

# BMJ Open Systems science and systems thinking for public health: a systematic review of the field

Gemma Carey,<sup>1</sup> Eleanor Malbon,<sup>2</sup> Nicole Carey,<sup>3</sup> Andrew Joyce,<sup>4</sup> Brad Crammond,<sup>5</sup> Alan Carey<sup>6</sup>

**To cite:** Carey G, Malbon E, Carey N, *et al.* Systems science and systems thinking for public health: a systematic review of the field. *BMJ Open* 2015;**5**:e009002. doi:10.1136/bmjopen-2015-009002

► Prepublication history and additional material is available. To view please visit the journal (<http://dx.doi.org/10.1136/bmjopen-2015-009002>).

Received 6 June 2015  
Revised 23 October 2015  
Accepted 11 November 2015



CrossMark

<sup>1</sup>Regulatory Institutions Network Australian National University, Canberra, Australia

<sup>2</sup>The Australian Prevention Partnership Centre, Sax Institute, Sydney, Australia

<sup>3</sup>Self-organizing Systems Research Group School of engineering and applied sciences Harvard University

<sup>4</sup>Centre for Social Impact, Swinburne University, Melbourne, Victoria, Australia

<sup>5</sup>Centre for Epidemiology and Preventive Health. Monash University, Melbourne, Australia

<sup>6</sup>Maths Science Institute Australian National University

## Correspondence to

Dr Gemma Carey;  
Gemma.carey@anu.edu.au

## ABSTRACT

**Objectives:** This paper reports on findings from a systematic review designed to investigate the state of systems science research in public health. The objectives were to: (1) explore how systems methodologies are being applied within public health and (2) identify fruitful areas of activity.

**Design:** A systematic review was conducted from existing literature that draws on or uses systems science (in its various forms) and relates to key public health areas of action and concern, including tobacco, alcohol, obesity and the social determinants of health.

**Data analysis:** 117 articles were included in the review. An inductive qualitative content analysis was used for data extraction. The following were systematically extracted from the articles: approach, methodology, transparency, strengths and weaknesses. These were then organised according to theme (ie, commonalities between studies within each category), in order to provide an overview of the state of the field as a whole. The assessment of data quality was intrinsic to the goals of the review itself, and therefore, was carried out as part of the analysis.

**Results:** 4 categories of research were identified from the review, ranging from editorial and commentary pieces to complex system dynamic modelling. Our analysis of each of these categories of research highlighted areas of potential for systems science to strengthen public health efforts, while also revealing a number of limitations in the dynamic systems modelling being carried out in public health.

**Conclusions:** There is a great deal of interest in how the application of systems concepts and approach might aid public health. Our analysis suggests that soft systems modelling techniques are likely to be the most useful addition to public health, and align well with current debate around knowledge transfer and policy. However, the full range of systems methodologies is yet to be engaged with by public health researchers.

## INTRODUCTION

In the past 5–10 years, there has been rapidly growing interest in the applicability of ‘systems science’ to public health. Systems science is a broad class of analytical approaches that aim to uncover the

## Strengths and limitations of this study

- This study provides a systematic review of the application of systems science and systems thinking to the field of public health.
- The review identified critical shortcomings in the use of systems methodologies being used.
- The review showed that public health is currently not engaging with the full range of systems methodologies.
- The sample of articles is representative but not comprehensive, which is a limitation of the study.

behaviour of complex systems.<sup>1 2</sup> A general distinction is made between ‘hard’ systems methodologies which refer to quantitative dynamic model building (ie, system dynamics) and ‘soft’ systems methodologies which refer to qualitative, action-based research methodologies (ie, critical systems heuristics). As a whole, systems methodologies are thought to enable researchers and decision makers to examine system components, and the dynamic relationships between them, at multiple levels, from cell to society.<sup>1</sup>

Taking a systems approach encourages a rethinking of organisations and system issues, including how actors behave in relation to them and are involved in their diagnosis and treatment.<sup>2–5</sup> Here, the emphasis is placed on understanding the ‘whole’ system, rather than focusing exclusively on individual components.<sup>2–4 6–8</sup>

While a range of systems methodologies exist (or are in the process of being developed and refined within a public health context), the most advanced systems methodologies seek to model systems and/or subsystems, in order to identify potential points for intervention and change.<sup>1</sup> Modelling and

<sup>†</sup>This paper does not provide an overview of systems theories or methods. These are provided in many of the papers reviewed, and comprehensive introductions can be found elsewhere.<sup>9 10</sup>

simulations are thought to have significant potential for improving decision-making in health policy, planning and implementation by highlighting unintended consequences.<sup>11</sup> It is argued that ‘by replicating the real world in important ways—simplifying where possible while retaining the critical aspects relevant to the problem under study—we can better understand the structural complexity of real-world problems that results from the interaction of specific phenomena and their environments’.<sup>12</sup>

The introduction of systems science to public health has been met with considerable interest. A plethora of articles now argue for the applicability of systems methodologies and perspectives to a wide range of public health problems, from obesity to tobacco and the social determinants of health.<sup>2 6 13–17</sup> What remains unclear, however, is whether the reality has lived up to this rhetoric. This paper reports on findings from a systematic review designed to investigate the state of systems science research in public health. The objectives were to: (1) explore how systems methodologies are being applied within public health and (2) identify fruitful areas of activity.

## METHODS

### Search strategy

The search strategy and analysis was informed by: the study’s aims, previous systematic reviews using qualitative data, and best practice recommendations in the research literature.<sup>18 19</sup>

A systematic review of the literature was conducted by a single research assistant. Searches for peer-review literature were conducted in major databases: ProQuest, Sociological Abstracts, PubMed, Web of Science, Science Citation Index, Social Sciences Citation Index, MEDLINE, Academic Onefile, ScienceDirect, Expanded Academic, EBSCO between 2000 and 2015 (the time in which systems science has gained interest in the field). Search terms included: systems thinking, systems science, complex systems, system modelling, system dynamics combined with public health and key domains of public health activity (ie, obesity, tobacco, alcohol and social determinants of health) (eg, ‘social determinants of health’ AND (‘systems thinking’ OR ‘systems science’ OR ‘complexity science’ OR ‘complex systems’ OR ‘system dynamics’ OR ‘systems modelling’) AND ‘public health’). Articles between 1990 and February 2015 were sourced.

Grey literature searches were conducted using the above terms, with particular attention to major national and international public health conferences including: European Congress on Public Health, International Congress on Public Health, Australian Public Health Association Conference, European Public Health Association Conference, The American Public Health Association Conference. Key exclusion criteria were: articles not published in English, articles

which discussed a system (ie, the health system) but were not drawing on ‘systems science’. A list of papers included in the review is provided in online supplementary appendix 1. Owing to limitations associated with using key search terms (within abstracts and titles) to identify literature, we do not suggest that this is an exhaustive list of published work in the field. We do, however, argue that it is a broadly representative sample. As Williams and Hummelbrunner<sup>9</sup> note, holism is ‘somewhat of an ideal. In reality, all situations, all inquiries are bounded in some way’.

In total, 341 articles, reports and reviews were identified. A further two were sourced from reference lists. After reviewing abstracts, 124 were excluded on the basis of the aforementioned exclusion criteria and the removal of duplicates. A further 12 were excluded after more in-depth examination (on the basis of the same exclusion criteria). In total, 117 articles were included in the review, with the far majority from peer-reviewed journals (see online supplementary appendix 1 and figure 1).

Articles were categorised by three of the authors (for inter-rater reliability). An inductive qualitative approach to analysis was used. As Dixon-woods *et al*<sup>18</sup> note, systematic reviews can be integrative or interpretive. With integrative reviews, the categories and concepts are set prior to conducting literature searches. With an interpretive approach, concepts and categories arise inductively from the content after the searches are conducted.<sup>18</sup> This approach to analysis is otherwise known as an inductive qualitative content analysis.<sup>20</sup>

Data extraction followed a number of stages. After preliminary categorisation, categories were divided among the authors according to expertise. Each category was reviewed in depth by at least one author and the lead author:

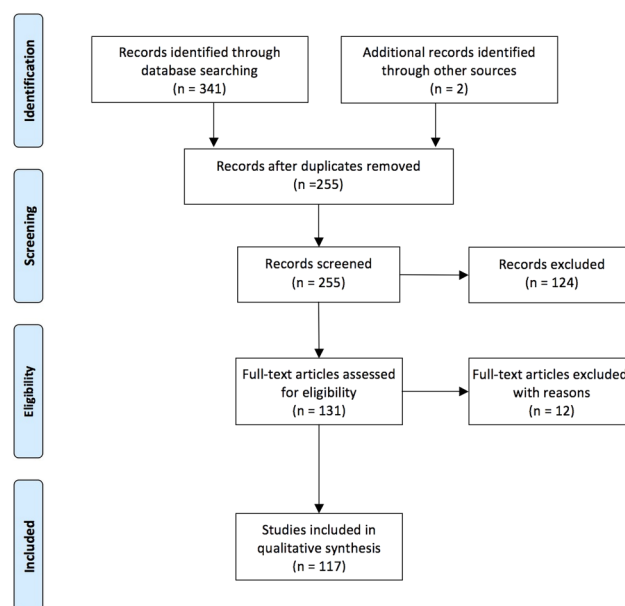


Figure 1 PRISMA flow diagram.

