System of Systems Engineering Collaborators Information Exchange (SoSECIE)

August 22, 2013
11:00 a.m. to Noon Eastern Time

System Re-Tasking to Achieve Resilience in an SoS

Ms. Payuna Uday and Dr. Karen Marais
Purdue University

Abstract
System-of-systems (SoS) are formed from the integration of independently operating complex systems that interact with one another to provide an overall capability which cannot be achieved by the individual systems alone. As a result, designing and operating an SoS is challenging both from an engineering as well as a managerial perspective.

Resilience is the ability of a system or organization to react to and recover from disturbances at an early stage with minimal effect on the dynamic stability. Typically, in large complex systems, redundancy features are used to increase the resilience of the system to perturbations. For instance, commercial satellites are fitted with multiple backup systems to limit performance loss in the event of failures. Traditional reliability analysis techniques, such as fault trees and event trees, are typically used to determine the level and types of redundancy to be included in the system design.

However, these approaches do not adequately satisfy the resilience needs of an SoS. Given the heterogeneity and, often wide geographic distribution, of the constituent systems, inclusion of backup redundant systems for an SoS is impractical and costly. Additionally, high levels of interdependency between the systems imply increased risks of failures cascading throughout the SoS. However, these hurdles, we argue, offer the unique opportunity to improve the resilience of the overarching system through unconventional means.

Here, we study a way to compensate for a loss of performance in one constituent system by re-tasking the remaining systems. Specifically, as one entity, or node in an SoS, experiences degraded performance or a failure mode, other entities can alter their operations to compensate for this loss. We call this “stand-in redundancy”. This raises several interesting questions, such as: (1) given the failure of a specific system, what is the best configuration to compensate for the loss?; (2) what level of performance can be recovered with the new configuration?; and (3) what is the upstream effect of stand-in redundancy on development costs and risks?

In this paper, we develop two concepts to implement stand-in redundancy in an SoS: (1) reactive resilience, and (2) proactive resilience. This research contributes to the topics of Early Development Planning, Architecture, and Modeling and Simulation.

Reactive resilience deals with performance recovery after a failure has occurred. In this case, for a specific capability, we study the reduction in overall SoS performance given various nodal failures, and then determine the level of performance that can be recovered by reconfiguring the rest of the SoS. We provide a method to rank the feasible configurations based on performance level recovery and ease of implementation.

Having studied the impact of total nodal failures on overall SoS performance, we expand the method to track the impact of gradual degradation of nodes on the same overall performance. As the nodes degrade over time, the corresponding reduction in SoS performance could result in a situation where a different configuration might fare better than the current one. This implies a forcible transition to a different SoS configuration before actual failure of the node. We call this proactive resilience, as this transition to a new configuration before nodal failure occurs improves the robustness of the overall SoS.

Biographies

Ms. Payuna Uday is a doctoral student in the School of Aeronautics and Astronautics at Purdue University. Her research is focused on studying and designing resilience in system-of-systems. Payuna received her master's degree from Purdue and her research involved evaluating the environmental mitigation potential of operational changes in aviation.. She completed her schooling in Dubai and holds a B.Tech. in electronics and communication engineering from the National Institute of Technology in Trichy, India.

Karen Marais is an Assistant Professor in the School of Aeronautics and Astronautics at Purdue University. Her research interests include safety, reliability, risk and economic analysis of complex socio-technical systems in general and aerospace and renewable service systems in particular. In addition, Dr. Marais conducts research on the environmental impact of aviation within the FAA PARTNER Center of Excellence.