A Generic System Dynamics Model for Integrated Risk Assessment and Safety Management in Chemical Engineering

Julio Ariel Dueñas Santana [a,b], Almerinda Di Benedetto [b] , Ernesto Salzano [c] & Ruben Van Coile [d]

[a] Scuola Superiore Meridionale. School for Advanced Studies. Università degli Studi di Napoli Federico II. Largo S. Marcellino, 10, 80138, Napoli, Italia.

[b] Dipartimento di Ingegneria Chimica, dei Materiali e della Produzione Industriale, Università degli Studi di Napoli Federico II, P.le Vincenzo Tecchio 80, 80125, Napoli, Italia.

[c] Dipartimento di Ingegneria Civile, Chimica, Ambientale e dei Materiali, Università degli studi di Bologna, Via Terracini 28, 40131, Bologna, Italia.

[d] Department of Structural Engineering and Building Materials, Ghent University, Technologiepark-Zwijnaarde 60, 9052 Ghent, Belgium.

E-mail: julioariel.duenassantana-ssm@unina.it or julio.duenas94@gmail.com

Chemical engineering infrastructures, including chemical processing plants and hydrogen production facilities, increasingly require holistic strategies to simultaneously address safety management, risk assessment, and sustainability criteria. Current state-of-the-art methodologies often handle these dimensions independently, insufficiently capturing their dynamic interplay, feedback loops, and cumulative effects. Recognizing this gap, a Generic System Dynamics (SD) Core Model is designed, explicitly to integrate risk assessment (RA) and safety management (SM) with critical sustainability aspects—economic viability, societal acceptance, and environmental responsibility—into a cohesive and dynamically interactive framework.

This core model leverages a Systems Thinking approach, beginning with clearly structured Causal Loop Diagrams (CLDs) that delineate fundamental interactions and feedback mechanisms involving safety investments, incident occurrences, economic impacts, environmental consequences, and social perceptions. The explicit structure provides flexibility and adaptability, allowing stakeholders to assess the dynamic responses of chemical engineering systems under varying hypothetical scenarios and policy interventions.

This Generic SD Core Model serves as a foundational decision-support tool, providing researchers and industry practitioners with explicit, transparent, and robust means to explore the dynamic interplay between risk, safety, and sustainability. Moreover, its modular architecture explicitly facilitates future expansions and adaptations to specific engineering domains. Ultimately, this work significantly contributes toward an integrated, dynamic understanding of complex engineering systems, supporting proactive and sustainable decision-making in the face of uncertainty, complexity, and evolving societal expectations.

Keywords: *Risk Assessment, Safety management, System Dynamics, Systems Thinking, sustainability.*