Causal Loop Diagramming of Socioeconomic Impacts of COVID-19

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The complexity, multidimensionality, and persistence of the COVID-19 pandemic have prompted both researchers and policymakers to turn to transdisciplinary methods in dealing with the wickedness of the crisis. While there are increasing calls to use systems thinking to address the intricacy of COVID-19, examples of practical applications of systems thinking are still scarce. We revealed and reviewed eight studies which developed causal loop diagrams (CLDs) to assess the impact of the COVID-19 pandemic on a broader socioeconomic system. We find that major drivers across all studies are the magnitude of the infection spread and government interventions to curb the pandemic, while the most impacted variables are public perception of the pandemic and the risk of infection.

Keywords: causal loop diagram ; COVID-19 ; network theory

1. Introduction

Despite a significant progress on vaccination, with almost four billion vaccine doses administered, the daily number of new COVID-19 cases worldwide is still around the 500,000 mark, and the daily number of deaths is close to 10,000 as of late July 2021 [1]. Furthermore, various new mutations of the virus, an uneven distribution of vaccines across different countries, the unwillingness of large parts of the populations in some countries to receive vaccination, as well as other factors contribute to the persistence of the COVID-19 crisis as the most pressing issue globally [2].

The COVID-19 pandemic is not only a grand challenge for the public health system, but it has also affected virtually all areas of human life. The spread of the virus, as well as various mitigation and adaptation measures have had a widespread effect on economic activity, job security, social relations, mental health, and trust in others and institutions [3]. This makes the challenge of "getting back to normal life" truly multi-dimensional and calls for an interdisciplinary approach [4]. However, multiple and potentially lagged interdependencies between various components of the affected systems are difficult to oversee and comprehend by the human brain in the absence of special tools, while the lack of a holistic perspective increases the risks of unintended adverse consequences [5][6]. Systems thinking has been suggested to unravel this challenge by accounting for essential links and feedback loops between issues that both scientists and policymakers tend to consider in isolation, creating a shared understanding of the problem and identifying potential leverage points [7][8].

Some scholars responded to this call advocating the use of systems thinking in a rather general sense [9][10][11], while others came up with some concrete examples of the application of systems thinking, usually through employing causal loop diagrams [2][4][12][13][14][15][16] or system dynamic models [17][18][19].

Causal loop diagramming (also termed systems mapping) is a principal qualitative system thinking tool used both inside academia and for communicating with policymakers and the general public [20]. Causal loop diagrams (CLDs) constitute a schematic description of the considered system depicting its components and the (causal) relations between them. Components are connected by directed links. Each link represents an impact (causal influence) of one component on another. The impact can be positive, in which case an increase/decrease of the state of the impacting component leads to an increase/decrease of the state of the impacted component, or negative, in which case an increase/decreases of the state of the impacting component leads to the opposite change of the state of the impacted component, i.e., a decrease/increase. CLDs are useful for formalizing mental models of individuals and groups, rapid identification of the possible drivers of the considered system's dynamics, and communicating feedback and archetypal structures in the considered system [20]. CLDs can be used as a standalone qualitative modeling tool or as a step toward developing a quantitative simulation, e.g., a system dynamics model [21].

This paper aims to review the state-of-the-art studies that construct CLDs to investigate the impact of the COVID-19 pandemic on a broader human–society–environment system. This review intends to formulate methodological as well as applied insights. Methodologically, our analysis provides observations (a) on what seems to be a common practice in research involving causal loop diagramming to analyze the socioeconomic impacts of COVID-19 from the systems perspective; (b) on major gaps in the existing CLDs that deal with systems impact of COVID-19; and (c) on what seems to be a good practice in the development, presentation, and analysis of CLDs. Observations (a), (b), and (c) can be useful for future CLD developers for benchmarking their work against the state-of-the-art, for positioning and focusing their research, and for increasing the impact of their research, respectively. The applied insights of this paper include observations that can guide quantitative model development to further analyze the multi-dimensional impacts of COVID-19 and policy-relevant observations.

2. Current Insight on CLDs

We analyzed eight studies aimed to illustrate the complexity and multi-dimensionality of the COVID-19 crisis using a practical tool of systems thinking—causal loop diagrams (CLDs). Here, we highlight some of the observations. First, we observed that the key components of the reviewed CLDs are consistent across all eight studies, however, different studies put different emphases on the main drivers and main affected components of the analyzed systems. This diversity of both drivers and affected variables supports the need for a transdisciplinary response to the pandemic [13].

The insights on common and rare components, as well as on drivers and the most affected elements can be useful for future CLD developers and quantitative modelers to guide their research. For example, CLD analysts may decide to focus on gaps revealed in the existing CLDs, e.g., inequality, or they may choose to focus on the most important components to dig deeper into their dynamics and impacts. However, the scope of some CLDs could be quite narrow, and therefore, reusing concepts from them for a more general study should be done carefully.

