Urban Dynamics Modeling Methods for Regional Health Equity

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Abstract

How do we understand urban dynamics to effectively inform community and population health? Improving urban health outcomes in the United States is closely tied to understanding and applying knowledge to regional health equity and trends. This paper addresses this gap by proposing the use of disaggregated geospatial or community unit level data in addition to novel person-oriented analyses with community participation as a central to developing insights that translate into policy.

We combine two different and easily accessible methods and illustrate their use across two urban contexts. First, we show how historical effects of "red lining" in Cleveland can be readily included into Stella interfaces by focusing on simulating a geographic community using extant data. Second, we show how configural frequency analysis (CFA) can yield novel insights into clustering of longitudinal patterns of municipal trends in St. Louis County.

We draw on two different projects to illustrate our approach. The first focuses on work developed for Cleveland, Ohio across a variety of projects (including projects that extend beyond Cleveland in terms of methods). The second focuses on characterizing trends using CFA from an earlier study (pre-Ferguson) highlighting different clusters of longitudinal patterns.

Reframing urban dynamics, and specifically geospatial inequities through the lens of system dynamics is not only feasible but highlights a critically important gap where disaggregated dynamics play a critical role to understanding regional health inequities.

Introduction

How do we understand urban dynamics to effectively inform community and population health driven by social determinants of health? *Urban Dynamics* (Forrester, 1969) was one of the first modern applications of computer modeling of cities with a focus on understanding the rise and decline of urban cores in the United States. Forrester (1969) reframed the urban crises in the US during the late sixties from a set of exogenous drivers (e.g., lack of economic opportunities, social unrest) to an endogenous perspective of living, dynamic systems composed of interacting accumulations or stocks (e.g., population, housing, employment, and capital investment) where nonlinear feedback mechanisms were the drivers of segregation, suburbanization, and growth and decline. Forrester emphasized that urban problems rarely stem from isolated failures. Instead, he argued, urban dynamics were being generated by the deeply embedded feedback structures across labor markets, housing, and financial institutions where well-intentioned policies exacerbated the very problems, they were intended to address.

Urban Dynamics originally focused on stock and flow structures aggregated at the level of a city with suburbs treated as outside the boundary of the endogenous system. This was controversial at a time when many attributed the decline of cities to urban sprawl and lack of affordable housing. Subsequent efforts (e.g., Mass, 1974; Schroeder et al., 1975) explored these assumptions through extension of model boundaries, sensitivity analyses, and replication to other communities (e.g., Lowell, Massachusetts), but largely left the aggregation of stocks within a city or municipality unquestioned. As the crises of cities in the US continued and modeling for urban planning became more controversial in 1970's stemming from not just the counterintuitive policy recommendations at odds with popular ideas, but also lack of transparency in model assumptions, computer modeling of urban dynamics using a variety of methods fell into scientific and policy disrepute in a "Requiem for Large-Scale Models" (Lee, 1973). Despite Urban Dynamics by Jay W. Forrester being regarded as an exception for its transparency in model assumptions, system dynamics urban modeling largely shifted from public debate into a back-office tool for practitioners and city managers (Alfeld, 1995). Its adoption in regional urban planning in the United States remained limited, even as post-industrial cities such as Baltimore, Philadelphia, Cleveland, and St. Louis continued to face economic challenges.

Urban public health disparities have highlighted the persistent impact of urban dynamics, renewing an emphasis to understand the social determinants of urban health over the last 20 years. This has been partly motivated by the standardization of Community Health Improvement Plans (CHIPs) anchored in an economic framework of how community and population health are produced (Evans & Stoddart, 1990) which took an explicit endogenous perspective on health drawing heavily on the thermostat metaphor (see Figure 1) in the original work.

