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Modelling the social determinants of health and simulating short-term and long-term intervention impacts for the city of Toronto, Canada

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ABSTRACT

There is a substantial body of evidence highlighting the importance of the social determinants of health in shaping the health of urban populations in Canada. The low socio-economic status of marginalized, disadvantaged, and precarious populations in urban settings has been linked to adverse health outcomes including chronic and infectious disease, negative health behaviours, barriers to accessing health care services, and overall mortality. Given the dynamic complexities and inter-relationships surrounding the underlying drivers of population health outcomes and inequities, it is difficult to assess program and policy intervention tradeoffs, particularly when such interventions are studied with static models. To address this challenge, we have adopted a systems science approach and developed a simulation model for the City of Toronto, Canada, utilizing system dynamics modelling methodology. The model simulates changes in health, social determinants, and disparities from 2006 and projects forward to 2046 under different assumptions. Most of the variables in the model are stratified by ethnicity, immigration status, and gender, and capture the characteristics of adults aged 25–64. Intervention areas include health care access, behaviour, income, housing, and social cohesion. The model simulates alternative scenarios to help demonstrate the relative impact of different interventions on poor health outcomes such as chronic disease rates, disability rates, and mortality rate. It gives insight into how much, and how quickly, interventions can reduce mortality and morbidity. We believe this will serve as a useful learning tool to allow diverse stakeholders and policy makers to ask "what if" questions and map effective policy directions for complex population health problems, and will enable communities to think about their health futures.

Introduction

People's health, wellbeing, and their likelihood of becoming ill or dying, are all affected by the broader social factors that influence the conditions in which people live, grow, work, and interact with others (CSDH, 2008; Lalonde, 1974). In the past couple of decades, a substantial body of national and international evidence has emerged that describes the crucial role of the social determinants of health (SDOH) in shaping population health, and the need to address them in order to truly advance population health in the 21st century (Braveman & Egerter, 2008; Braveman, Egerter, & Mockenhaupt, 2011; Braveman, Egerter, & Williams, 2011; Marmot, Friel, Bell, Houweling, & Taylor, 2008; Raphael, 2004; Yen & Syme, 1999). These determinants range from macro level social factors, such as education, political and economic conditions, and racial discrimination, to more proximate factors, such as people's behaviours, genetic make-up, social networks, and access to health care services. Not surprisingly, the SDOH have been recognized as structural in nature; underlying disparities in health, and ultimately shaping the inequities in health that socially disadvantaged populations experience (Braveman, Cubbin, Egerter, Williams, & Pamuk, 2010; Marmot et al., 2008; Raphael, 2004). A strong and growing body of literature has attempted to elucidate the causal pathways and mechanisms that link the SDOH to health outcomes. In their recent review of the SDOH, Braveman and colleagues highlight the interconnection between the macro- and the micro-level determinants and assert that upstream social determinants have an impact on the downstream conditions in which people live (Braveman, Egerter, & Williams, 2011). Although knowledge about the pathways through which social determinants influence health has accumulated and is growing, the complexity that is involved

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with studying and understanding these determinants, the exact pathways through which they operate, and how they affect population health outcomes continue to pose real challenges for advancing the field, and for developing coherent, practical interventions at the community level.

Population health is a function of complex systems (Diez Roux, 2007), made of individuals, organizations, institutions, communities, and subsystems which are dynamic, interdependent and interact over time. Among factors that compound the complexity are multiple levels of determinants, multiple pathways linking each determinant to outcomes, the intersection of these levels and the potential feedback relationships between all of these factors. Essential to note are also intergenerational influences and the accumulation of risk and social disadvantage across the life span (Braveman, Egerter, & Williams, 2011), further adding to the intricacies associated with population health research, particularly, intervention research (Hawe & Potvin, 2009).

Addressing population health problems and reducing systemic health inequalities calls for the active confrontation of substantial policy challenges. The range of possible interventions is wide, and the underlying factors that drive population health and health inequities are complex, especially in urban settings. The health, social and related service systems, and government policies, are equally complicated and fragmented. Moreover, resources are typically finite and constrained. They are subject to shifting political and economic instabilities. As such, it is difficult to identify and assess the effect of any particular policy and program intervention. This especially holds true as perceived timelines for intervention impact are short while, in reality, there is a considerable lag period that is often unaccounted for. We therefore need to consider new ways of approaching population health interventions, and the complex systems within which they are implemented, in order to enhance our ability to consider not only the intended impacts, but also, the often unanticipated effects (Milstein, 2008; Schwaninger, 2009).

