MATHEMATICAL SCIENCES

DISMA/CRT - Network models for societal-scale systems

Funded By	Dipartimento DISMA FONDAZIONE CRT CASSA DI RISPARMIO DI TORINO [P.iva/CF:06655250014]
Supervisor	COMO GIACOMO - giacomo.como@polito.it
Contact	COMO GIACOMO - giacomo.como@polito.it FAGNANI FABIO - fabio.fagnani@polito.it
Context of the research activity	Production, financial, transportation, and energy networks are key societal-scale systems whose behavior strongly affects our welfare. While optimized to properly work under nominal conditions, such systems often exhibit an undesirable and sometimes unpredictable behaviors when hit by shock events. At the root of the fragility of these systems is their network nature. This project aims at developing mathematical methodologies for the analysis and a resilient design of such systems.
	Production, financial, transportation, and energy networks are key societal-scale systems whose behavior strongly affects our welfare. While optimized to properly work under nominal conditions, such systems often exhibit an undesirable and sometimes unpredictable behaviors when hit by shock events. At the root of the fragility of these systems is their network nature. Indeed, interconnections allow for the propagation of risk, as local shocks can possibly trigger cascading disruptions capable of affecting a large part of the system. This project aims at developing mathematical methodologies to address such issues in a rigorous scientific way, offering both analytical and computational tools for the analysis and design of societal-scale systems. The project has two main lines: depending on the PhD student's interest, the research will mainly focus on one of them: (1) Integrated Supply Chains and Financial Networks Recent international events such as the Covid-19 pandemic and the Russian invasion of Ukraine have had important consequences on industrial production in several sectors, putting its resilience in danger. The crisis originated in the real sector, namely, in the production of goods, and has spilled over to the financial sector, namely, to the production of financial services from banks and other intermediaries. The fragility of real networks has then affected financial networks, causing losses and bankruptcies all over the ecosystem. We propose a model that combines economic equilibrium theory and Bayesian networks and that connects supply chains and financial networks. Our aim is to study the consequences of supply chain disruptions on the

Objectives	whole ecosystem (e.g. default cascades) building credit risk models which are directly connected to the systemic problems in production and supply chains, designing early warn- ing systems, enhancing resilience and protection mechanisms. This methods will be applied to case studies to analyze their current input-output connections as well as financial ties and their fragility, and to show how their resilience can be increased using risk pooling and suitably designed protection mechanisms. (2) Mobility and Energy Systems The ongoing technological revolution in transportation and energy poses funda- mental new scientific challenges that this project intends to address. First, we will introduce dynamical models that couple the physical variables (traffic and energy flows) and the decisional ones (information flows, price dynamics, users' behavior) and study them both from an analytic and a simulation perspective. Second, we will develop new tools, based on game theory and information the- ory, for the resilient control of such systems and the design of infrastructures and institutions. Our final goal is the synthesis of efficient and resilient market mechanisms, taxation, incentives, and information systems in order to influence all agents and push them toward optimal welfare. Bibliography 1. A. Alleyne et al, "Control for societal-scale challenges: Road map 2030," 2023. 2. D. Acemoglu, V.M. Carvalho, A. Ozdaglar, and A. Tahbaz-Salehi, "The Network Origins of Aggregate Fluctuations," Econometrica 80 (5), pp. 1977–2016, 2012. 3. P. Glasserman and H.P. Young, "How likely is Contagion in Financial Networks?," Journal of Banking & Finance, 50(C), pp. 383–399, 2015. 4. V. M. Carvalho and A. Tahbaz-Saleh, "Production Networks: A Primer," Annual Review in Economics, 11, pp. 635–663, 2019. 5. L. Massai, G. Como, F. Fagnani, "Systemic risk and equilibria in saturated networks," Mathematics of Operations Research 47 (3), pp. 1781–1801, 2022. 6. G Como, K. Savla, D Acemoglu, M.A. Dahleh, and E. Frazzoli, "Ro- bust Distributed Routing in Dynamical Flow Networks-Part I: Locally Responsive Policies and Weak Resilience," IEEE Transactions on Auto- matic Control, 58(2), pp. 317–332, 2013. 7. G. Como and R. Maggistro "Distributed dynamic pricing of multiscale transportation networks," IEEE Transactions on Automatic Control, 67(4), pp. 1625–1638, 2021. 8. D. Bergemann and S. Morris, "Information design: A unified perspective," Journal of Economic Literature, 57(1), pp. 44–95, 2019. 9. M. Roozbehani, M.A. Dahleh, S.K. Mitter, "Volatility of power grids under real-time pricing," IEEE Transactions on Power Systems 27 (4), pp. 1926 –1940, 2012. 10. K. Bimpikis, S. Ehsani, R. and Ilkilic, "Cournot competition in networked markets", Management Science, 65(6), pp. 2445–2945, 2019.

Skills and competencies for the development of the activity	Basic knowledge of undergraduate mathematics (calculus, linear algebra, probability) and a strong interest in network models.