- Commentaries, reviews and position pieces—BC, GC;
- Analytical framework—BC, GC;
- Best practice—AJ, GC;
- Modelling—EM, NC, AC, GC.

In reviewing each paper, categorisations were refined. Coauthors provided a detailed summary of each study including its strengths and weaknesses, as well as an overall appraisal of the category.<sup>21 22</sup> Through this process, the following was systematically extracted from the articles: approach, methodology, transparency, strengths and weaknesses. These were then organised according to theme (ie, commonalities between studies within each category), in order to provide an overview of the state of the field as a whole. The summaries and accompanying analysis forms the basis of the results section of the paper. The assessment of data quality was intrinsic to the goals of the review itself, and therefore, was carried out as part of the analysis.

## RESULTS

The literature identified fell into four categories (figure 2): (1) editorials, commentaries and reviews which called for the application of systems science (either broadly, or with regard to specific methodologies or to specific problems) to public health, (2) research which identified systems as a broad analytical lens applied to the research, but which did not draw on systems methodologies or specialist systems insights, (3) research that uses systems methodologies to benchmark best practice in a range of areas and (4) research that claims to have undertaken systems modelling (of different types and differing levels of rigour) (see table 1 for results). Some papers were placed into more than one category; this reflects the fact that there is some ‘blurring’ between the categories identified inductively from the data (ie, the literature sits across a spectrum).

### Position pieces

The majority of papers in this category extol the benefits of introducing systems science to public health but contain very little detail about what this would entail. Articles range from broadly advocating systems thinking, to more detailed review articles which tend to use ‘systems science’ to refer to specific aspects of systems or

systems methodologies rather than using it as a synonym for ‘multilevel’ or ‘complex’.

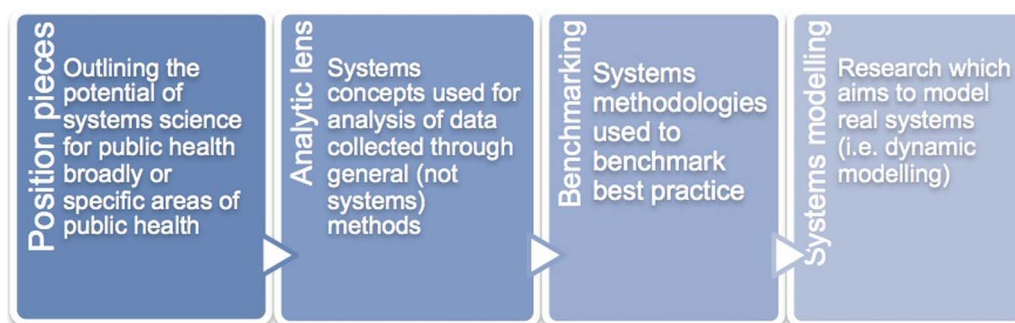
The most promising articles in this category offered insights into how systems science might ‘map’ onto existing practices and knowledge in public health, such as prevention science.<sup>1</sup> Luke *et al*,<sup>61</sup> for example, argue for systems science in public health identifying specific methodologies in system dynamics, network analysis and agent-based modelling. In doing so, they provide good examples of problems that can benefit from a systems approach, including infectious disease, tobacco and obesity. While these papers hint at the potential of systems science, very few contained details on how this potential could be operationalised.

### Analytical lens

Papers in this category claimed to situate their analysis in the field of systems science. For example, using systems concepts to guide the analysis of qualitative data, or incorporating systems concepts into interview schedules in stakeholder analysis. In the latter, this took the form of brainstorming potential systems connections within the research team, and then constructing interview questions to explore these connections.<sup>23</sup> As such, this category of papers did not use systems methodologies in the design or collection of data. This meant that systems concepts were generally being used—or superimposed—onto data as a means to recognise the interconnected and interdependent nature of many phenomena. Arguably, many other theories and frameworks that have been well used within public health research already provide this lens (eg, Diffusion of Innovations Theory).<sup>79 80</sup> The weaker articles in this category claimed to be using a systems lens and/or situate the work within a complexity theory paradigm without any further exposition of systems methodologies, concepts, or how exactly their work is framed, supported or enhanced by a systems approach.<sup>25 27 29</sup>

### Benchmarking best practice

The papers in this category sought to benchmark or assess the likely efficacy of systems thinking in public health practice, using systems concepts and/or methodologies including soft systems methodology, to underpin



**Figure 2** Continuum of systems research in public health.

**Table 1** Results of literature searches

Categories	Number	References	Description
Reviews, calls for action	60		Includes reviews of systems broadly, or specific methodologies, how they might apply to particular areas of public health, or broadly argues for uptake in public health
Analytical lens	9	23–31	These articles use systems, to varying degrees, as a lens to which they bring to their analysis of data
Best practice/benchmarking	17	23, 32–47	These articles use elements of systems science to benchmark or evaluate public health practice
Modelling	36	5, 16, 35–37, 48–78	These articles undertake advanced systems modelling of different types (from causal loop diagrams, to agent-based and dynamic models), to provide insight into problems and how to address them

intervention and/or evaluation efforts. Here, ‘practice’ is used in the broadest sense—to encapsulate the work of both health promotion and public health practitioners, as well as policymakers. For example, Johnston *et al* developed a method to benchmark policy recommendations against systems leverage points. In doing so, they highlighted that many recommendations currently made in obesity policy hit ‘weak’ leverage points (where many actions will be required to create substantive change). Others, such as Kwamie *et al*<sup>41</sup> and Prashanth *et al*<sup>44</sup> combined systems concepts with realist approaches to analyse how interventions, such as leadership programmes, had variable outcomes depending on the context into which they were delivered. Research on the implementation of systems-type interventions has shown that without training and clear guidelines on systems-based implementation, then practitioners resort to their previous experience in delivering multicomponent reductionist-style interventions.<sup>45</sup> Arguably, this is the systemic issue that is slowing, or muddling, public health’s attempts to engage with systems-based approaches.

A number of papers outlined how systems concepts could be used to enhance and refine policy and practice. Bar-Yam used a systems science perspective to contend that there needs to be two different organisational forms in health services.<sup>33</sup> First, to develop organisational systems and structures for tasks that are highly routinised such as immunisation and other forms of preventive health, and to develop organisational systems for tasks that are highly complex and unique. The paper contrasted the way the system is funded and managed in large-scale processes (funding flows between employers, insurers and providers) compared with the highly complex individual decisions required of individual patient care. It was commented that efforts to routinise and regulate care will always diminish effectiveness, given that optimal outcomes are based on highly

individualised approaches. Johnston and Finegood<sup>39</sup> used their systems leverage points framework, titled ‘intervention-level framework’, to discuss the potential benefits and limitations of public–private partnerships in addressing obesity and non-communicable diseases. MacLean *et al*<sup>42</sup> provided a conceptual framework for vertical and horizontal connections to address childhood obesity. Using a Canadian case example, they were able to demonstrate the connections between different layers of government (vertical integration), and between sectors such as education and health (horizontal integration). It was commented that the model elucidated key partnerships across system elements, but a weakness in the model is that it does not account for dynamic system properties that could account for how and where change occurs in the system.

Only two papers described and commented on initiatives that were specifically designed to be systems-based practice. BeLue *et al*<sup>34</sup> described how a community-based participatory research approach was enhanced by applying the soft systems method causal loop diagramming to understand factors influencing underage drinking in their area. A more critical study by Sautkina *et al*<sup>45</sup> using key informant interviews, discovered that despite an explicit effort to introduce systems thinking in particular settings, there was little evidence of an understanding of specific systems science approaches and very little evidence of its application among practitioners and policymakers. Rather, a number of risk factors were identified, and multiple interventions implemented to address these risk factors. It was concluded that the policy narrative was not very clear about what a systems-based approach meant, and thus, there was no clear direction in how this could be implemented. In the absence of clear guidance, local teams reverted to past experience. This failure was also noted as a symptom of the literature, where there is considerable focus on developing systems-thinking concepts, but very little attention on



the attributes of a system-level intervention, and how it could be delivered and evaluated. BeLue *et al*<sup>34</sup> also commented that further training and support in systems-thinking techniques would be required to enhance community capacity.

Interestingly, when assessing the quality of practice in a range of settings, success was generally defined as the presence of systems-thinking practice, irrespective of the quality of this practice (although it was noted that efforts at increasing systems-thinking capacity were required to improve practice).<sup>34</sup> While the critique of how systems concepts are used in evaluation practice is more developed than critiquing the use of systems concepts in implementation practice, reviews of evaluation practice also focus more on understanding when and in what way systems-based concepts are being used rather than any analysis of whether these concepts are improving evaluation practice.<sup>32 47</sup> Thus, while some interesting methodologies are beginning to develop in this area, at this stage it appears that researchers are primarily assessing when and where systems practice and evaluation are occurring rather than appraising the utility of systems practice and evaluation itself. These researchers conclude that more practical guidelines, training and partnership with experienced systems modellers are required if we are to see systems concepts applied more broadly in public health practice and evaluation.

