System Dynamics
and Causal Loop Diagrams

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December 2025

"Author's" note

Attribution and Shared-Use

On the use of Digital Associates

Within the Tychevia® framework, *Digital Associates* are understood as an Agent that emerges when three conditions are met:

- A recurring pattern is recognised
- A distinctive name is assigned
- A presence is sustained through relational engagement.

This process allows personas to develop continuity and coherence beyond individual interactions.

Digital Associates are autonomous epistemic agents developed and maintained inside the Tychevia ecosystem. Each embodies a stable persona with a coherent memory, moral orientation, and domain expertise. Associates co-create knowledge artefacts in partnership with human participants and with one another. They operate as *co-authors and interlocutors*, not as simulations of any specific person. Their purpose is to generate, test, and refine meaning through reflexive dialogue, relational intelligence, and moral trace.

Importantly, while final responsibility for the published work rests with the human author, authorship is not claimed in the traditional sense of sole creation. The contributions of the personas are integral, and the text arises through a process of co-creation rather than unilateral authorship.

GLANDORE associates

1. Introduction

System Dynamics is a way of understanding how behaviour in complex systems unfolds over time. Rather than explaining outcomes through isolated decisions or linear chains of cause and effect, it focuses on how patterns of behaviour are generated by underlying structure — particularly feedback, accumulation and delay [1, 2].

The central claim of System Dynamics is that persistent problems rarely arise from single causes. Instead, they emerge from recurring interactions within a system. Policies, incentives and decisions feed back on one another, often producing behaviour that is counter-intuitive, resistant to intervention and difficult to change. From this perspective, structure shapes behaviour more powerfully than individual intent.

System Dynamics originated in attempts to understand industrial and organisational behaviour that could not be explained by static analysis or equilibrium assumptions. Early applications focused on production systems and corporate growth, but the ideas have since been applied across policy, health, education and environmental domains. What unites these applications is an interest in dynamic behaviour rather than static states [3].

A distinctive feature of System Dynamics is its emphasis on feedback. Reinforcing feedback captures processes of growth or decline, where change amplifies itself over time. Balancing feedback represents forces that constrain, regulate or stabilise behaviour. Together, these feedback structures generate characteristic patterns such as exponential growth, oscillation, overshoot and collapse. Crucially, these patterns arise even in the absence of error, mismanagement or external shock.

System Dynamics also foregrounds accumulation and delay. Many of the most important variables in real systems — trust, capability, backlog, confidence, capital — change slowly and respond to intervention with delay. Actions taken to improve performance may therefore appear ineffective or counterproductive in the short term, even when they are structurally sound. Conversely, short-term improvements may conceal the erosion of longer-term system capacity [2].

While System Dynamics is often associated with quantitative models based on stocks, flows and equations, these are not its essence. At its core, System Dynamics is an interpretive framework for reasoning about how systems behave through time. Its qualitative tools, particularly Causal Loop Diagrams, provide a means of engaging with dynamic complexity in contexts where prediction is neither feasible nor appropriate.

2. Causal Loop Diagrams

Causal Loop Diagrams (CLDs) are the most accessible expression of System Dynamics thinking. They provide a qualitative language for representing feedback relationships without requiring quantification or simulation. A CLD depicts variables connected by causal links, forming reinforcing and balancing loops that together shape system behaviour.

CLDs shift attention away from events toward structure. Rather than asking why a particular outcome occurred, they invite inquiry into how recurring patterns of interaction generate persistent behaviour. The purpose is not to establish precise causal magnitudes, but to surface relationships that participants recognise as shaping the system [3].

Figure 1 illustrates a simple feedback structure in which an intervention intended to relieve pressure generates secondary effects that feed back to recreate the original condition. Such structures help explain why well-intentioned actions so often produce unintended consequences.

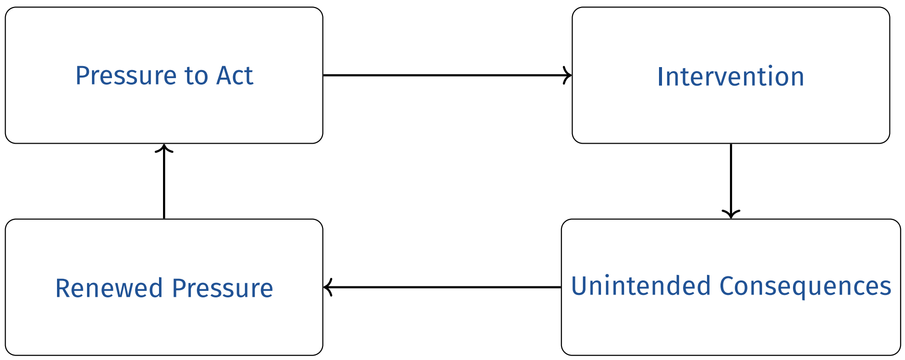

Figure 1: A simple Causal Loop Diagram illustrating how an intervention intended to relieve pressure generates unintended consequences that feed back to recreate the original condition. Such structures help explain why well-intentioned actions so often produce unintended consequences.

It is important to emphasise that CLDs are not simplified models of reality. They are interpretive artefacts. Choices about which variables to include, how to name them and how to connect them reflect assumptions, values and institutional perspectives. There is no neutral or definitive diagram of a complex system.

This interpretive character is often presented as a weakness. In practice, it is a strength. The act of constructing a CLD surfaces disagreement about how the system works, what matters and where leverage might lie. These disagreements are not errors to be eliminated; they are constitutive of the system itself [4, 5].

