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INTEGRATED POLICY SIMULATION IN COMPLEX SYSTEM-OF-SYSTEMS

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ABSTRACT

This study presents an integrated framework for evaluation of different policy scenarios in complex System-of-Systems. The proposed framework uses a bottom-up approach and hybrid simulation paradigms to model the micro-dynamics of a System-of-Systems and to investigate the desired policy outcomes. The application of the proposed framework is presented in the evaluation of financing policies in infrastructure System-of-Systems in which a hybrid agent-based/system dynamics platform was created to model the micro-behaviors of different entities affecting the level of investment. The created model provides a platform for conducting scenario analysis and investigating the landscape of desired policy outcomes. The results show that the proposed framework facilitates: (1) investigation of the impacts of the adaptive behaviors of different entities as well as the uncertainties; and (2) identification of the highly likely scenarios which lead to the desired policy outcomes.

1 INTRODUCTION

Systems-of-Systems are characterized by the adaptive behaviors and autonomy of their components which lead to emergent properties (Maier 1998). These characteristics affect the outcomes of policies in Systems-of-Systems. Policymakers who evaluate policies face *known unknowns* (policy outcomes whose nature is known but their probability of occurrence is not known) as well as *unknown unknowns* (policy outcomes whose nature and probability of occurrence are not known) due to the adaptive behaviors of the players in complex Systems-of-Systems. Thus, the landscapes of policy problems change over time, and traditional ex-post policy assessment approaches (such as statistical analysis) do not provide robust tools to achieve desired outcomes (Mostafavi et al. 2013). This study proposes an integrated framework for policy simulation in complex Systems-of-Systems and demonstrates the application of the proposed framework in the context of the evaluation of financing policies in transportation infrastructure.

2 SYSTEM-OF-SYSTEMS FRAMEWORK

Many researchers have recognized the limitations of the traditional ex-post methods (e.g., statistical approaches) in capturing the complexity of public policy analysis and management in complex System-of-Systems. Such models do not capture the complexity of policy problems, competing values, emergent behaviors, interdependencies, and uncertainties (Pfeffer and Salancik 2003). These issues can be addressed using innovative frameworks which facilitate understanding the probable macro patterns of a System-of-Systems based on the micro behaviors of its adaptive components. Such models (so-called ex-ante analysis) facilitate considering various probabilities of possibilities to provide a set of "robust" solutions across different parameter values, scenarios, and model representations (Bankes 2002).

The proposed framework includes three phases: definition, abstraction, and implementation. In the definition phase, the context and boundaries of a policy problem are identified. The abstraction phase

deals with the investigation of the key players, activities, and interactions affecting the outcomes of policies. In the implementation phase, a bottom-up simulation model is created and different policy scenarios are investigated. The implementation phase also includes meta-modeling in which the landscape of several policy scenarios will be evaluated using data from several replications of the simulation experimentation.

3 EVALUATION OF FINANCING POLICIES IN TRANSPORTATION INFRASTRUCTURE

Evaluation of financing policies is of great importance to address the existing need for infrastructure renewal in the U.S. Expansion of financing for infrastructure is affected by the activities of and interactions between various players in the process, such as the federal government, local agencies, private organizations, and the general public (Mostafavi et al. 2011).

The application of the proposed framework is demonstrated for the assessment of sustainable financing policies in highway transportation infrastructure. Using the proposed framework and data obtained from a wide range of sources ranging from historical records and case studies to interviews with subject matter experts, the micro-behaviors of different entities pertaining to infrastructure financing were explored. These data then were used to create a hybrid agent-based/system dynamics model for micro-simulation of sustainable financial innovation policies. Using this model and Monte-Carlo experimentation, the policy landscape of transportation infrastructure in the U.S. was simulated. The created policy landscape was used for identification of the highly likely desired scenarios for the closure of the financing gap pertaining to highway transportation infrastructure. This distinctive approach was the first of its kind to simulate the U.S. transportation infrastructure policy landscape by simulating the micro-dynamics of the system.

4 CONCLUDING REMARKS

The results suggest that the simulation model provides the following benefits for policy analysis: (i) simulation and visualization of the outcomes of policies across different states and at various policy horizons, (ii) comparison of the outcomes of different policies based on different financing characteristics of states, (ii) creation of the landscape of financing policies, (iv) identification of the desired scenarios, and (v) quantification of the likelihood of desirable outcomes as a result of different policies. This framework has the potential to be adopted for investigation of the landscape of sustainable policies in different contexts related to complex System-of-Systems.

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