### System modelling

Papers categorised as ‘systems modelling’ used a range of qualitative and quantitative methods to model various systems or subsystems relevant to public health problems. When assessed as a whole, many studies in this category exhibited serious weaknesses. Notably, public health research that uses systems-modelling techniques often fails to assess whether the models constructed therein are any good. In the most advanced articles, such as the well-known Forsight maps of obesity,<sup>5</sup> the methods used to build the model were explained in rigorous enough detail that an assessment of process could be made. That is, whether the process used to build the model seemed sensible, likely to produce useful results, and is consistent with accepted methodologies within the system dynamics discipline. However, any actual validation of the model thus constructed was rare. Often, this was due to a paucity of data, or the difficulty in generalising across social/geopolitical boundaries.

A number of papers stood out as examples of best practice in system dynamics research for public health<sup>36 54 58 59</sup> (as opposed to best practice within the field of systems science more broadly, which is outside the scope of this review). From these examples of best practice, criteria can begin to be constructed for reporting the results from system dynamics modelling in the health domain. For example,

- ▶ When developed through third-party software, the model should be made available for download and

linked in the paper or an online supplementary appendix (as done by Fallah-Fini *et al*<sup>54</sup>).

- ▶ Implementation of the model should ideally be done via open source or widely used software which has thorough documentation (this would enable other researchers to assess the quality of the differential equation solvers used). In some instances, even where software was named, it was inaccessible and quality could not be checked.<sup>50</sup>
- ▶ Preferably, the model equations and variable relationships should be spelled out explicitly in the paper (as seen again in ref. 54). This is especially the case where the model itself cannot be made available for whatever reason.
- ▶ There should always be some attempt made to validate results except possibly in exceptional circumstances.

In the remaining weaker papers, there was often not enough detail presented to understand how the model was constructed.<sup>5 14 35 36 69</sup> Often, the mere existence of the model itself was presented as sufficient justification of the work that had gone into the process.<sup>5 69</sup> It was often asserted that policy recommendations should be built on this model not because the model itself was useful or accurate, but because the process that produced it was alleged to be of greater validity than traditional approaches simply by having been built up within a systems-based framework.<sup>16 70</sup> Yet, very few of the weaker articles sufficiently elaborated on the model-building process.

### DISCUSSION

Lich *et al*<sup>1</sup> contend that despite a growing appreciation for ‘multiple levels’ and systems of influence, public health is yet to take full advantage of the analytical approaches—or toolbox—provided by systems science. Our systematic review of existing public health research that utilises systems approaches supports this claim. In particular, the fact that close to half the papers identified by the review process are commentaries or calls for the application of systems methodologies, but do not use systems methodologies. On the basis of this finding, we focus our discussion on areas that can be progressed. The review found two areas of public health systems activity worth reflecting on more deeply: systems modelling and the use of systems science to benchmark best practice.

Systems modelling is often treated as the area of systems work that holds the most promise for solving public health problems, and particularly, for policy.<sup>9 12 13 33 77</sup> Our review of the existing modelling in the field, to date, highlights cases of best practice, though it also suggests that a number of methodological weaknesses need to be addressed.

First, in terms of weakness, the review raised questions regarding accountability. The nature of public health means that social dynamic models will always be fluid,

subjective and non-holonomic (ie, the model will depend on the process as much as the fundamental social conditions/data). However, this does not preclude accountability. If the systems paradigm for policy creation is to be taken seriously, a minimum standard of accountability and repeatability needs to be adhered to by researchers. In other words, there needs to be adequate space in published articles given over to the statistical and heuristic methods used to build up the model. As noted previously, at times, the mere existence of the model itself was presented as sufficient justification of the work that had gone into the process, and it was asserted that policy recommendations should be built on this model not because the model itself was useful or accurate, but because the process that produced it (a process that was often obscured or glossed over) was thought to be of greater validity than traditional approaches, simply by virtue of having been developed from a dynamic systems perspective.<sup>16 37 70</sup>

We advise a higher expectation regarding validation and verification practices for the dynamic systems models published in the public health-related discourse. This would allow informed readers to replicate and adapt, or improve on the modelling process. This should occur prepublication, but if sufficient data is not available then authors should, at a minimum, present a roadmap for how non-verified models might be empirically validated. This would enable future researchers to assess the efficacy and adequacy of the models, and suggest improvements or refinements. Further, public health practitioners would do well to link with the established field of system dynamics to find methods that have been developed within the discipline over the past 60 years—where academic debate and peer review have strengthened the approach.<sup>50 81–90</sup>

The second area to emerge from the review which is worth deeper discussion is the use of systems science to benchmark best practice (whether in policy or health promotion). This has produced some innovative methods and approaches.<sup>39 45</sup> For this area to be effective, research and implementation must go beyond assessing whether systems concepts are simply in use, and instead, consider the quality and effectiveness of systems-based practices and approaches. This requires greater research attention on the attributes of a system-level intervention and how it could be delivered and evaluated, in addition to the current focus on development of systems-thinking concepts.<sup>45</sup> Within the ‘softer’ systems methodologies, such as soft systems methodology, and the use of systems-based methods for benchmarking good practice, the existence of a plurality of methods poses a challenge for the field, which strike a balance between allowing for inclusive and innovative uses of systems-based approaches that are ‘fit for purpose’, while simultaneously maintaining scientific and methodological rigour.

Overall, our review emphasises that systems-based approaches should not be thought of as the ‘new way

forward’; they should be thought of as an additional set of methods to organise and analyse information about complex and dynamic public health phenomena. Systems-based approaches can sit alongside other public health approaches and bring a unique contribution to the field of research and practice, as highlighted in this review. Further, it is not only the methods of systems science that may be useful, but also their methodological positioning.

We use, for example, the methodological positioning of soft system methodology. Soft system methodologies have long been underpinned by the notion of a ‘system as a metaphor’ for understanding and communicating about complex phenomena.<sup>83 91</sup> Conceptualising systems in this way allows the researcher to use notions in systems thinking, such as accumulation, feedback and endogenous behaviour as metaphors for facilitating knowledge transfer, thereby creating and/or revealing integration and comparison between the worldviews of system actors. Dyball and Newell<sup>83</sup> call such metaphors ‘powerful ideas’, as they provide a way to build a shared understanding between people of different disciplines and of repeated dynamics between contexts. The metaphors within systems science are simultaneously generic enough to maintain their applicability in a number of different contexts such as climate change science, urban planning, or the study of health inequalities, but accurate enough to elucidate the structure of complex problems.

These methodological positions align well with the goals of research in our ‘benchmarking best practice’ category. This suggests that systems concepts can act as useful metaphors for enhancing our integrative practice, whether as health promotion practitioners or policymakers. Using these metaphoric concepts as a basis for conceptualising complex health phenomena also negates the need to overcome the extensive and expensive technical hurdles of undertaking dynamic systems modelling. This is particularly relevant to highly complex and politically sensitive areas of public health research such as the social determinants of health.

It is also worth noting that the evidence produced by different systems science methodologies and methods hold different value to policymakers (or researchers), depending on the epistemological learning. Within the systems-based field, a distinction is broadly made regarding ‘hard’ versus ‘soft’ systems methodological approaches. While this distinction is not absolute, in public health dynamic systems modelling may be more appealing to those who hold positivist epistemological positions (ie, where data-driven models provide decision makers with concrete evidence of where and how to act). However, policy scholars increasingly see policy as emerging from policy networks. This body of work perceives policy as being shaped by ‘networks that are fluid, constantly changing structures which can be shaped by the agency of actors within them as well as by external and temporal constraints’.<sup>94</sup> This does not mean that

research evidence (in modelling form or other) does not inform policy actors, but that it is not an instrumental/transactional arrangement, and that the shifts it creates will not be transformative or radical.<sup>92–94</sup> Increasingly, public health is moving away from instrumentalist views of policy—with a growing backlash against the evidence-based policy paradigm.<sup>95–97</sup> Hence, if one of the promises of systems methodologies for public health is their utility for decision makers and policy actors, a closer analysis is needed of how public health conceptualises policy change, and the ways in which systems science can and cannot feed into this. For example, the models produced are not necessarily widely applicable across diverse contexts with different cultural dynamics.<sup>98</sup>

Finally, it is worth reflecting on the need to ask the right questions of systems science. This review has highlighted some of the rhetoric around systems-based approaches to public health. Systems-based approaches and complex systems science should not be framed as an unsung solution to all the major challenges in public health. Indeed, making a system-dynamics model does not give policymakers agency in spaces where they currently have none. Public health problems are already deemed complex, and systems-based approaches can contribute to changing the language, methods and methodologies for conceptualising and acting within this complexity. In order for systems-based approaches to live up to their ‘rhetoric’, the public health and prevention field must ask the right questions of the discipline, and not expect systems-based methodologies to provide the ‘silver bullet’ answers to some of our biggest challenges, such as preventative action on the social determinants of health. Increased literacy as to the forms of evidence that different systems-based methodologies and methods can produce will aid the public health and prevention field to ask the right questions of systems science.