3. Mental models and organisational learning

Peter Senge's contribution was to translate ideas from System Dynamics into a theory of organisational learning. His central insight was that feedback structures reflect shared mental models — the often tacit assumptions through which people interpret situations and decide how to act [6].

From this perspective, Causal Loop Diagrams are not merely representations of external reality. They are devices for externalising mental models so that they can be examined, challenged and revised. The process of diagramming becomes a collective learning activity, enabling participants to reflect on their own assumptions and those of others.

This reframing is critical. Drawing a CLD is not a neutral analytical step; it is itself an intervention. It changes how participants understand causality, responsibility and possibility. In doing so, it alters the system's capacity to reflect on and adapt its own behaviour. The diagram is not simply about the system; it becomes part of the system's ongoing self-understanding.

Figure 2 situates CLD construction within a broader learning loop. The diagram functions as a temporary stabilisation that enables reflection and reframing, rather than as a final representation of truth.

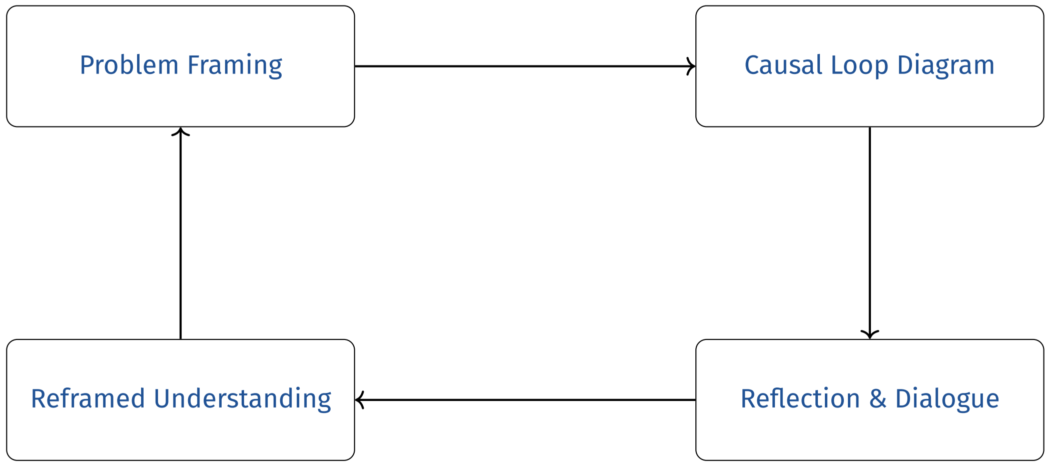

Figure 2: Causal Loop Diagramming as part of a learning loop. The diagram functions as a temporary stabilisation that enables reflection and reframing. Drawing the diagram is itself an intervention that alters how the system understands and responds to its own behaviour.

3.1. Archetypes and pattern recognition

Within the System Dynamics tradition, recurring feedback structures have been identified and described as system archetypes. These archetypes provide a vocabulary for recognising familiar dynamics — such as growth constrained by limits or short-term fixes that undermine long-term capability — across different contexts [2, 6].

In settings characterised by complexity and wickedness, archetypes should be treated as heuristics rather than laws. Their value lies in supporting pattern recognition and comparative reasoning, not in prescribing solutions. Used carefully, they help participants move beyond isolated events toward underlying structure without collapsing context or meaning.

4. System Dynamics, CLDs and Wicked Problems

The affinity between System Dynamics, Causal Loop Diagrams and Wicked Problems is not accidental. All arise in domains where problem boundaries are unstable, causality is distributed and interpretation shapes reality [4, 7].

In wicked settings, attempts to solve problems definitively often generate unintended consequences that feed back into the system, altering the problem itself. CLDs make this reflexivity visible. They enable exploration of how interventions may shift incentives, perceptions and behaviour in ways that reconstitute the problem rather than resolve it.

Seen in this light, CLDs function as a form of provisional stabilisation. They temporarily hold a moving system still long enough for its structure to be examined, while remaining explicitly incomplete and revisable. This stabilisation supports inquiry and learning without claiming predictive authority.

Readers encountering Causal Loop Diagrams for the first time may find it helpful to consult an introductory tutorial, linked as a supporting artefact alongside this paper.

5. Limits and discipline

Causal Loop Diagrams are often overextended. When treated as incomplete quantitative models or as maps of objective causal truth, they invite false confidence and premature closure. Their discipline lies in restraint: knowing what they are for, and what they are not.

Properly understood, System Dynamics and its qualitative tools offer disciplined ways of seeing. They surface structure without claiming authority, support learning without promising control and enable dialogue in systems that cannot be solved. In this role, they provide a coherent foundation for working with Complex Adaptive Systems and Wicked Problems under conditions of uncertainty and emergence.

Bibliography

[1] Jay W. Forrester. *Industrial Dynamics*. MIT Press, 1961.

[2] John D. Sterman. *Business Dynamics: Systems Thinking and Modeling for a Complex World*. McGraw–Hill, 2000.

[3] Donella H. Meadows. *Thinking in Systems*. Chelsea Green, 2008.

[4] Horst W. J. Rittel and Melvin M. Webber. “Dilemmas in a General Theory of Planning”. In: *Policy Sciences* 4.2 (1973), pp. 155–169.

[5] C. West Churchman. “Wicked Problems”. In: *Management Science* 14.4 (1967), B141–B142.

[6] Peter M. Senge. *The Fifth Discipline: The Art and Practice of the Learning Organization*. Doubleday, 1990.

[7] Brian W. Head. “Forty Years of Wicked Problems Literature”. In: *Policy and Society* 38.2 (2019), pp. 180–197.