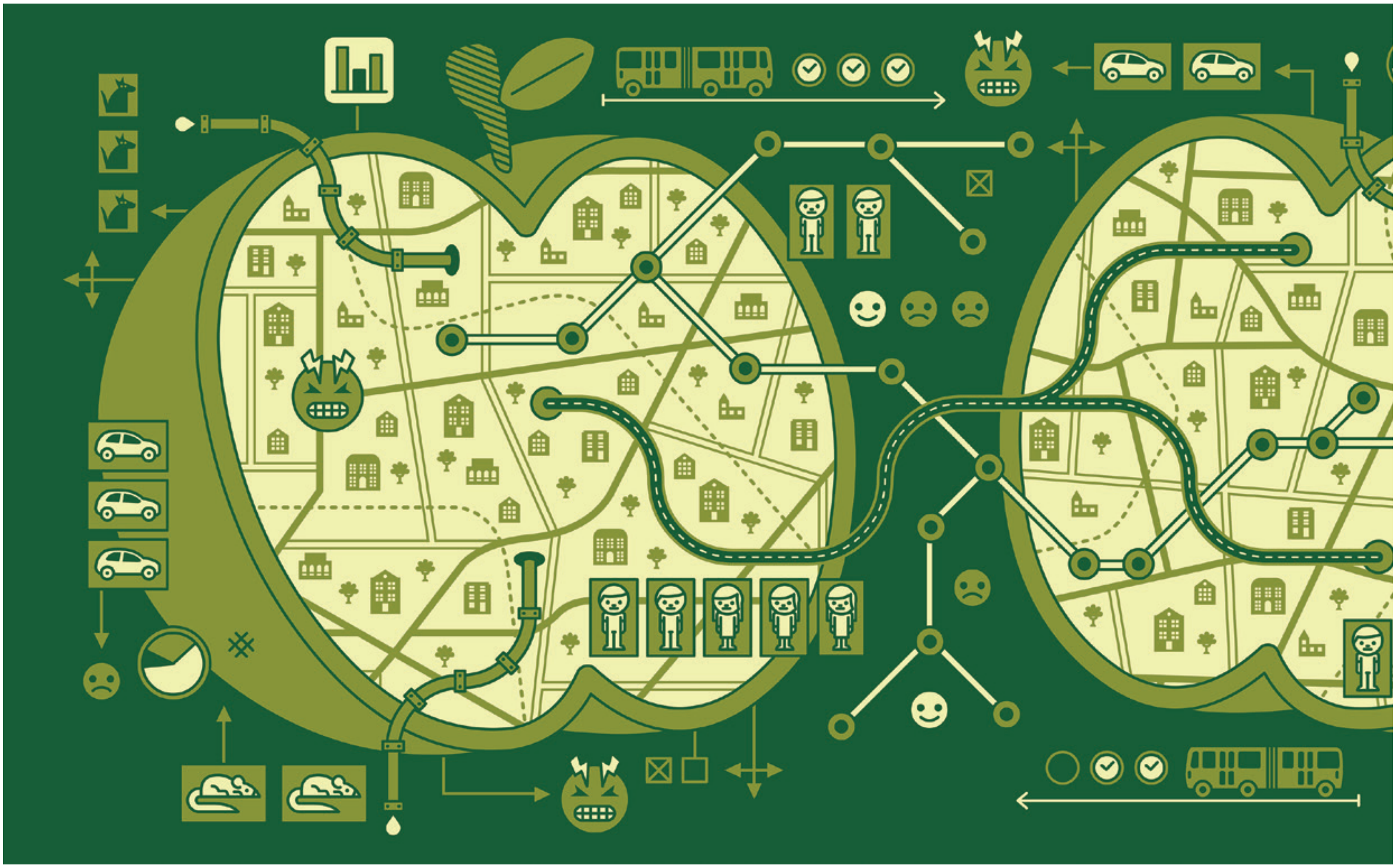


POLICY

Urban physics

Cities are complex environments. Planning interventions that borrow principles from theoretical physics could help to improve peoples' lives.