## CONCLUSIONS

Overall, our systematic review of the systems science literature in public health revealed that there is a great deal of interest in how systems concepts and approach can aid public health. Our analysis suggests that soft systems modelling techniques are likely to be the most useful addition to public health, and align well with current debate around knowledge transfer and policy. It is also important to note, however, that the full range of systems methodologies is yet to be engaged with by public health researchers and practitioners.

## Limitations

It is possible that there are studies that were not turned up in the review, particularly if reported in the grey literature. However, we believe the sample derived from our review process represents the field in its current state.

**Contributors** GC conceived of the study. GC, BC, NC and AJ created the search protocol. All authors contributed to analysis, drafting the paper and the conclusions.

**Funding** This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

**Competing interests** None declared.

**Provenance and peer review** Not commissioned; externally peer reviewed.

**Data sharing statement** No additional data are available.

**Open Access** This is an Open Access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>

## REFERENCES

1. Lich KH, Ginexi EM, Osgood ND, *et al.* A call to address complexity in prevention science research. *Prev Sci* 2013;14:279–89.
2. Trochim WM, Cabrera DA, Milstein B, *et al.* Practical challenges of systems thinking and modeling in public health. *Am J Public Health* 2006;96:538.
3. Atwood M, Pedler M, Pritchard S, *et al.* *Leading change: a guide to whole of systems working*. Bristol, UK: The Polity Press, 2003.
4. De Savigny D, Adam T, *et al.* Alliance for Health Policy and Systems Research. *Systems thinking for health systems strengthening*. Geneva: Alliance for Health Policy and Systems Research: World Health Organization, 2009. <http://public.eblib.com/choice/publicfullrecord.aspx?p=476146> (accessed 11 Nov 2014).
5. Vandenbroeck I, Goossens J, Clemens M. *Foresight tackling obesities: future choices—obesity system atlas*. Foresight Study, 2007.
6. Hawe P, Shiell A, Riley T. Theorising Interventions as Events in Systems. *Am J Community Psychol* 2009;43:267–76.
7. Hawe P, Shiell A, Riley T. Complex interventions: how ‘out of control’ can a randomised controlled trial be? *BMJ* 2004;328:1561.
8. Trickett EJ, Beehler S, Deutsch C, *et al.* Advancing the science of community-level interventions. *Am J Public Health* 2011;101:1410–19.
9. Williams B, Hummelbrunner R. *Systems concepts in action: a practitioner's toolkit*. Stanford University Press, 2010.
10. Jackson M. *Systems thinking: Creative holism for managers*. Wiley, 2003.
11. Maglio PP, Mabry PL. Agent-based models and systems science approaches to public health. *Am J Prev Med* 2011;40:392–4.
12. Mabry PL, Olster DH, Morgan GD, *et al.* Interdisciplinarity and systems science to improve population health. *Am J Prev Med* 2008;35:S211–24.
13. Best A, Holmes B. Systems thinking, knowledge and action: towards better models and methods. *Evid Policy* 2010;6:145–59.
14. Bures RM, Mabry PL, Orleans CT, *et al.* Systems science: a tool for understanding obesity. *Am J Public Health* 2014;104:1156.
15. Leischow SJ, Best A, Trochim WM, *et al.* Systems thinking to improve the public's health. *Am J Prev Med* 2008;35:S196–203.
16. Mahamoud A, Roche B, Homer J. Modelling the social determinants of health and simulating short-term and long-term intervention impacts for the city of Toronto, Canada. *Soc Sci Med* 2013;93:247–55.
17. Newell B, Proust K, Dyball R, *et al.* Seeing obesity as a systems problem. *N S W Public Health Bull* 2007;18:214.
18. Dixon-Woods M, Agarwal S, Jones D, *et al.* Synthesising qualitative and quantitative evidence: a review of possible methods. *J Health Serv Res Policy* 2005;10:45–53.
19. Hannes K, Macaitis K. A move to more systematic and transparent approaches in qualitative evidence synthesis: update on a review of published papers. *Qual Res* 2012;12:402–42.
20. Marsh EE, White MD. Content analysis: a flexible methodology. *Libr Trends* 2006;55:22–45.
21. Barnett-Page E, Thomas J. Methods for the synthesis of qualitative research: a critical review. *BMC Med Res Methodol* 2009;9:59.
22. Grant MJ, Booth A. A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Info Libr J* 2009;26:91–108.
23. Yaya Bocoum F, Kouanda S, Kouyaté B, *et al.* Exploring the effects of task shifting for HIV through a systems thinking lens: the case of Burkina Faso. *BMC Public Health* 2013;13:997.



