Modeling, Anticipating, and Preparing for Catastrophic Risks to Communities as Complex Interdependent Systems of Systems

Presented at the 2012 DFG-NSF Research Conference: *Reckoning with the Risk of Catastrophe*

Yacov Y. Haimes  haimes@virginia.edu
L. R. Quarles Professor of Systems and Information Engineering, and Founding Director (1987), Center for Risk Management of Engineering Systems
University of Virginia
04 October 2012
Strategic Preparedness
(Is a Systems of Systems Challenge)

Natural and human-induced disasters affect organizations in myriad ways, not only because of the inherent interconnectedness and interdependencies among human, cyber, and physical infrastructures, but primarily, and most importantly, because of the dependence of organizations on the effectiveness of humans, and on the leadership humans provide to the organizations they serve and represent.
Strategic Preparedness Connotes

*a systems-of systems decisionmaking process and its associated actions:*

(i) implemented in advance of a natural or human-induced disaster;

(ii) aimed at reducing consequences (e.g., recovery time, community suffering, and cost);

(iii) and/or controlling their likelihood to a level considered acceptable (through enhanced resilience and reduced vulnerability to specific emergent forced changes.)
My Four-Perspective Message

(i) Strategic preparedness must build on the theory of scenario structuring, which is foundational for risk analysis, and for modeling complex interdependent systems of systems;
My Four-Perspective Message

(i) Strategic preparedness must build on the theory of scenario structuring--foundational for risk analysis, and for modeling complex interdependent systems of systems;

(ii) The states of a system are the fundamental building blocks of mathematical models and of risk analysis;
My Four-Perspective Message

(i) Strategic preparedness must build on the theory of scenario structuring--foundational for risk analysis, and for modeling complex interdependent systems of systems;

(ii) The states of a system are the fundamental building blocks of mathematical models and of risk analysis;

(iii) The vulnerability and resilience of a system are manifestations of the states of that system, and they are functions of the states and the initiating event (its timing and characteristics).
My Four-Perspective Message

(iv) The intrinsic shared States provide a powerful mechanism for understanding and exploiting the interdependencies among the subsystems of systems of systems
My Message

(i) Strategic preparedness must build on the theory of scenario structuring--foundational for risk analysis, and for modeling complex interdependent systems of systems;

(ii) The states of a system are the fundamental building blocks of mathematical models and of risk analysis;

(iii) The vulnerability and resilience of a system are manifestations of the states of that system, and they are functions of the states and the initiating event (its timing and characteristics).

(iv) The intrinsic shared States provide a powerful mechanism for understanding and exploiting the interdependencies among the subsystems of systems of systems.
Theory of Scenario Structuring

Theory of Scenario Structuring (TSS)
[Kaplan and Garrick 1981]
and
Hierarchical Holographic Modeling (HHM)
[Haimes 1981]

Both address the multiple perspectives of a system and promote the consideration of every conceivable emergent forced change.

A joint paper streamlined the TSS and the HHM
[Kaplan, Haimes, and Garrick 2001].
Emergent Forced Changes

They are trends in external or internal sources of risk to a system that may adversely affect specific states of that system.

Unanticipated, undetected, misunderstood or ignored emergent forced changes, whether they originate from within or from outside a system, are likely to affect a multitude of states of that system with potentially adverse consequences.
States of a System

Given a system’s model, the states of a system are the smallest set of independent system variables such that the values of the members of the set at time $t_0$ along with known inputs, decisions, random and exogenous variables completely determine the value of all system variables for all $t \geq t_0$ (under certain conditions).
Identifying the shared states and decisions within and among the subsystems that make up a system of systems constitutes the fundamental core for understanding and modeling the inherent interconnectedness and interdependencies that characterize systems of systems.
Shared States among the Submodels

Central role of shared states in meta-modeling:
(i) capture the strong couplings among the subsystems;
(ii) serve as an agent in systems identification by providing additional direct information;
(iii) represent the essence of each subsystem by a finite number of essential state variables; and
(iv) improve our understanding of the intricate relationships that characterize the transitions among the states of the subsystems.
Modeling Complex Systems of Systems

(i) Modeling complex systems of systems is surreal;

(ii) The trial-and-error of process of modeling systems of systems, may not enable modelers to explain the reasons behind any variability among submodels;

(iii) Nevertheless, the very process of modeling such variability may highlight limited databases, inconsistent assumptions, unrecognized epistemic and aleatory uncertainties, and a host of technical or other reasons that ought not to be dismissed.
Phantom System Models (PSM)

*Systems Engineering: 15 (2), 2012*

Artists, are the quintessential modelers. They represent, through their artwork, the influence of the culture and social environment within which they live.

In an analogous way, systems modelers represent the multi-perspectives of a system to gain a better understanding of its inherent shared states (interconnectedness and interdependencies) to answer specific questions relevant to the system.
Since no single model is capable of representing the essence of a complex system of systems, there is a need to effectively coordinate and integrate the multiple models of a complex system of systems.

Meta-model coordination and integration of systems of systems, which is central to the PSM, builds on the Hierarchical Holographic Modeling and on the shared states among the submodels.
Meta-Modeling

The hierarchical coordination and integration of the results generated by the multiple models at the subsystems level are achieved at the meta-modeling phase within the PSM.

This is accomplished by observing, estimating, and assessing the outputs for given inputs, and by building on the intrinsic shared states within and among the subsystems.
Epilogue

Complex systems are commonly composed of interconnected and intra- and inter-dependent subsystems (shared states and decisions), which in their essence constitute systems of systems with multiple functions, operations, and stakeholders.

It is impracticable to represent within a single model all the aspects of a truly complex system of systems that may be of interest at any given time.
This Presentation Builds on:


Y. Y. Haimes, On the Complex Quantification of Risk: Systems-Based Premises on Terrorism, *Risk Analysis* 31(8), 1175-1186.