SPECIAL FEATURE
Systems of the Third Kind: Distinctions, Principles, and Examples

Theme Editors' Introduction

Rick Dove (rick.dove@incose.org), Jack Ring (jack.ring@incose.org), and Thomas Tenorio, (thomas.tenorio@incose.org)

> NEVADA DMV ISSUES FIRST AUTONOMOUS VEHICLE TESTING LICENSE TO GOOGLE
> *Google's self-driving test vehicle will display a red license plate with an infinity symbol*
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> The Nevada Department of Motor Vehicles has approved Google's license application to test autonomous vehicles on Nevada public roads. It is the first license issued in the United States under new laws and regulations that put Nevada at the forefront of autonomous vehicle development. [. . .] The license plates displayed on the test vehicle will have a red background and feature an infinity symbol on the left side.
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> "I felt using the infinity symbol was the best way to represent the 'car of the future.'" Department Director Bruce Breslow said. "The unique red plate will be easily recognized by the public and law enforcement and will be used only for licensed autonomous test vehicles. When there comes a time that vehicle manufactures market autonomous vehicles to the public, that infinity symbol will appear on a green license plate."
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> (Nevada Department of Motor Vehicles 2012)

Figure 1. The Google self-driving car with Nevada's first autonomous-vehicle testing license

The Nevada license is for road testing. A test that includes an alert qualified driver ready to take control if the car decides or behaves inappropriately. We train and test pilots that way. But unlike pilot's, who can be learning situational response and flying technique from an instructor, and will continue to do so thereafter, the Google-car currently behaves and responds according to pre-determined algorithms. The car is not yet a full-fledged system of the 3rd kind, as will be distinguished in this theme's lead-off essay; but here we go.

Autonomous cars are one thing, autonomous weapons are another. As the US Department of Defense's recently released *Unmanned Systems Integrated Roadmap* frames the problem, "Today's iteration of unmanned systems involves a high degree of human interaction." The Department of Defense "must continue to pursue technologies and policies that introduce a higher degree of autonomy to reduce the manpower burden and reliance on full-time high-speed communications links while also reducing decision loop cycle time" (2011: vi).

In this theme issue we choose to categorize systems of the first kind as *deterministic*, of the second kind as *probabilistic*, and of the third kind as *non-deterministic*. Systems of the third kind include variations of currently popular labels such as chaotic, complex-adaptive, autonomous, resilient, sustainable, agile, and human activity. They move among us already: cars that drive themselves in urban environments, helicopters that land autonomously, lethal weapons that decide when and where to shoot, unmanned aircraft in the national airspace. Some work alone; others are being taught to work in packs and swarms. Emergent behavior is expected, with consequences, and with virtually no systems engineering guidance.

Calling it like it is, W. Ross Ashby (1984: 273) issues this warning about the self-organizing system:

> There is no difficulty, in principle, in developing *synthetic organisms as complex and as intelligent as we please*. But we must notice two fundamental qualifications: first, their intelligence will be an adaptation to, and a specialization towards, their particular environment, with no implication of validity for any other environment such as ours; and secondly, their intelligence will be directed towards keeping their own essential variables within limits. They will be fundamentally selfish. So we now have to ask: In view of these qualifications, can we yet turn these processes to our advantage?

If so, then autonomous systems may be able to cope on our behalf with non-deterministic problem systems. The system engineering challenge is to devise the degree of autonomy that is fit for purpose.

The current INCOSE view of systems and systems engineering does not cope with the kinds of problematic situations with which society wants our help. Specifically, although the systems engineering community is reasonably successful in devising solutions for problematic situations that behave as state-determined systems or as probabilistic (but ergodic) systems, the systems engineering community has not established a record of success in devising systems that can cope with non-deterministic situations. Meanwhile, the number of non-deterministic situations is increasing rapidly.

The systems engineering of autonomous systems has two major facets: the systems engineering of the autonomous systems themselves (i.e., their design and construction), and the systems engineering of test and evaluation of these systems. This latter facet is the more important of the two—since even though test and evaluation of autonomous systems is currently informed by very little engineering experience and knowledge, it still determines what systems will be unleashed. To prevent disastrous results, test and evaluation must get out in front and stay in front of the accelerating advances in autonomous systems development.

“The future’s already here, it’s just not very evenly distributed” (Gibson 1999). Thank goodness, systems engineering isn’t ready yet.

The essays in this special feature are intended to spur interest within the systems engineering community by opening the door on some of the largely unaddressed systems engineering issues of non-deterministic systems. The intent is to launch a dialogue, within INCOSE and beyond, for guiding the incorporation of non-deterministic systems in the systems engineering field of discourse. We hope to raise a sense of urgency for systems engineering thought on effective test and evaluation of these systems.

To be a part of this dialogue, contact Thomas Tenorio for access to the forum hosted by the Autonomous System Test and Evaluation Working Group. We also welcome further discussion and debate within the pages of *INSIGHT*.

Essays in This Issue

Systems of the Third Kind: Distinctions, Implications, and Initiatives

In a fitting lead-off essay, Jack Ring and Thomas Tenorio present clear distinctions between the three kinds of systems. Jack is an INCOSE Fellow, chair of the Autonomous Systems Test and Evaluation Working Group, and managing member of Ontopilot, LLC. Tom is cochair of the same working group and is principal systems analyst at White Sands Missile Range in New Mexico (US). Jack and Tom outline the gaps in our systems engineering tools and capabilities for dealing with non-deterministic systems, and propose some remedies.