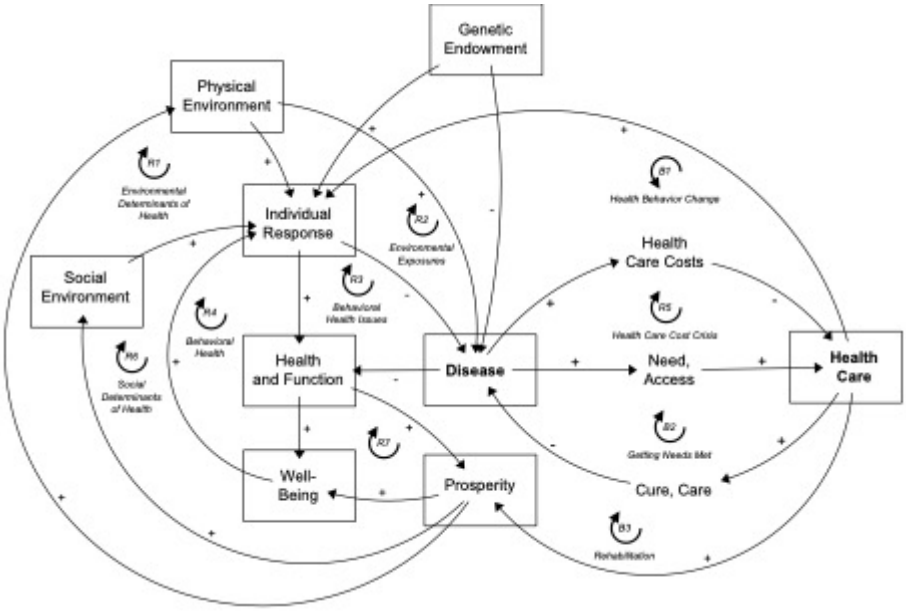

Figure 1 Adaptation of Evans and Stoddart (1990) framework as a causal loop diagram where boxes represent accumulations.

CHIPs became widely adopted across approximately 2,200 public health departments in the United States, where departments were required to develop and evaluate them every 3 to 5 years as a condition of accreditation and access to prevention funding. The widespread adoption of CHIPs was essentially a form of dynamic performance management, and more specifically, the adoption of dynamic performance governance (Bianchi & Grippi, 2024) applied to community and population health. The results of these efforts increasingly pointed to the need to address deeper structural and system barriers to improving urban health and health inequities with a call for regional equity and addressing the root causes of structural racism that recognized the social epidemiology of disease as a complex adaptive system (e.g., Burrell et al., 2021; Gullett et al., 2022; Kuhlberg et al., 2023; Payne-Sturges et al., 2023; Payne-Sturges et al., 2021; powell, 2008).

Despite the increased emphasis to take a systems approach to identify and address the underlying systemic drivers of urban health, calls for systems change and opportunities for system dynamics as a method to make a major contribution have stalled. We have, as a field, fallen into the very trap that Forrester cautioned against—valuing the model over the process of developing a model and appreciating the importance of people to advocate for counterintuitive policy change. More specifically, in cases such as the St. Louis Ferguson Commission and Cleveland Urban Agenda, the case and political motivation for systems level change through measurement and evaluation has strong support. However, where system dynamics has great potential to contribute, the field

has fallen short in terms of not adequately understanding and responding to the practical policy questions about how to advance and achieve ***regional equity***.

In this paper, we argue that efforts to address this and make a much more significant impact on improving urban dynamics of community and population health come from addressing two fundamental barriers to understanding urban dynamics of health. The first is understanding that urban dynamics of health needs to be disaggregated at the level of communities (e.g., census tracts, zip codes, neighborhoods, blocks) to better understand and address the spatial disparities that are baked into the social urban infrastructure of many US cities. The second is understanding that the dynamics of the system within these spatially disaggregated areas are more heterogeneous when it comes to trends and include both positive and negative outliers that do not correspond to conventional distributional analysis. And third, what happens at these local levels of spatial units in terms of feedback theories can best be understood by directly engaging communities to identify and unpack the feedback mechanisms and accumulations driving multiple spatially clustered outcomes from income, homeownership, wealth to lead exposures, nutrition and gun violence.

