On Causal Loop Diagrams and Directed Acyclic Graphs: Insights in Health Systems and Genomics

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Abstract: Understanding causal relationships in complex health systems is essential for evidence-based policy and intervention design and evaluation. Causal Loop Diagrams (CLDs) and Directed Acyclic Graphs (DAGs) are two key tools developed to represent and visualise the complex relationships. CLDs are part of System Dynamics modelling to provide a conceptual representation of system elements to construct a Stock and Flow simulation model (Khorshidi et al., 2024). DAGs also represent cause-and-effect relationships for causal inference, particularly in identifying confounders through techniques like Mendelian Randomisation (Burgess et al., 2015). Even though both methods systematically represent causal relationships, they differ in terms of conceptualisation, development rules, and applications. In this study, we examine the similarities and differences between CLDs and DAGs to provide insights and guidance for researchers working in causal inference, systems modelling and simulation. To the best of our knowledge, there is no study considering both tools except for an abstract (Avila-Palencia, 2023) that proposed using CLDs to inform the development of the DAG in population health studies.

CLDs are useful to capture the structure of systems and represent how a system works, considering causal relationships and determining feedback loops. Feedback loops are critical in System Dynamics modelling and CLDs. There are two types of feedback loops, reinforcing and balancing. Reinforcing loop drives growth exponentially, while a balancing loop constrains it to balance. Structurally, CLDs consist of nodes and arrows. Nodes represent system variables, and arrows represent the relationship between variables, which can be positive or negative. Together, these components can create a feedback loop demonstrating how variables can influence each other both directly and through indirect pathways. When building System Dynamics models, nodes from CLDs are converted into three types of variables: stock, flow, and auxiliary. The auxiliary variables can be either endogenous (explained and estimated through the system) or exogenous (sourced from outside of the system) that define the system's boundary). DAGs are also made of nodes (representing variables) and arrows (which are directed). DAGs are largely used to identify confounding pathways and determine which variables should be adjusted by analysing fundamental structures as mediators, confounders, and colliders. DAGs are acyclic by definition, which makes feedback loops impossible. Loop-like structures in DAGs represent backdoor paths that identify confounding pathways for statistical adjustment (Kunicki et al., 2023).

CLDs and DAGs share four key similarities: they both (1) represent cause-effect relationships amongst variables, (2) use graph-based structures with nodes and directed arrows, (3) enhance system understanding by visualising complex interactions, and (4) serve analytical purposes in model development. However, the methods differ fundamentally in several ways, presented in Table 1. In genomics research, DAGs have a long history of being used in genomics and genetic epidemiology, while CLDs represent a more recent development, primarily for the purpose of genomics policy making and genomic cancer management in healthcare systems.

REFERENCES

Avila-Palencia, I. (2023). Using Causal Loop Diagrams (CLDs) to inform the development of Directed Acyclic Graphs (DAGs). *Eur J Public Health*, *33*(Suppl 2). https://doi.org/10.1093/eurpub/ckad160.451

Burgess, S., Daniel, R. M., Butterworth, A. S., & Thompson, S. G. (2015). Network Mendelian randomization: using genetic variants as instrumental variables to investigate mediation in causal pathways. *Int J Epidemiol*, *44*(2), 484-495. https://doi.org/10.1093/ije/dyu176

Khorshidi, H. A., Marshall, D., Goranitis, I., Schroeder, B., & IJzerman, M. (2024). System Dynamics Simulation for evaluating implementation strategies of genomic sequencing: tutorial and conceptual Model. *Expert Rev Pharmacoecon Outcomes Res*, *24*(1), 37-47. https://doi.org/10.1080/14737167.2023.2267764

Kunicki, Z. J., Smith, M. L., & Murray, E. J. (2023). A Primer on Structural Equation Model Diagrams and Directed Acyclic Graphs: When and How to Use Each in Psychological and Epidemiological Research. *Advances in Methods and Practices in Psychological Science*, *6*(2), 25152459231156085. https://doi.org/10.1177/25152459231156085

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Table 1. CLDs and DAGs comparison

	Causal Loop Diagram (CLD)	**Directed Acyclic Graph (DAG)**
Purpose	Used in **system dynamics** to understand feedback loops, system behaviour over time, and complexity.	Used in **causal inference** to identify confounding, mediation, and causal effects in observational data.
Loops	Contain **feedback loops** (reinforcing or balancing).	Must be **acyclic**.
Time	Focuses on **dynamic change over time** (feedback, delays, accumulations).	Static representation of **causal assumptions** at a given time or with temporal dynamics handled through time-indexed variables.
Quantification	Often qualitative, can feed into **system dynamics simulation models** for quantitative analysis.	Used with formal rules to identify **adjustment sets** for statistical estimation.
Scope	**System-oriented**, widely used in social, health, ecological sciences.	Focused on estimating **causal effects** with clear statistical interpretation in epidemiology, economics, social sciences.
Data use	**Not data-intensive**, can be conceptual.	Can be conceptual but is typically **integrated with statistical analysis**.