Determinism and Determination in Socio-Technological Systems

Fifty years of knowledge development in self-organizing systems has occurred since Ross Ashby’s 1962 question and caution: “Can we yet turn these processes to our advantage?” (273). Doug McDavid revisits this question with a look at how to turn new understandings to our advantage. Doug retired as an executive consultant with IBM’s Global Business Services and Almaden Research Lab; he was a member of the IBM Academy of Technology, and maintains a continuing focus on business architecture in private practice. In his essay, Doug explores manufactured intelligence, its limits, and a worrisome vision of the future. He closes with pressing questions of accountability that need to be answered by system engineering processes.

Non-Determinism in Systems Engineering

Eric D. Smith suggests that non-determinism can only be defined as a quality, and consequently systems engineers of complex systems need to understand how to deal with pure qualities. An INCOSE-certified Associate Systems Engineering Professional, Eric is an assistant professor at the University of Texas at El Paso within the Department of Industrial, Manufacturing, and Systems Engineering. He did his dissertation research at the interface of systems engineering, cognitive science, and multicriteria decision making. Here Eric explores the complementarity of emergent qualitative attributes and the logical parts of systems, offering models for analyzing complex system paradoxes.

A Test-of-Design Rubric for Autonomous Systems

Systems with multiple independent backup modes, often used in autonomous systems, are usually thought to have low probability of catastrophic failure, yet occur with unexpectedly high frequency. Jack K. Horner shows why. Jack is president of JKH Consulting, LLC, in Los Alamos, New Mexico, a software- and systems-engineering consulting firm. Jack’s essay provides an eye-opening risk analysis of Japan’s tsunamiravaged Fukushima-Daiichi nuclear facility, as it should have been done. He shows why it is not uncommon to underestimate risk in such backup configurations. He finishes with models appropriate for evaluating risk in systems with multiple independent backup modes.

Decisions of the Third Kind

David G. Ullman looks at system design as the evolution of information punctuated by decisions. He outlines four kinds of decisions: informal (the "zero" kind), structured, probabilistic, and adaptive (the third kind).

Dave is professor emeritus of mechanical design and computer-aided design at Oregon (US) State University. He is also chief scientist at Robust Decisions Inc. He is a fellow of the American Society of Mechanical Engineering, the author of *Making Robust Decisions: Decision Management For Technical, Business, and Service Teams* (2006), and has taught, researched, and written about design and decision-making for over 25 years. Dave's essay closes with suggestions on implementing decisions of the third kind, and relates these decisions to lifecycle management.

Simulation-Based Engineering of Context-Sensitive Systems

John R. Clymer is an INCOSE Fellow, retired professor of electrical engineering and systems engineering at California (US) State University, Fullerton, and retired principal investigator for the Applied Research Center for Systems Science at the same university. John is internationally known in the general area of simulation-based systems engineering, and shares insights here with two examples: pre-requirement mission analysis and concept formulation for a fire-control system, and a distributed vehicle-traffic control network that exhibits emergent behavior. Finally, he discusses a simulation tool that has all the features needed to do systems analysis of non-deterministic and nonlinear systems.

Stochastic Simulation Challenges for Systems of Systems

From the Aerospace Systems Design Laboratory at the Georgia (US) Institute of Technology, we have a threesome of authors: Burak Bagdatli is a PhD student, Kelly Griendling is a research engineer and branch chief for system-of-systems engineering; and Dimitri Mavris is the Boeing Chaired Professor and director of the laboratory. They discuss a variety of executable models for stochastic system of systems simulations that they have found useful, focusing on the challenges of sufficient repetitions and interpretation of results. They suggest that some of these problems can be handled effectively by visual analytics.

Righteousness and Conscience as a Path to Socially Acceptable Autonomous Behavior

Rick Dove suggests that the test and evaluation of autonomous systems cannot be limited to an event in the systems engineering "V" model, but must be a continuous, on-board process carried out by integrated yet independent agents who monitor the behavior of both self and peers. Rick chairs the Systems Security Engineering Working Group and teaches agile and self-organizing systems at Stevens Institute of Technology (New Jersey, US). Here he shows behavior monitoring as natural and necessary processes practiced by social animals and humans as precedent, and references concepts and technology that can make this practical in engineered systems. He calls out areas that need new attention in systems engineering.

Quorum Sensing in Multi-Agent Systems

Quorum sensing is the name of a dynamic process seen in nature, which provides a means for a group of independent agents (such as bacteria or honeybees) to determine when a sufficient population exists to initiate a collective action that would fail with insufficient number. Probabilistic in mechanism, a quorum-sensing system drives an autonomous system of the second kind. Jeff Hamar and Rick Dove describe this type of system in pattern form, as a candidate for dealing with certain non-deterministic problem systems. Jeff is a systems engineer and systems architect in the United States defense industry, completing a graduate certificate in agile systems engineering at Stevens Institute of Technology. Rick teaches courses on agile and self-organizing systems at Stevens Institute of Technology, and chairs the INCOSE Systems Security Engineering Working Group.

System Development Progress Disambiguation

For projects involving significant extent, variety, and ambiguity, Steve Krane looks at the development process as a system of the third kind, with numerous reasons for uncertainty in the development path. He suggests that a crucial need under these conditions is a method to assess whether a systems engineering-and-development project is following due process. Steve is an engineering fellow at Parker Hannifin Corporation, where he is engaged in the specification, modeling, and engineering of hydraulic and flight-control systems. In this essay Steve describes a situational-awareness method for assessing due-process discipline, which he refers to as system development progress disambiguation.

References

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