We make three main contributions. First, we illustrate how spatial disparities can be productively represented in system dynamics models, not as abstractions, but in ways that easily translate and convey information reflecting the lived experience of living in marginalized communities. Second, we draw on person-oriented analysis applied to communities to illustrate how clusters of communities identify potential reference modes. Third, we speak to the relevance and importance of the methods for directly engaging residents most affected by using group model building.

Background

In this section, we review the main foundations of work including defining regional equity and why this matters, developing an understanding of reference modes that might need to be disaggregated into longitudinal patterns or reference modes, and a statistical approach to identifying such patterns that draws on person-oriented analysis from developmental psychology.

Regional Equity

Regional equity developed in response to a policy agenda focused on regionalism that emphasized the regionally aggregated outcomes in urban conditions. There was a concern that policy agendas and investments, while benefitting a region in aggregate, would benefit some communities and neighborhoods while leaving many other neighborhoods behind. Some scholars of urban planning in places such as St. Louis took regionalism toward an even greater extreme

by encouraging communities to see themselves as competitors of other communities within the same region as a way of advancing regional economic development.

Such views largely ignored cumulative discrimination (Blank, 2005) from practices such as “red lining” (Reece et al., 2015) that systematically depreciated the value of homes in low-income and marginalized neighborhoods–impacts that are still visible today nearly a century later across a wide range of community level indicators from poverty and housing to lead exposures, gun violence, and maternal health disparities. More specifically, such arguments presupposed structural and procedural justice while claiming to solve distributional injustices through competition and thereby promoting little to no historical empirical support.

Regional equity refers to the policies and outcomes across a disaggregated map of neighborhoods where census tracts, zip codes or blocks often serve as proxies. More specifically, regional equity is the “proactive policymaking that gives all people access to neighborhood resources, connections to opportunity-rich areas throughout the region, and a voice in the future of their communities” (powell, 2008, p. 85).

Decomposing Reference Modes

Reference modes are formal descriptions of the dynamic problem to be solved and central in system dynamics. The term ‘reference modes’ is unique to system dynamics and hence often mistreated as a jargon term versus a concept fundamental to defining the boundaries of a feedback system.

All signals (information, causal influences) can be considered from complementary perspectives of the time and frequency domain. That is, anything that can be represented over time can be equivalently, represented as a composition of different frequencies. And anything in the frequency domain can be translated and uniquely represented in the time domain. These are mathematical facts.

Fundamentally, feedback systems filter what comes into, passes through, and what gets amplified in a system. It is something that most electrical engineers get exposed to and hopefully learn in a basic analog circuits course. Mechanical engineers, physicists, ecologists, musicians, and dancers are also likely to have intuitive or learned knowledge of such systems because they emphasize experientially understanding the frequency domain. The idea of a reference mode in system dynamics builds upon this knowledge by first specifying the variables of interest, and second, the time domain of interest. Reference modes are most often expressed as time series or behavior over time graphs, but they can also be verbal descriptions (Richardson & Pugh, 1986).

The centrality of reference modes is often overlooked or misunderstood in system dynamics. For example, often system dynamicists use the term ‘reference mode’ to refer to the set of behavior patterns of a system that they are aiming to replicate and satisfy the behavior reproduction test (Sterman, 2000). This would suggest that a reference mode is any trend over time in the real system that could be replicated by a simulation variable, essentially, every observed variable in the system under study. Others define the reference mode as an important tool for problem structuring to narrow the scope of a study (including Sterman).

Saeed (1998) drew attention to the problem of defining reference modes that involved multiple levels of spatially related systems and called for more formal approaches to decomposing reference modes. Saeed was concerned at the time about the dynamics of developmental economics across a region that was experiencing a variety of exogenous and endogenous drivers of economic growth that were interacting in complex ways in the frequency domain.

Person Oriented Analysis

Person oriented analysis in psychology developed in response to the prevailing variable-oriented analysis. In a variable oriented analysis, the focus is on understanding how associations between different observations exist and the central tendencies of a system. Person oriented analysis recognizes that there are exceptions that tend to cluster and are also the results of complex systems. For example, in a variable oriented analysis, we might focus on the aggregate and uniform fluid dynamics of a system. In a “person” oriented analysis, we would recognize that rocks and other obstructions in combination with the “persons” flowing through the system would alter trajectories in the flows in meaningful ways to form clusters that could not otherwise be explained in terms of the association between variables.

