A Hetero-functional Graph Theory for modeling interdependent smart city infrastructure

An increasing percentage of the world's population is living in cities. As the urban population rises, it places an increasing stress on the services provided by the city's infrastructure. Concurrently, there is a desire to reduce the presence of physical infrastructure in the urban landscape. The challenge of improving infrastructure performance while reducing its physical footprint requires a holistic approach that recognizes the interdependency of the city's infrastructure. Smart city projects have the ability to reach across disciplines and leverage that interdependency.

Effectively leveraging the interdependency of the city's (cyber-)physical systems requires a deep understanding of the integrated system. Traditionally, a city's infrastructure systems have been represented using physics-based models specific to the discipline. Electric power systems have been modeled using the power flow equations, road networks with transportation simulators, and water distributions systems with hydraulic models. Quantitative methods that transcend the domains to define measures of resilience and sustainability are often based on graph theory. These methods, however, do not address the interdependency and heterogeneity of these infrastructures. Other domain transcending methods, such as model-based systems engineering, allow for the modeling of interdisciplinary engineering systems, but lack quantitative capabilities. Over the past decade, Hetero-functional Graph Theory has been developed to address this need. In brief, hetero-functional Graph Theory draws upon both graph theory and model-based systems engineering to develop quantitative, structural representations of interdependent multi-disciplinary engineering systems.

Recently, Hetero-functional Graph Theory has been reconciled and published in the book *"A Hetero-functional Graph Theory for Modeling Interdependent Smart City Infrastructure"* by Wester C.H. Schoonenberg, Inas S. Khayal, and Amro M. Farid. The book first discusses the background and mathematical concepts in Hetero-functional Graph Theory, and then applies the theory to a three-layer smart city infrastructure test case entitled *Trimetrica.* The system consists of a water distribution system, an electric power system, and an electrified transportation system. The example demonstrates the mathematical representation of these systems as a single interdependent infrastructure system. Such a model can be used to explore the impact of smart city projects across multiple (cyber-)physical systems.