There is a growing body of work in population and public health that draws on systems thinking concepts and mathematical modelling techniques. These influences can sharpen our thinking, refining our understanding of how determinants of health interact and shape health outcomes (Cilliers, 1998; Kauffman, 1993).

Objective

This paper reports on a project to develop a system dynamics simulation model addressing the complex web of social determinants that shape the health of populations and influence health disparities. The model focuses on elucidating the causal pathways between important population health risk factors and health outcomes, while identifying specific policy options related to the social determinants of health that have an impact on a range of selected health outcomes including mortality, chronic illness, disability, and unhealthy behaviour. The model represents the population within the geographical boundaries of the City of Toronto. Specific social determinants of health were selected for inclusion in the model (PHAC, 2004). These include social cohesion, health care access, housing, income, and health-related behaviour.

The Wellesley Urban Health Model (WUHM) is unique in two respects. First, we apply system dynamics modelling techniques to a range of social determinants of health in an urban context. Second, we draw on participatory strategies to ensure that community perspectives inform the modelling process.

Rationale for using system dynamics methodology

A systems science approach can offer a holistic understanding of dynamically complex problems and provides tools for solving such problems through the use of various modelling methodologies. One such method is system dynamics (Forrester, 1961, 1971; Meadows, 2008; Sterman, 2000, 2006), which draws on both qualitative mapping and quantitative computer simulation modelling techniques. Founded on feedback systems theory, it recognizes that the overall behaviour of any dynamic and complex system emerges from the underlying structure of that system, made up of various parts that interact over time to make up the whole (Richardson, 1991). While system dynamics places a particular focus on practical management of complex systems, and has evolved a rich set of supporting tools and approaches, it does bear a family resemblance to other areas of systems science, such as complexity theory and general systems theory (Bar-Yam, 2004; Boccara, 2004; Manson, 2001; Phelan, 2001, Schwaninger 2009). System dynamics also shares some features with dynamical systems theory, including the use of differential equations, the mathematical analysis of stability and instability, and the recognition of the role of path-dependence and lock-in effects.

Complex systems are characterized by hierarchy, self-organization, evolution and adaptation, and emergent behaviours, which result from the feedback loops, nonlinearities, and time delays among system components (Forrester, 1961, 1971; Sterman, 2000, 2006). Failure to account for these dynamic complexities often leads to poor policy decisions. System dynamics models offer a way of understanding these properties by simulating causal relationships of multiple variables over time, under different assumptions (e.g., different policy environments), and act as 'what if' tools for identifying high leverage policy interventions (Meadows, 1999).

Since the 1970s, and particularly the past two decades, system dynamics modelling has been increasingly used in health research to address critical public and population health issues (Hassmiller Lich, Osgood, & Mahamoud, 2010; Homer & Hirsch, 2006; Homer et al., 2010; Milstein, Homer, & Hirsch, 2010; Osgood et al., 2011; Tengs, Osgood, & Lin, 2001). Given the complexity associated with population health intervention research, dynamic modelling, complemented by other analytical methods, can help us understand the social determinants of poor health and health disparities and enable us to identify, assess, and develop effective interventions. Dynamic models can also allow for the inclusion of divergent stakeholder and community perspectives while helping to build consensus critical to policy development. Systems science approaches such as system dynamics modelling have the potential to transform population health research, particularly in the analysis of interventions and alternative futures.

Methods

The primary goal of the WUHM project was to construct a model which could give insight into the interdependent and dynamic factors that shape population health outcomes and health disparities in Toronto, Canada. The model aims to specify and map the array of determinants that affect health issues for a place-based population. In developing this model, we have looked to local research with communities to identify a range of issues of concern, with an eye towards exploring alternative health futures and identifying an array of action-oriented policy choices and options to reduce health disparities (Bierman et al., 2009; Hulchanski, 2007; McKeown et al., 2008; Teelucksingh & Galabuzi, 2005; Wilson, 2009). The model relies upon aggregate secondary data that is publicly available through Statistics Canada and did not require an ethical review process.

Model construction

The construction of the WUHM involved a multi-disciplinary team with skills in epidemiology, the social and behavioral