The idea of person-oriented analyses in developmental and community psychology has become increasingly important as community scholars recognize wide variations of outcomes across communities where statistical analyses have controlled for poverty, race/ethnicity, and other social determinants of health. For example, some neighborhoods appear to be protective while others put residents at much higher risks even when all other factors are accounted for.

Person or systems-oriented analyses build upon the idea that systems structure dynamics in ways that create both positive and negative clusters. There are multiple methods for doing a person or system oriented longitudinal analysis including latent growth curve modeling and configural frequency analysis. In this paper, we focus on the idea of configural frequency analysis (CFA) for longitudinal data applied to communities (von Eye et al., 2008; von Eye et al., 1996).

Approach

We combine two different and easily accessible methods and illustrate their use across two different contexts. First, we show how historical effects of "red lining" in Cleveland can be readily included into Stella interfaces by focusing on simulating a geographic community (e.g. zip codes or census tracts) using extant data. Second, we illustrate how CFA can yield interesting longitudinal patterns for municipalities in St. Louis County. We argue that these results open up empowering opportunities for directly engaging residents to envision transformative policies that change urban dynamics toward a more meaningful form of regional equity.

Methods

This paper draws on two distinct contexts and data sources. First, for developing a model of regional equity and representation in system dynamics models, we use data, models and examples based on public data from Cuyahoga County incorporated into a Stella interface. Specifically, we represent geospatial units of communities (in this case, census tracts) explicitly as the units of analysis by arraying the model across census tracts. The procedure to do this is relatively easy for any given outcome available at a geospatial level of analysis with accompanying shapefiles and taking ~45 to 60 minutes in total.

Second, we conduct the CFA analysis and plots for an earlier study from St. Louis by first estimating the linear associations as a proxy for the regional trends using a base model and then identifying the clusters as types and antitypes. Both procedures were implemented in open-source code using R packages.

Results

We draw on two different projects to illustrate our approach. The first focuses on work developed for Cleveland, Ohio across a variety of projects (including projects that extend beyond Cleveland in terms of methods). The second focuses on characterizing trends using CFA from an earlier study (pre-Ferguson) highlighting different clusters of longitudinal patterns.

Regional Equity

Figure 2 shows the interface developed and published as a Stella interface for illustrating the differences between a status quo scenario, equality framed policy scenario, and equity framed policy scenario. In a status quo scenario, the system is in a dynamic equilibrium. This does not mean that efforts are not underway to address inequities, just that whatever programs are doing are effectively maintaining the status quo. Empirically, this is the situation for many cities over the last 100 years or so, and specifically Cleveland. It does not mean that efforts from

philanthropists to address marginalization and negative outcomes do not matter or have not made an impact—quite the opposite—it means that such efforts are holding and preventing the dam from breaking. Such efforts are important to understand and appreciate.

The equality simulation scenario focuses on addressing gaps by redistributing resources equally. This is like extending public policies that seek to address population health outcomes whereby programs distribute resources independent of need. In this scenario, a household with significant socioeconomic advantages would have "equal" access to public programs and benefits. The results shown are not from any other special access or privileges but arise from the equal distribution of resources.

The third scenario (results not shown—go ahead and see this for yourself) focuses on an equity policy whereby investments are prioritized by need such that the communities with highest need receive the most and those with the lowest need the least. Note that the aggregate need is the same for both the equality and equity-oriented policies.