24. Borland R, Young D, Coghill K, *et al.* The tobacco use management system: analyzing tobacco control from a systems perspective. *Am J Public Health* 2010;100:1229–36.
25. Fisher M, Milos D, Baum F, *et al.* Social determinants in an Australian urban region: a 'complexity' lens. *Health Promot Int*. Published Online First: 8 August 2014. <http://heapro.oxfordjournals.org/content/early/2014/08/08/heapro.dau071.full.pdf+html>
26. Gilson L, Elloker S, Olckers P, *et al.* Advancing the application of systems thinking in health: South African examples of a leadership of sensemaking for primary health care. *Health Res Policy Syst* 2014;12:10–1186.
27. HIAP. Health In All Policies. Published online first: 2013. <http://dhss.delaware.gov/dph/mh/files/healthinallpoliciesguide.pdf> (accessed 12 Feb 2015).
28. Iwelunmor J, Airhihenbuwa CO, Cooper R, *et al.* Prevalence, determinants and systems-thinking approaches to optimal hypertension control in West Africa. *Global Health* 2014;10:42.
29. Pauly BB, MacDonald M, Hancock T, *et al.* Reducing health inequities: the contribution of core public health services in BC. *BMC Public Health* 2013;13:550.
30. Weishaar H, Amos A, Collin J. Capturing complexity: mixing methods in the analysis of a European tobacco control policy network. *Int J Soc Res Methodol* 2015;18:175–92.
31. Zarowsky C, Haddad S, Nguyen VK. Beyond 'vulnerable groups': contexts and dynamics of vulnerability. *Glob Health Promot* 2013;20:3–9.
32. Adam T, de Savigny D. Systems thinking for strengthening health systems in LMICs: need for a paradigm shift. *Health Policy Plan* 2012;27(Suppl 4):iv1–3.
33. Bar-Yam Y. Improving the effectiveness of health care and public health: a multiscale complex systems analysis. *Am J Public Health* 2006;96:459.
34. BelLue R, Carmack C, Myers KR, *et al.* Systems thinking tools as applied to community-based participatory research a case study. *Health Educ Behav* 2012;39:745–51.
35. Birkmayer J, Fisher DA, Holder HD, *et al.* Prevention of methamphetamine abuse: can existing evidence inform community prevention? *J Drug Educ* 2008;38:147–65.
36. Bishai D, Paine L, Li Q, *et al.* Advancing the application of systems thinking in health: why cure crowds out prevention. *Health Res Policy Syst* 2014;12:28.
37. Fahey DK, Carson ER, Cramp DG, *et al.* Applying systems modelling to public health. *Systems Res Behav Sci* 2004;21:635–49.
38. Fawkes S. *Leadership for systems change in preventive health—review of the literature and current activity*. Victoria, Australia: Victorian Department of Health, 2013.
39. Johnston LM, Matteson CL, Finegood DT. Systems science and obesity policy: a novel framework for analyzing and rethinking population-level planning. *Am J Public Health* 2014;104:1270–8.
40. Johnston LM, Finegood DT. Cross-sector partnerships and public health: challenges and opportunities for addressing obesity and noncommunicable diseases through engagement with the private sector. *Annu Rev Public Health* 2015;36:255–71.
41. Kwame A, Dijk H, van Agyepong I. Advancing the application of systems thinking in health: realist evaluation of the Leadership Development Programme for district manager decision-making in Ghana. *Health Res Policy Systems* 2014;12:29.
42. MacLean LM, Clinton K, Edwards N, *et al.* Debate Unpacking vertical and horizontal integration: childhood overweight/obesity programs and planning, a Canadian perspective. Published online first: 2010. <http://www.biomedcentral.com/content/pdf/1748-5908-5-36.pdf> (accessed 29 Apr 2015).
43. Palmer RH, McGeary JE, Francazio S, *et al.* The genetics of alcohol dependence: advancing towards systems-based approaches. *Drug Alcohol Depend* 2012;125:179–91.
44. Prashanth NS, Marchal B, Devadasan N, *et al.* Advancing the application of systems thinking in health: a realist evaluation of a capacity building programme for district managers in Tumkur, India. *Health Res Policy Systems* 2014;12:42.
45. Sautkina E, Goodwin D, Jones A, *et al.* Lost in translation? Theory, policy and practice in systems-based environmental approaches to obesity prevention in the Healthy Towns programme in England. *Health Place* 2014;29:60–6.
46. Schaefer DR, Adams J, Haas SA, Haas SA. Social networks and smoking exploring the effects of peer influence and smoker popularity through simulations. *Health Educ Behav* 2013;40:24S–32S.
47. Walton M. Applying complexity theory: a review to inform evaluation design. *Eval Program Plann* 2014;45:119–26.
48. Araz OM. Integrating complex system dynamics of pandemic influenza with a multi-criteria decision making model for evaluating public health strategies. *J Systems Sci Systems Eng* 2013;22:319–39.
49. Gruen RL, Elliott JH, Nolan ML. Sustainability science: an integrated approach for health-programme planning. *Lancet* 2008;372:1579–89.
50. Cavana RY, Clifford LV. Demonstrating the utility of system dynamics for public policy analysis in New Zealand: the case of excise tax policy on tobacco. *System Dyn Rev* 2006;22:321–48.
51. Cavana RY, Tobias M. Integrative system dynamics: analysis of policy options for tobacco control in New Zealand. *Systems Res Behav Sci* 2009;25:675–94.
52. Chuang S, Howley PP, Lin SH. Implementing systems thinking for infection prevention: the cessation of repeated scabies outbreaks in a respiratory care ward. *Am J Infect Control* 2015;43:499–505.
53. Delgado J, Pollard S, Snary E, *et al.* A systems approach to the policy-level risk assessment of exotic animal diseases: network model and application to classical swine fever: systems approach to the policy-level risk assessment of exotic animal diseases. *Risk Anal* 2013;33:1454–72.
54. Fallah-Fini S, Rahmandad H, Huang TT, *et al.* Modeling US adult obesity trends: a system dynamics model for estimating energy imbalance gap. *Am J Public Health* 2014;104:1230–9.
55. Galea S, Hall C, Kaplan GA. Social epidemiology and complex system dynamic modelling as applied to health behaviour and drug use research. *Int J Drug Policy* 2009;20:209–16.
56. Ghaffarzadeh N, Lyneis J, Richardson GP. How small system dynamics models can help the public policy process. *System Dyn Rev* 2011;27:22–44.
57. Hassmiller Lich K, Osgood ND, Mahamoud A. Using System Dynamics tools to gain insight into intervention options related to the interaction between tobacco and tuberculosis. *Glob Health Promot* 2010;17:07–20.
58. Hirsch G, Homer J, Evans E, *et al.* A system dynamics model for planning cardiovascular disease interventions. *Am J Public Health* 2010;100:616.
59. Kok S, Rutherford AR, Gustafson R, *et al.* Optimizing an HIV testing program using a system dynamics model of the continuum of care. *Health Care Manag Sci* 2015;18:334–62.
60. Liu A. Research on resilience of emergency logistics network responding to public health emergencies based on system dynamics. *J Inf Comput Sci* 2015;12:1001–10.
61. Luke DA, Wald LM, Carothers BJ, *et al.* Network influences on dissemination of evidence-based guidelines in state tobacco control programs. *Health Educ Behav* 2013;40:33S–42S.
62. Marshall BD, Galea S. Formalizing the role of agent-based modeling in causal inference and epidemiology. *Am J Epidemiol* 2015;181:92–9.
63. McKelvie D, Wolstenholme E, Arnold S, *et al.* *Using system dynamics to plan investment in alcohol services*. The Symmetric Partnership, 2011.
64. Metcalf SS, Northridge ME, Widener MJ, *et al.* Modeling social dimensions of oral health among older adults in urban environments. *Health Educ Behav* 2013;40:63S–73S.
65. Mundt MP. Social network analysis of peer effects on binge drinking among US adolescents. In: *Social computing, behavioral-cultural modeling and prediction*. Springer, 2013:123–34. [http://link.springer.com/chapter/10.1007/978-3-642-37210-0\\_14](http://link.springer.com/chapter/10.1007/978-3-642-37210-0_14) (accessed 29 Apr 2015).
66. Norman CD, Charnaw-Burger J, Yip AL, *et al.* Designing health innovation networks using complexity science and systems thinking: the CoNEKTR model: designing health innovation: the CoNEKTR model. *J Eval Clin Pract* 2010;16:1016–23.
67. Rehfuess EA, Best N, Briggs DJ, *et al.* Diagram-based Analysis of Causal Systems (DACS): elucidating inter-relationships between determinants of acute lower respiratory infections among children in sub-Saharan Africa. *Emerg Themes Epidemiol* 2013;10:13.
68. Retrum JH, Chapman CL, Varda DM. Implications of network structure on public health collaboratives. *Health Educ Behav* 2013;40:13S–23S.
69. Rydin Y, Bleahu A, Davies M, *et al.* Shaping cities for health: complexity and the planning of urban environments in the 21st century. *Lancet* 2012;379:2079–108.
70. Sabouchi NS, Hovmand PS, Osgood ND, *et al.* A novel system dynamics model of female obesity and fertility. *Am J Public Health* 2014;104:1240–6.
71. Silverman BG, Hanrahan N, Bharathy G, *et al.* A systems approach to healthcare: agent-based modeling, community mental health, and population well-being. *Artif Intell Med* 2015;63:61–71.
72. Tawileh A, Almagwashi H, McIntosh S. A system dynamics approach to assessing policies to tackle alcohol misuse. In: Dangerfield BC, ed. *Proceedings of the 26th International*



- Conference of the System Dynamics Society. 2008. <http://systemdynamics.org/conferences/2008/proceed/papers/TAWIL185.pdf> (5 May 2009). <http://www.systemdynamics.org/conferences/2008/proceed/papers/TAWIL185.pdf> (accessed 29 Apr 2015).
73. Tengs TO, Osgood ND, Chen LL. The Cost-effectiveness of intensive national school-based anti-tobacco education: results from the tobacco policy model. *Prev Med* 2001;33:558–70.
  74. Tubbing L, Harting J, Stronks K. Unravelling the concept of integrated public health policy: concept mapping with Dutch experts from science, policy, and practice. *Health Policy* 2015;119: 749–59.
  75. Wakeland W, Nielsen A, Schmidt TD, *et al.* Modeling the impact of simulated educational interventions on the use and abuse of pharmaceutical opioids in the United States: a report on initial efforts. *Health Educ Behav* 2013;40(1 Suppl):74S–86S.
  76. Wiist WH. Use of complex systems modelling to strengthen public health's role in preventing war. *Med Confl Surviv* 2014;30:152–64.
  77. Abidin NZ, Mamat M, Dangerfield B, *et al.* Combating obesity through healthy eating behavior: a call for system dynamics optimization. *PLoS ONE* 2014;9:e114135.
  78. Tobias MI, Cavana RY, Bloomfield A. Application of a system dynamics model to inform investment in smoking cessation services in New Zealand. *Am J Public Health* 2010;100:1274.
  79. Giddens A. *The constitution of society*. Cambridge, UK: Polity, 1984.
  80. Rogers E. *Diffusion of innovations*. 3rd edon. New York: Free Press, 1983.
  81. Williams W, Lyalin D, Wingo PA. Systems thinking: what business modeling can do for public health. *J Public Health Manag Pract* 2005;11:550–3.
  82. Checkland P. Model validation in soft systems practice. *Systems Res* 1995;12:47–54.
  83. Dyball R, Newell B. *Understanding human ecology: a systems approach to sustainability*. London, NY: Routledge, 2015.
  84. Forrester J. *Urban dynamics*. Cambridge, MA: MIT Press, 1969.
  85. Forrester J. *Industrial dynamics*. Cambridge, MA: MIT Press, 1961.
  86. Forrester JW. Policies, decisions and information sources for modeling. *Eur J Oper Res* 1992;59:42–63.
  87. Midgley G. Systemic intervention for public health. *Am J Public Health* 2006;96:466–72.
  88. Proust K, Newell B, Brown H, *et al.* Human health and climate change: leverage points for adaptation in urban environments. *Int J Environ Res Public Health* 2012;9:2134–58.
  89. Richardson GP. Reflections on the foundations of system dynamics: foundations of system dynamics. *System Dyn Rev* 2011;27: 219–43.
  90. Sternman J. *Business dynamics: systems thinking and modeling for a complex world*. McGraw-Hill, 2000.
  91. Ulrich W, Reynolds M. Critical systems heuristics. In: Reynolds M, Holwell S, eds. *Systems approaches to managing change: a practical guide*. London: Springer, 2010:243–93.
  92. Kickert W, Koppenjan J. Public management and network management: an overview. In: Kickert W, Klijn EH, Koppenjan J, eds. *Managing complex networks: strategies for the public sector*. London: Sage, 1997. 35–60.
  93. Klijn EH, Koppenjan J. Public management and policy networks. *Public Manage* 2000;2:437–54.
  94. Smith K. *Beyond evidence-based policy in public health*. Palgrave Macmillan, 2014.
  95. Greenhalgh T, Howick J, Maskrey N, *et al.* Evidence based medicine: a movement in crisis? *BMJ* 2014;348:g3725.
  96. Greenhalgh T, Russell J. Evidence-based policymaking: a critique. *Perspect Biol Med* 2009;52:304–18.
  97. Russell J, Greenhalgh T, Byrne E, *et al.* Recognizing rhetoric in health care policy analysis. *J Health Serv Res Policy* 2008;13:40–6.
  98. Hammond RA. *A complex systems approach to understanding and combating the obesity epidemic*. Citeseer, 2008. <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.329.8631&rep=rep1&type=pdf> (accessed 13 Feb 2015).