Quantitative modeling and in particular systems dynamics (SD) modeling [21] can benefit from this review, as modelers can use the discussed CLDs a basis for their models. The author of [4] supports this point of view: "[CLDs] have the potential to be converted into Stock and Flow diagrams that allow quantification of results". For example, CLDs can be used to extend the traditional SIR-type system dynamic models to make them more realistic and useful for decision making [22]. The most essential system components identified in this review can guide the choice of variables in models.

Our insights in this part can also be useful for policymakers. The analysis of drivers can indicate candidate leverage points for the mitigation of the adverse consequences of COVID-19 and improve the resilience of the socioeconomic system to "provide a basis for effective response to the control of the pandemic" [4] and "bounce forward" from the shock caused by the pandemic [7]. The analysis of the most impacted components carried out in the same subsection can draw the attention of policymakers to areas where unintended and unwanted effects may be anticipated.

Second, we observed that the average number of links per node across the reviewed CLDs does not depend on the diagram size. We proposed that this might be because the CLD developers regarded three to four links per node as an appropriate representation of complexity in their studies. This and other observations discussed can be useful for future developers of CLDs in the context of COVID-19 for benchmarking their models and planning their efforts and scope.

Third, we revealed a higher-than-expected prevalence of two- and three-component feedback loops in the reviewed CLDs. This is different from the results obtained by [23], which found a low prevalence of these feedback structures in cognitive maps developed in the context of sustainable agriculture. This difference can be explained by the fact that the CLDs that we reviewed were developed by researchers familiar with systems thinking, which, according to [23], leads to a higher complexity of the developed cognitive models. Furthermore, in the same subsection and consistently with [23], almost all of the CLDs that we reviewed underrepresent "multiple effects" and "indirect effects" motifs, and they also underrepresent "multiple causes" motifs, which are, on the contrary, prevalent in [23]. The latter fact can probably be attributed to the novelty of the COVID-19 pandemic. Interestingly, while all authors discuss the feedback loops identified in their CLDs, none of them explicitly analyze multiple causes or effects for any components of the considered system [14]. This could be attributed to the fact that humans tend to perceive effects as more abstract and distant phenomena than causes, as suggested by the construal-level theory [24]. These observations can be useful for CLD developers for benchmarking their analysis as well as for researchers generally focusing on complexity and systems thinking.

Fourth, our observations made on good practices of development, presentation and analysis of CLDs can be helpful for future CLD developers. In terms of CLD development, we suggested that a detailed description of the design procedure enhances trust in the developed CLD. In terms of CLD presentation, highlighting meaningful subsystems of a large system helps reading a complex CLD. Finally, in terms of analysis, feedback loops and other smaller structures which constitute CLD building blocks such as archetypes and motifs can shine the light on the system complexity and help understand its behavior.

We conclude that despite the numerous recent calls to use systems thinking for addressing the complexity of the COVID-19 crisis, its practical applications are currently scarce; for example, [2] notes in this regard that “systems thinking approach to analyze the consequences of the COVID-19 outbreak is relatively novel and not extensively used”. More recent studies generally do not contain more complex causal structures than the earlier ones. Therefore, we assume that they do not build upon the past models. Only one of the reviewed CLDs is explicitly based on another existing CLD. A plausible explanation of this fact is that CLDs are often developed for a specific purpose with a further aim to inform a more sophisticated model or analysis. However, we are not aware if any of the reviewed CLDs have been used for such a purpose up to the date of our writing.

We suggest that CLDs could benefit from a rigorous description of the development procedure and information sources used. This would improve their credibility and enable other researchers to enhance them further or conduct other types of analysis. Moreover, sharing the model source file can also be beneficial, especially since most of the reviewed maps showed consistency in the most important components and interactions and the degree of their complexity. Therefore, the reusability of CLDs could be key to enhance the efficiency of research efforts and/or to promote more advanced studies.

Being a useful systems-thinking tool, CLDs also have a series of limitations. As with every model, a CLD constitutes a major simplification of the considered real system. CLDs do not distinguish stocks and flows, which, along with the feedback structures, are the essential concepts in modeling systems behavior [20][25]. CLDs are inherently static and therefore cannot account for the dynamics of the modeled system, i.e., behavior over time [25], without being translated into a computer simulation model. CLDs invite users for a mental simulation, which, however, can be challenging even for relatively simple CLDs [20].

Notwithstanding these limitations, we argue that the reviewed papers demonstrate the power of systems thinking to inform a holistic picture of the pandemic’s impact on a broader socioeconomic system. Indeed, CLDs are helpful for an initial exposition of the complexities brought about by COVID-19 for policymakers and the general public. They promote critical thinking [26] and show how deeply the pandemic affects all areas of human activity and that there is no easy “silver bullet” to solve this wicked problem [27], thus calling for a transdisciplinary approach. We suggest that building more comprehensive CLDs and having formal tools for their analysis [28][29][30] can further unleash the potential of systems thinking to inform decision making in circumstances of a wicked problem, such as the COVID-19 crisis—either as a standalone tool or as an input to more sophisticated models and analyses. As no single modelling approach can serve as a panacea for addressing a complex policy issue, CLDs should ideally be used in combination with other methods and models to provide reliable policy advice.

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