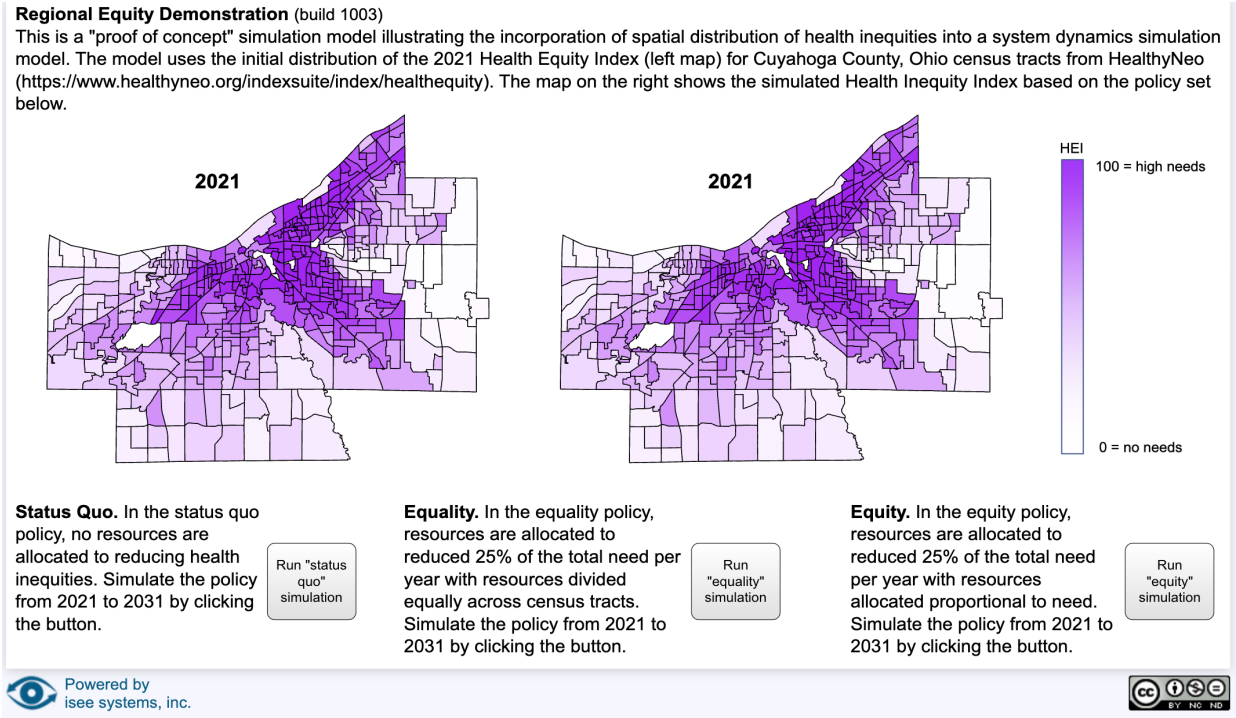

Figure 2 Interface to prototype used to illustrate regional urban health equity

The main result is that, whereas an equality-oriented policy may mitigate the intensity of regional inequities, an equity-oriented policy more directly addresses their underlying causes.

Clusters of Longitudinal Trends as Reference Modes

The special distributions and contrasts between status quo, equality-oriented policies and equity-oriented policies have been powerful examples of how we can "change the map" and why paying attention to the underlying structure matters. But they hide the underlying trends and regional dynamics over time.

Specifically, Saeed (1992, 1994, 1998) has called attention to this problem when considering multiple cases embedded within larger systems by pointing out that the observed dynamic of any particular system is the composition of both an endogenous response and exogenous environmental trends. For example, in looking at economic trends in multiple developing countries, Saeed showed how some components of the trend were specific to a country, others were regional, and still others were reflective of global economic trends. Statistical techniques such as using contrasts with longitudinal data and spectral decomposition with time series data provide one approach to establishing the empirical basis of observed trends, but they do not solve the problem of identifying trends due to the endogenous response of a system. This is a problem in multiple case study research designs exhibiting different types of behavior; for example, in studies of municipalities where some municipalities are doing well, others are oscillating, and still others are in decline. Which trends, if any, are real and which are due to natural variation and shared regional trends? In multiple case study designs of policy and environment changes (e.g., policy and environment changes for healthy eating and active living, crime prevention), trying to answer such questions can prove challenging even for participants of the system, as they are likely to give explanations of trends that conflate endogenous and exogenous generated dynamics.