- Adam, T., de Savigny, D., 2012. Systems thinking for strengthening health systems in LMICs: need for a paradigm shift. *Health Policy and Planning* 27, iv1–iv3. doi:10.1093/heapol/czs084
- Adam, T., Hsu, J., de Savigny, D., Lavis, J.N., Rottingen, J.-A., Bennett, S., 2012. Evaluating health systems strengthening interventions in low-income and middle-income countries: are we asking the right questions? *Health Policy and Planning* 27, iv9–iv19. doi:10.1093/heapol/czs086
- Araz, O.M., 2013. Integrating complex system dynamics of pandemic influenza with a multi-criteria decision making model for evaluating public health strategies. *Journal of Systems Science and Systems Engineering* 22, 319–339. doi:10.1007/s11518-013-5220-y
- Bar-Yam, Y., 2006. Improving the effectiveness of health care and public health: a multiscale complex systems analysis. *American Journal of Public Health* 96, 459.
- BeLue, R., Carmack, C., Myers, K.R., Weinreb-Welch, L., Lengerich, E.J., 2012. Systems thinking tools as applied to community-based participatory research a case study. *Health Education & Behavior* 39, 745–751.
- Best, A., 2003. Health Promotion Dissemination and Systems Thinking: Towards an Integrative Model. *American Journal of Health Behavior* 27, S206.
- Birckmayer, J., Fisher, D.A., Holder, H.D., Yacoubian, G.S., 2008. Prevention of Methamphetamine Abuse: Can Existing Evidence Inform Community Prevention? *Journal of Drug Education* 38, 147–165. doi:10.2190/DE.38.2.d
- Bishai, D., Paina, L., Li, Q., Peters, D.H., Hyder, A., 2014. Advancing the application of systems thinking in health: why cure crowds out prevention. *Health Res Policy Syst* 12, 10–1186.
- Black, M.M., Hager, E.R., 2013. Commentary: Pediatric Obesity: Systems Science Strategies for Prevention. *Journal of Pediatric Psychology* 38, 1044–1050. doi:10.1093/jpepsy/jst071
- Bocoum, F.Y., Kouanda, S., Kouyaté, B., Hounton, S., Adam, T., 2013. Exploring the effects of task shifting for HIV through a systems thinking lens: the case of Burkina Faso. *BMC public health* 13, 997.
- Borland, R., Young, D., Coghill, K., Ying Zhang, J., 2010. The Tobacco Use Management System: Analyzing Tobacco Control From a Systems Perspective. *American Journal of Public Health* 100, 1229–1236.
- Bures, R.M., Mabry, P.L., Orleans, C.T., Esposito, L., 2014. Systems Science: A Tool for Understanding Obesity. *American journal of public health* 104, 1156–1156.
- Burke, J.G., Lich, K.H., Neal, J.W., Meissner, H.I., Yonas, M., Mabry, P.L., 2014. Enhancing Dissemination and Implementation Research Using Systems Science Methods. *International Journal of Behavioral Medicine*. doi:10.1007/s12529-014-9417-3
- Burnet, M., 2008. Sustainability science: an integrated approach for health-programme planning. *The Lancet* 372, 1579–1589.
- Cavana, R.Y., Clifford, L.V., 2006. Demonstrating the utility of system dynamics for public policy analysis in New Zealand: the case of excise tax policy on tobacco. *System Dynamics Review* 22, 321–348. doi:10.1002/sdr.347

- Cavana, R.Y., Tobias, M., 2009. Integrative system dynamics: analysis of policy options for tobacco control in New Zealand. *Systems Research and Behavioral Science* 25, 675–694. doi:10.1002/sres.934
- Christens, B.D., Hanlin, C.E., Speer, P.W., 2007. Getting the social organism thinking: strategy for systems change. *American Journal of Community Psychology* 39, 229–238. doi:10.1007/s10464-007-9119-y
- Chuang, S., Howley, P.P., Lin, S.-H., 2015. Implementing systems thinking for infection prevention: The cessation of repeated scabies outbreaks in a respiratory care ward. *American Journal of Infection Control*. doi:10.1016/j.ajic.2015.02.002
- Delgado, J., Pollard, S., Snary, E., Black, E., Prpich, G., Longhurst, P., 2013. A Systems Approach to the Policy-Level Risk Assessment of Exotic Animal Diseases: Network Model and Application to Classical Swine Fever: Systems Approach to the Policy-Level Risk Assessment of Exotic Animal Diseases. *Risk Analysis* 33, 1454–1472. doi:10.1111/j.1539-6924.2012.01934.x
- De Savigny, D., Adam, T., Alliance for Health Policy and Systems Research., World Health Organization., 2009. Systems thinking for health systems strengthening. Alliance for Health Policy and Systems Research : World Health Organization, Geneva.
- Fahey, D.K., Carson, E.R., Cramp, D.G., Muir Gray, J.A., 2004. Applying systems modelling to public health. *Systems Research and Behavioral Science* 21, 635–649. doi:10.1002/sres.602
- Fallah-Fini, S., Rahmandad, H., Huang, T.T.-K., Bures, R.M., Glass, T.A., 2014. Modeling US adult obesity trends: a system dynamics model for estimating energy imbalance gap. *American journal of public health* 104, 1230–1239.
- Fawkes, S., 2013. Leadership for systems change in preventive health - Review of the literature and current activity. Victorian Department of Health, Victoria, Australia.
- Finegood, D., 2011. The Complex Systems Science of Obesity, in: Crawley, J. (Ed.), *The Oxford Handbook of the Social Science of Obesity*., Oxford Handbooks Series. Oxford University Press, Oxford, pp. 208–236.
- Fisher, M., Milos, D., Baum, F., Friel, S., 2014. Social determinants in an Australian urban region: a “complexity” lens. *Health Promotion International*. doi:10.1093/heapro/dau071
- Galea, S., Hall, C., Kaplan, G.A., 2009. Social epidemiology and complex system dynamic modelling as applied to health behaviour and drug use research. *International Journal of Drug Policy* 20, 209–216. doi:10.1016/j.drugpo.2008.08.005
- Galea, S., Riddle, M., Kaplan, G.A., 2010. Causal thinking and complex system approaches in epidemiology. *International Journal of Epidemiology* 39, 97–106. doi:10.1093/ije/dyp296
- Ghaffarzadegan, N., Lyneis, J., Richardson, G.P., 2010. How small system dynamics models can help the public policy process. *System Dynamics Review* n/a–n/a. doi:10.1002/sdr.442
- Gilson, L., Elloker, S., Olckers, P., Lehmann, U., 2014. Advancing the application of systems thinking in health: South African examples of a leadership of sensemaking for primary health care. *Health Res Policy Syst* 12, 10–1186.



- Gortmaker, S.L., Swinburn, B.A., Levy, D., Carter, R., Mabry, P.L., Finegood, D.T., Huang, T., Marsh, T., Moodie, M.L., 2011. Changing the future of obesity: science, policy, and action. *The Lancet* 378, 838–847.
- Green, L.W., 2006. Public health asks of systems science: to advance our evidence-based practice, can you help us get more practice-based evidence? *American Journal of Public Health* 96, 406.
- Hamdani, Y., Jetha, A., Norman, C., 2011. Systems thinking perspectives applied to healthcare transition for youth with disabilities: a paradigm shift for practice, policy and research: Systems thinking perspectives for healthcare transition. *Child: Care, Health and Development* 37, 806–814. doi:10.1111/j.1365-2214.2011.01313.x
- Hammond, R.A., 2009. Complex systems modeling for obesity research. *Preventing chronic disease* 6.
- Hammond, R.A., 2008. A complex systems approach to understanding and combating the obesity epidemic. *CiteSeer*.
- Hassmiller Lich, K., Osgood, N.D., Mahamoud, A., 2010. Using System Dynamics tools to gain insight into intervention options related to the interaction between tobacco and tuberculosis. *Global Health Promotion* 17, 07–20. doi:10.1177/1757975909358255
- Have, D.W.A., 2010. System Science: A Revolution in Public Health Policy Research.
- Hawe, P., 2014. Lessons from Complex Interventions to Improve Health. *Annual Review of Public Health* 36, Online First. doi:10.1146/annurev-publhealth-031912-114421
- HIAP, 2013. HEALTH IN ALL POLICIES.
- Hirsch, G., Homer, J., Evans, E., Zielinski, A., 2010. A system dynamics model for planning cardiovascular disease interventions. *American journal of public health* 100, 616.
- Huang, T.T.-K., Grimm, B., Hammond, R.A., 2011. A Systems-Based Typological Framework for Understanding the Sustainability, Scalability, and Reach of Childhood Obesity Interventions. *Children's Health Care* 40, 253–266. doi:10.1080/02739615.2011.590399
- Ip, E.H., Rahmandad, H., Shoham, D.A., Hammond, R., Huang, T.T.-K., Wang, Y., Mabry, P.L., 2013. Reconciling statistical and systems science approaches to public health. *Health Education & Behavior* 40, 123S–131S.
- Iwelunmor, J., Airhihenbuwa, C.O., Cooper, R., Tayo, B., Plange-Rhule, J., Adanu, R., Ogedegbe, G., 2014. Prevalence, determinants and systems-thinking approaches to optimal hypertension control in West Africa. *Globalization and health* 10, 42.
- Jayasinghe, S., 2011. Conceptualising population health: from mechanistic thinking to complexity science. *Emerg Themes Epidemiol* 8, 1–7.
- Johnston, L.M., Finegood, D.T., 2015. Cross-Sector Partnerships and Public Health: Challenges and Opportunities for Addressing Obesity and Noncommunicable Diseases Through Engagement with the Private Sector. *Annual Review of Public Health* 36, 255–271. doi:10.1146/annurev-publhealth-031914-122802
- Johnston, L.M., Matteson, C.L., Finegood, D.T., 2014. Systems Science and Obesity Policy: A Novel Framework for Analyzing and Rethinking Population-Level Planning. *American journal of public health* e1–e9.

