factors was obtained.

Keywords: affordability; systems engineering; tradespace exploration; utility; expense; epoch; era

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1. Introduction and Background

As the architecting of complex engineering systems faces much uncertainty with respect to their dynamic operating contexts and the evolving needs of stakeholders, conceptual design formulation and system development are often subjected to multiple revisions that lead to unanticipated delays and changes in technical specifications. The accumulation of these outcomes often leads to rising costs and schedule slippages, which can eventually compromise the success of the system or program in development. High-profile failures in system and program delivery in the last decade, especially in the defense and aerospace industry, have resulted in a paradigm shift in systems architecting and acquisition. Performance is no longer regarded as *sine qua non*, and simulation of complexity in these systems and programs often require considerations and analysis beyond a single cost attribute[1]. This has necessitated the need to additionally account for multiple cost and schedule parameters elicited from stakeholders during early-phase design. This emerging paradigm in systems engineering is the *design for affordability*[2,3], where systems and programs are architected to satisfy multiple performance, cost and schedule needs of stakeholders. Affordability has thus emerged as a high priority ility that directs the early stage design process towards developing systems with greater cost effectiveness and schedule effectiveness.

1.1. Establishing the Current Affordability Paradigm

Affordability became prominent within systems engineering semantics after the recent issuance of defense memorandums that "mandated affordability as a requirement" for future defense acquisitions[2,3]. Since then, many attempts have been made to propose frameworks for affordability analysis[1,4,5], and integrate them with existing systems engineering methods to generate affordable design solutions. With the push for "designing for affordability as a requirement*"* in acquisition management, various systems engineering approaches have been taken to better design systems or programs that are more manageable under explicit cost, schedule and performance considerations. Quantitative methods like lifecycle cost decomposition[1], probabilistic interval schedule and cost estimation[4], and plotting of Sand Charts[5] have been used alongside numerous visualization tools to quantify affordability during the systems architecting process.

However, current processes for performing early lifecycle affordability tradeoffs remain under-developed. Affordability tradeoffs have been limited to static tradeoffs of systems between performance and costs in current operating environments, or in single point futures. There is also a lack of a consensual definition and a set of guiding principles for affordability within the systems engineering community. This gap in knowledge about the meaning and implications of pursuing affordability has resulted in the variety of approaches currently in existence, with few being able to explicitly capture the dynamic elements of the system or program and its operating environment over its lifecycle. A common definition and a common set of principles for affordability can integrate approaches taken by the government, industry and academia into a concerted effort for reducing overall system or program costs and schedule slippages. Given that systems and programs exist in a dynamic and uncertain world, designing for affordability not only necessitates new methods capable of evaluating them across many possible alternative futures, but also a new philosophy for treating the affordability paradigm.

1.2. Defining Affordability as an Ility

The systems engineering discipline has been advanced through the use of non-traditional design criteria called "ilities"[6], which are system properties that often manifest and determine value after a system is put into initial use. Ilities concern wider impacts with respect to time and stakeholders and can better promote the development of successful systems as compared to solely technical criteria. Commonly known ilities such as survivability[7] and evolvability[8] have already been defined in many engineering fields and their inclusion in the design process often leads to desirable outcomes. Affordability can thus be treated as an ility that drives the design of more affordable yet technically sound architectures. With affordability as an ility, advanced systems engineering methods like *tradespace exploration* can be applied in the enumeration, evaluation, identification and selection of affordable designs.