Figure 3 highlights an example of a geospatial cluster of trends identified using CSA for St. Louis municipalities. Of interest to stakeholders at the time was that all of the communities in this configuration underwent annexations or mergers between previously established municipal boundaries. Importantly, the trends or reference modes of population for these communities, while growing overall, indicated an "overshoot and collapse" pattern. Annexation of municipal services might have seemed a smart move for these communities, but over time, it seemed to have backfired with long-term losses overshadowing short-term gains.

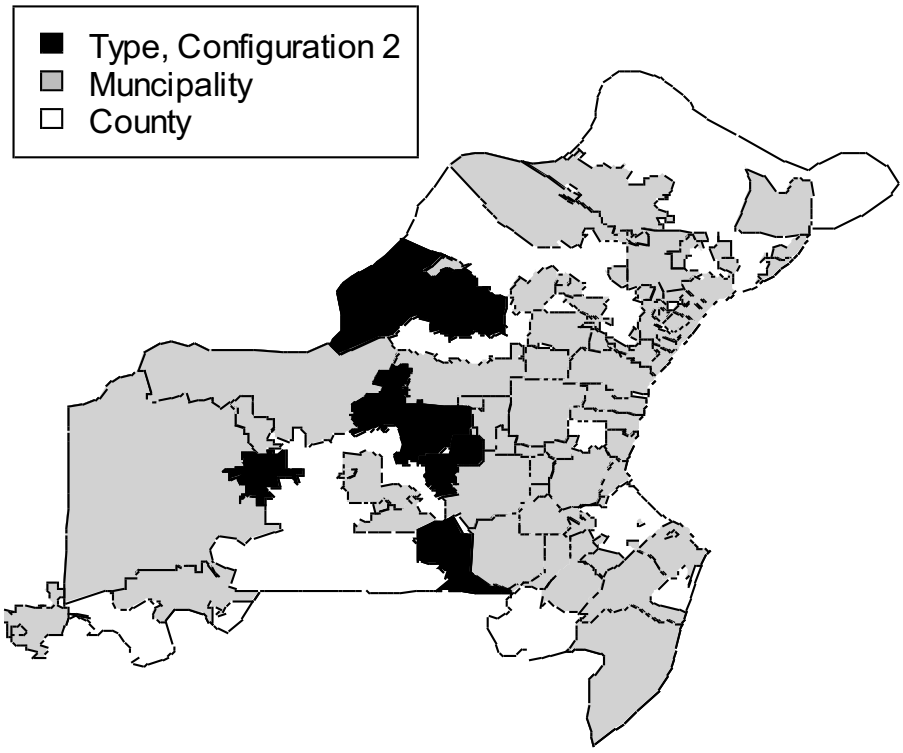

Figure 3 Geospatial plot of St. Louis municipalities identified through CFA as a positive type configuration based on longitudinal trends from 1980 to 2000.

Table 1 Total Population of Municipalities in Configuration 1 by Year

	1980	1990	2000
Ballwin	12656	21816	31223
Des Peres	8254	8395	8923
Ellisville	6233	7545	8710
Fenton	2417	3346	4248
Maryland Heights	5676	25402	25937
Town and Country	3187	9510	10879

Note 1: All of the communities in configuration 2 underwent annexation.

Note 2: Configuration 2 corresponds to a pattern that is concave down and slowing down:

Structure Determines Behavior and Community Engagement and Participation Matters

Where regional equity speaks to meaningful distribution of outcomes and CFA toward identifying positive and negative outliers of trends, both motivate the engagement of a wide range of experts, from residents with lived experience in communities to professionals and policy makers focused on regional outcomes.

Conclusion

Reframing urban dynamics, and specifically geospatial inequities through the lens of system dynamics is not only feasible but highlights a critically important gap where dynamics might make a significant impact. In this paper we highlight the feasibility of two distinct methods that advance a program of research—disaggregating spatial units of analysis in interfaces and the use of CFA for identifying clusters of trends as reference modes. We know that "structure determines behavior" and hence, the significance of engaging and directly involving communities to advance this research.

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