BY KEVIN POLLOCK

The ideal city. That was what the French had in mind when they made Hanoi the capital of colonial Indochina at the turn of the twentieth century. To modernize the tropical city, French administrators, technocrats and engineers built railways, bridges and an opera house. But rather than becoming a symbol of success in their southeast Asian colonial project, Hanoi became an example of urban apartheid. The European quarter was renovated with wide, tree-lined avenues, and large, spacious villas. Whereas the old quarter, home to the native Indochinese, was a place of narrow roads and overcrowded buildings.

One part of the modernization plan did not have the intended effect, however. The colonialists had built a system of more than 15 kilometres of underground pipes that flushed waste away in the European quarter — an improvement inspired by the discovery in the late nineteenth century that proper sewers could avert cholera outbreaks by preventing the contamination of drinking water. The old quarter, by contrast, made do with a basic drainage system that dumped untreated waste into the nearby Red River. During the floods, which commonly occurred during the rainy season, the streets in the old city were filled with human faeces.

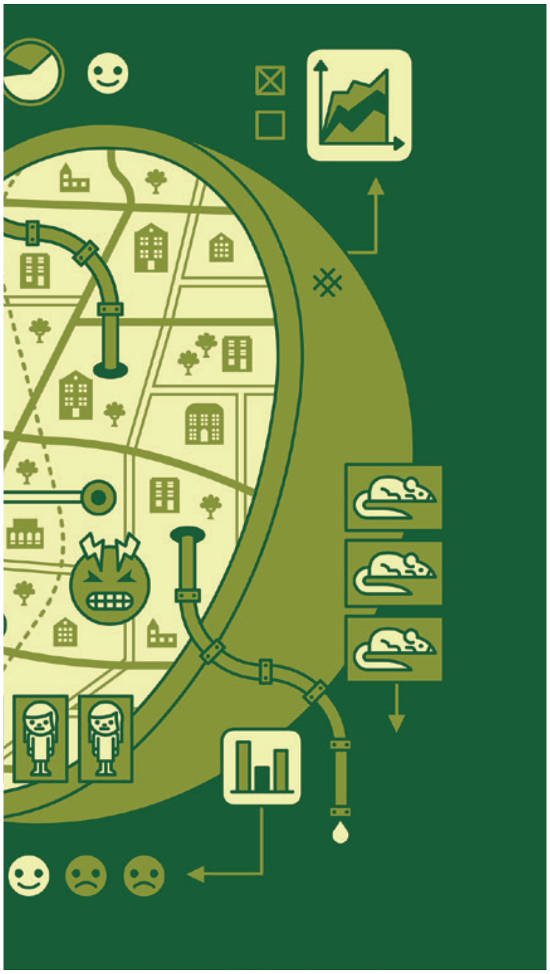
But the same sewage pipes that spared the colonialists from cholera also served as an ideal breeding ground and mass transportation system for the rat population — harbingers of other serious diseases such as the bubonic plague. Hanoi's wealthiest homes, equipped with indoor plumbing amenities such as running water and flushing toilets, became overrun with the rodents as they left their subterranean homes in search of food. Between 1906 and 1908, plague killed at least 263 people in colonial Hanoi. Bubonic plague remained a risk throughout French colonial rule and the rat problem, although effectively managed, persists today.

By trying to solve one threat to urban health, the French inadvertently introduced another. This pattern has recurred throughout the history of modern cities, as urban policies and interventions perpetually yield unpredicted, and sometimes dire, consequences. This is typical of a network as physically and socially complex as a city. Implementing policies to fix what's broken without introducing a new set of problems is in many ways the central challenge of urban improvement. A way of thinking borrowed from theoretical physics may be the best chance that urban planners have of overcoming it.