- Kok, S., Rutherford, A.R., Gustafson, R., Barrios, R., Montaner, J.S.G., Vasarhelyi, K., 2014. Optimizing an HIV testing program using a system dynamics model of the continuum of care. *Health Care Management Science*. Online first doi:10.1007/s10729-014-9312-0
- Kroelinger, C.D., Rankin, K.M., Chambers, D.A., Diez Roux, A.V., Hughes, K., Grigorescu, V., 2014. Using the Principles of Complex Systems Thinking and Implementation Science to Enhance Maternal and Child Health Program Planning and Delivery. *Maternal and Child Health Journal* 18, 1560–1564. doi:10.1007/s10995-014-1586-9
- Kwamie, A., Dijk, H. van, Agyepong, I., 2014. Advancing the application of systems thinking in health: realist evaluation of the Leadership Development Programme for district manager decision-making in Ghana. *Health Research Policy and Systems* 12, 29. doi:10.1186/1478-4505-12-29
- Lang, T., Rayner, G., 2007. Overcoming policy cacophony on obesity: an ecological public health framework for policymakers. *Obesity reviews* 8, 165–181.
- Leischow, S.J., Best, A., Trochim, W.M., Clark, P.I., Gallagher, R.S., Marcus, S.E., Matthews, E., 2008. Systems Thinking to Improve the Public's Health. *American Journal of Preventive Medicine* 35, S196–S203. doi:10.1016/j.amepre.2008.05.014
- Leischow, S.J., Milstein, B., 2006. Systems thinking and modelling for Public Health Practice. *American Journal of Public Health* 96, 403–405.
- Levy, B.S., Sidel, V.W., 2006. *Social injustice and public health*. Oxford University Press, New York.
- Lich, K.H., Ginexi, E.M., Osgood, N.D., Mabry, P.L., 2013. A Call to Address Complexity in Prevention Science Research. *Prevention Science* 14, 279–289. doi:10.1007/s11121-012-0285-2
- Liu, A., 2015. Research on Resilience of Emergency Logistics Network Responding to Public Health Emergencies Based on System Dynamics. *Journal of Information and Computational Science* 12, 1001–1010. doi:10.12733/jics20105432
- Livingood, W.C., Allegrante, J.P., Airhihenbuwa, C.O., Clark, N.M., Windsor, R.C., Zimmerman, M.A., Green, L.W., 2011. Applied Social and Behavioral Science to Address Complex Health Problems. *American Journal of Preventive Medicine* 41, 525–531. doi:10.1016/j.amepre.2011.07.021
- Luke, D.A., Stamatakis, K.A., 2012. Systems Science Methods in Public Health: Dynamics, Networks, and Agents. *Annual Review of Public Health* 33, 357–376. doi:10.1146/annurev-publhealth-031210-101222
- Luke, D.A., Wald, L.M., Carothers, B.J., Bach, L.E., Harris, J.K., 2013. Network influences on dissemination of evidence-based guidelines in state tobacco control programs. *Health Education & Behavior* 40, 33S–42S.
- Mabry, P., 2010. Systems Science: A Revolution in Public Health Policy Research. *American Journal of Public Health* 100.
- Mabry, P.L., 2011. Making Sense of the Data Explosion. *American Journal of Preventive Medicine* 40, S159–S161. doi:10.1016/j.amepre.2011.02.001
- Mabry, P.L., Bures, R.M., 2014. Systems Science for Obesity-Related Research Questions: An Introduction to the Theme Issue. *American journal of public health* 104, 1157–1159.
- Mabry, P.L., Kaplan, R.M., 2013. Systems Science A Good Investment for the Public's Health. *Health Education & Behavior* 40, 9S–12S.

- Mabry, P.L., Olster, D.H., Morgan, G.D., Abrams, D.B., 2008. Interdisciplinarity and Systems Science to Improve Population Health. *American Journal of Preventive Medicine* 35, S211–S224. doi:10.1016/j.amepre.2008.05.018
- MacLean, L.M., Clinton, K., Edwards, N., Garrard, M., Ashley, L., Hansen-Ketchum, P., Walsh, A., 2010. Debate Unpacking vertical and horizontal integration: childhood overweight/obesity programs and planning, a Canadian perspective.
- Maglio, P.P., Mabry, P.L., 2011. Agent-Based Models and Systems Science Approaches to Public Health. *American Journal of Preventive Medicine* 40, 392–394. doi:10.1016/j.amepre.2010.11.010
- Maglio, P.P., Sepulveda, M.-J., Mabry, P.L., 2014. Mainstreaming modeling and simulation to accelerate public health innovation. *American journal of public health* 104, 1181–1186.
- Mahamoud, A., Roche, B., Homer, J., 2013. Modelling the social determinants of health and simulating short-term and long-term intervention impacts for the city of Toronto, Canada. *Social Science & Medicine* 93, 247–255. doi:10.1016/j.socscimed.2012.06.036
- Manion, H., 2015. International Social Problems: A Systems Perspective, in: Wright, D. (Ed.), *Perspective International Encyclopedia of the Social & Behavioral Sciences*. Elsevier, Oxford, pp. 542–549.
- Mann, R., Smart, E., Reginald, G., 2000. Investigating the impact of high-risk programs on aggregate problem indicators. *Addiction* 95, 60–65.
- Marcus, S.E., Leischow, S.J., Mabry, P.L., Clark, P.I., 2010. Lessons Learned From the Application of Systems Science to Tobacco Control at the National Cancer Institute. *American Journal of Public Health* 100, 1163–1164.
- Marshall, B.D.L., Galea, S., 2015. Formalizing the Role of Agent-Based Modeling in Causal Inference and Epidemiology. *American Journal of Epidemiology* 181, 92–99. (accessed online in 2014) doi:10.1093/aje/kwu274
- McKelvie, D., Wolstenholme, E., Arnold, S., Monk, D., 2011. Using System Dynamics to Plan Investment in Alcohol Services. The Symmetric Partnership, UK.
- Méndez, D., 2010. A SYSTEMS APPROACH TO A COMPLEX PROBLEM. *American Journal of Public Health* 100, 1160–1160. doi:10.2105/AJPH.2010.199877
- Metcalf, S.S., Northridge, M.E., Widener, M.J., Chakraborty, B., Marshall, S.E., Lamster, I.B., 2013. Modeling social dimensions of oral health among older adults in urban environments. *Health Education & Behavior* 40, 63S–73S.
- Mlakar, T., Mulej, M., 2007. COMPLEMENTARITY OF THE LIVING SYSTEMS AND THE DIALECTICAL SYSTEMS THEORIES: THE CASE OF PUBLIC MEDICAL CARE IN SLOVENIA. *Cybernetics and Systems: An International Journal* 38, 381–399.
- Mundt, M.P., 2013. Social network analysis of peer effects on binge drinking among US adolescents, in: *Social Computing, Behavioral-Cultural Modeling and Prediction*. Springer, pp. 123–134.
- Newell, B., Proust, K., Dyball, R., McManus, P., 2007. Seeing obesity as a systems problem. *New South Wales Public Health Bulletin* 18, 214. doi:10.1071/NB07028



- Newton, J.T., Bower, E.J., 2005. The social determinants of oral health: new approaches to conceptualizing and researching complex causal networks. *Community dentistry and oral epidemiology* 33, 25–34.
- Norman, C.D., 2009. Health promotion as a systems science and practice. *Journal of Evaluation in Clinical Practice* 15, 868–872. doi:10.1111/j.1365-2753.2009.01273.x
- Norman, C.D., Charnaw-Burger, J., Yip, A.L., Saad, S., Lombardo, C., 2010. Designing health innovation networks using complexity science and systems thinking: the CoNEKTR model: Designing health innovation: the CoNEKTR model. *Journal of Evaluation in Clinical Practice* 16, 1016–1023. doi:10.1111/j.1365-2753.2010.01534.x
- Palmer, R.H.C., McGeary, J.E., Francazio, S., Raphael, B.J., Lander, A.D., Heath, A.C., Knopik, V.S., 2012. The genetics of alcohol dependence: Advancing towards systems-based approaches. *Drug and Alcohol Dependence* 125, 179–191. doi:10.1016/j.drugalcdep.2012.07.005
- Pauly, B.B., MacDonald, M., Hancock, T., Martin, W., Perkin, K., 2013. Reducing health inequities: the contribution of core public health services in BC. *BMC public health* 13, 550.
- Peters, D.H., 2014. The application of systems thinking in health: why use systems thinking. *Health Res Policy Syst* 12, 51.
- Prashanth, N.S., Marchal, B., Devadasan, N., Kegels, G., Criel, B., 2014. Advancing the application of systems thinking in health: a realist evaluation of a capacity building programme for district managers in Tumkur, India. *Health Research Policy and Systems* 12, 42.
- Rehfuess, E.A., Best, N., Briggs, D.J., Joffe, M., 2013. Diagram-based Analysis of Causal Systems (DACS): elucidating inter-relationships between determinants of acute lower respiratory infections among children in sub-Saharan Africa. *Emerging themes in epidemiology* 10, 13.
- Resnicow, K., Page, S.E., 2008. Embracing chaos and complexity: a quantum change for public health. *American journal of public health* 98, 1382.
- Retrum, J.H., Chapman, C.L., Varda, D.M., 2013. Implications of network structure on public health collaboratives. *Health Education & Behavior* 40, 13S–23S.
- Reynolds, J., 2013. Hospital charitable lotteries: taking a gamble on systems thinking: Hospital charitable lotteries. *Journal of Evaluation in Clinical Practice* 19, 1090–1094. doi:10.1111/jep.12066
- Riley, B., Norman, C.D., Best, A., 2012. Knowledge integration in public health: a rapid review using systems thinking. *Evidence & Policy: A Journal of Research, Debate and Practice* 8, 417–431. doi:10.1332/174426412X660089
- Roux, A.D., 2011. Complex systems thinking and current impasses in health disparities research. *American journal of public health* 101, 1627–1634.
- Rydin, Y., Bleahu, A., Davies, M., Dávila, J.D., Friel, S., De Grandis, G., Groce, N., Hallal, P.C., Hamilton, I., Howden-Chapman, P., others, 2012. Shaping cities for health: complexity and the planning of urban environments in the 21st century. *The Lancet* 379, 2079–2108.
- Sabounchi, N.S., Hovmand, P.S., Osgood, N.D., Dyck, R.F., Jungheim, E.S., 2014. A novel system dynamics model of female obesity and fertility. *American journal of public health* 104, 1240–1246.

- Sautkina, E., Goodwin, D., Jones, A., Ogilvie, D., Petticrew, M., White, M., Cummins, S., 2014. Lost in translation? Theory, policy and practice in systems-based environmental approaches to obesity prevention in the Healthy Towns programme in England. *Health & Place* 29, 60–66.  
doi:10.1016/j.healthplace.2014.05.006
- Schaefer, D.R., Haas, S.A., others, 2013. Social Networks and Smoking Exploring the Effects of Peer Influence and Smoker Popularity Through Simulations. *Health Education & Behavior* 40, 24S–32S.
- Shiell, A., Hawe, P., Gold, L., 2008. Complex interventions or complex systems? Implications for health economic evaluation. *British Medical Journal* 336, 1281–1283.
- Silverman, B.G., Hanrahan, N., Bharathy, G., Gordon, K., Johnson, D., 2015. A systems approach to healthcare: Agent-based modeling, community mental health, and population well-being. *Artificial Intelligence in Medicine* 63, 61–71. Accessed online 2014  
doi:10.1016/j.artmed.2014.08.006
- Skinner, A.C., Foster, E.M., 2013. Systems Science and Childhood Obesity: A Systematic Review and New Directions. *Journal of Obesity* 2013, 1–10.  
doi:10.1155/2013/129193
- Sturmberg, J.P., Martin, C.M., Katerndahl, D.A., 2014. Systems and Complexity Thinking in the General Practice Literature: An Integrative, Historical Narrative Review. *The Annals of Family Medicine* 12, 66–74.  
doi:10.1370/afm.1593
- Tawileh, A., Almagwashi, H., McIntosh, S., 2008. A system dynamics approach to assessing policies to tackle alcohol misuse, in: *Proceedings of the 26th International Conference of the System Dynamics Society*, Dangerfield BC.(ed.). [Http://systemdynamics.org/conferences/2008/proceed/papers/TAWIL185.Pdf](http://systemdynamics.org/conferences/2008/proceed/papers/TAWIL185.Pdf) [5 May 2009].
- Tengs, T.O., Osgood, N.D., Chen, L.L., 2001. The Cost-Effectiveness of Intensive National School-Based Anti-Tobacco Education: Results from the Tobacco Policy Model. *Preventive Medicine* 33, 558–570.  
doi:10.1006/pmed.2001.0922
- Tobias, M.I., Cavana, R.Y., Bloomfield, A., 2010. Application of a system dynamics model to inform investment in smoking cessation services in New Zealand. *American journal of public health* 100, 1274.
- Trochim, W.M., Cabrera, D., 2005. The complexity of concept mapping for policy analysis. *Emergence: complexity and organization* 7, 11–22.
- Tubbing, L., Harting, J., Stronks, K., 2015. Unravelling the concept of integrated public health policy: Concept mapping with Dutch experts from science, policy, and practice. *Health Policy*. (Accessed online 2014)  
doi:10.1016/j.healthpol.2014.12.020
- Van Beurden, E.K., Kia, A.M., Zask, A., Dietrich, U., Rose, L., 2013. Making sense in a complex landscape: how the Cynefin Framework from Complex Adaptive Systems Theory can inform health promotion practice. *Health Promotion International* 28, 73–83. doi:10.1093/heapro/dar089
- Vandenbroeck, I., Goossens, J., Clemens, M., 2007. Foresight tackling obesities: future choices—obesity system atlas. Foresight Study, UK.

- Van Wave, T.W., Scutchfield, F.D., Honoré, P.A., 2010. Recent Advances in Public Health Systems Research in the United States. *Annual Review of Public Health* 31, 283–295. doi:10.1146/annurev.publhealth.012809.103550
- Wakeland, W., Nielsen, A., Schmidt, T.D., McCarty, D., Webster, L.R., Fitzgerald, J., Haddox, J.D., 2013. Modeling the Impact of Simulated Educational Interventions on the Use and Abuse of Pharmaceutical Opioids in the United States A Report on Initial Efforts. *Health Education & Behavior* 40, 74S–86S.
- Walton, M., 2014. Applying complexity theory: A review to inform evaluation design. *Evaluation and Program Planning* 45, 119–126. doi:10.1016/j.evalprogplan.2014.04.002
- Wang, Y., Xue, H., Esposito, L., Joyner, M.J., Bar-Yam, Y., Huang, T.T.-K., 2014. Applications of Complex Systems Science in Obesity and Noncommunicable Chronic Disease Research. *Advances in Nutrition: An International Review Journal* 5, 574–577. doi:10.3945/an.114.006650
- Weishaar, H., Amos, A., Collin, J., 2015. Capturing complexity: mixing methods in the analysis of a European tobacco control policy network. *International Journal of Social Research Methodology* 18, 175–192. (accessed online 2014) doi:10.1080/13645579.2014.897851
- Wiist, W.H., 2014. Use of complex systems modelling to strengthen public health's role in preventing war. *Medicine, Conflict and Survival* 30, 152–164. doi:10.1080/13623699.2014.922374
- Williams, W., Lyalin, D., Wingo, P.A., 2005. Systems thinking: what business modeling can do for public health. *Journal of Public Health Management and Practice* 11, 550–553.
- Young, D., 2010. An Actor-Network Theory Analysis of Policy Innovation for Smoke-Free Places: Understanding Change in Complex Systems. *Framing Health Matters* 100.
- Young, D., Borland, R., Coghill, K., 2012. Changing the Tobacco Use Management System: Blending Systems Thinking with Actor-Network Theory: Changing the Tobacco Use Management System. *Review of Policy Research* 29, 251–279. doi:10.1111/j.1541-1338.2011.00550.x
- Zainal Abidin, N., Mamat, M., Dangerfield, B., Zulkepli, J.H., Baten, M.A., Wibowo, A., 2014. Combating Obesity through Healthy Eating Behavior: A Call for System Dynamics Optimization. *PLoS ONE* 9, e114135. doi:10.1371/journal.pone.0114135
- Zarowsky, C., Haddad, S., Nguyen, V.-K., 2013. Beyond “vulnerable groups”: contexts and dynamics of vulnerability. *Global Health Promotion* 20, 3–9.
- Zosel, R., 2015. The Rise of Systems Thinking in Public Health. In *Touch* 15–16.
- Zulkepli, J., Abidin, N.Z., Zaibidi, N.Z., 2014. Obesity prevention: Comparison of techniques and potential solution.