COMPLEX MODELS

Cities are complicated. They comprise large numbers of people, and the many ecological, cultural, social and economic entities that make up their environment. All these factors interact in time and space to form complex systems that constantly evolve in response to changes in climate, environment and people.

The characterization of cities as complex systems is based on work that originated in an entirely different field. Physicist and Nobel laureate Philip W. Anderson proposed complexity



JAN KALLWEJT

theory in his 1972 article ‘More Is Different’ in an effort to understand the “shift from quantitative to qualitative differentiation” in his discipline of many-body physics (P. W. Anderson *Science* **177,** 393–396; 1972). The behaviour of complex aggregates of elementary particles such as the atomic nucleus could not be understood solely in terms of the properties of their individual components. Instead, Anderson reasoned, at each level of complexity entirely new properties appear, and each level of understanding requires a new conceptual structure. An atom in isolation can be thought of as “a featureless, symmetrical little ball”, he wrote, but the presence of other particles and environmental conditions changes the shape and reactivity of that atom. Failure to take these changes into account renders the understanding of any measurable observations difficult, if not impossible.

The same is true of cities. As one expands from the perspective of an individual urban dweller to the neighbourhood or town level, new interactions emerge and the complexity of the network increases. Since its inception, Anderson’s theory of complex systems has spread beyond particle physics to a variety of other disciplines, including biology and economics.

One of those applying systems thinking to urban environments is Luis Bettencourt, a complex systems specialist at the Santa Fe Institute in New Mexico. Like Anderson, Bettencourt trained as a theoretical physicist — he used empirical data and statistics to model the early Universe. But his fascination with cities and complex social organizations brought him to the institute’s Cities, Scaling and Sustainability project, an interdisciplinary effort to develop a general theory of urbanization that is capable of describing cities quantitatively.

“We create models of a city at the systems level,” he explains, “in order to describe the physical and social networks of people and businesses, and understand how those mesh with urban space and infrastructure. Just imagine the math of that.”

By analysing as much data about cities as possible — everything from crime statistics to efficiency of public transport — Bettencourt and his colleagues have been able to identify key variables and interactions to formulate a picture of an urban system. These models have allowed the team to demonstrate that many of the factors affecting urban well-being are tied, in remarkably predictable ways, to the size of a city; as population grows, so too does crime, for instance. Modelling is also useful in understanding how well-meant health interventions in cities can have unforeseen effects. Although models of complex urban systems can’t provide planners with specific policies to enact to improve health and well-being, they can help to explain one of the trickiest properties of complex systems: feedback.

LOOPED THINKING

Complex systems such as cities are alive with feedback loops. The effects of an intervention in one area can produce changes in another, which can, in turn, either amplify or oppose the original intervention. The simplest example of a feedback loop is a thermostat: as the temperature drops below the target level, the heating clicks into life and warms up the room. The increased temperature then feeds back, and the heating is switched off.

In the case of the thermostat, the loop is by design. But in cities, unexpected loops abound. Once again, Hanoi provides a classic example. Faced with the rat problem, in 1902 French colonialists began to pay rat catchers to reduce the population. Wages were dependent on the number of severed tails presented to the authorities. But the rodent bounty did not work as planned — some made the most of the financial opportunity and began breeding rats for their tails.

Feedback loops can also be seen in cities that expand their road networks to tackle traffic congestion. Although the additional road capacity does initially reduce congestion, over time the effect is usually to entice more people to drive, and consequently to bring about more traffic jams, a higher risk of accidents and increased vehicle emissions. Such a loop cannot be described in isolation, however. The effects of the intervention can be seen elsewhere. Where roads are built can affect decisions about housing and energy, and the time spent commuting in traffic can reduce the time spent exercising, increasing the level of obesity (see ‘Making connections’).

As is the case with any public expenditure, most would agree that urban policy should ideally be evidence based. But with seemingly endless loops of cause and effect to negotiate, determining whether an urban policy has been a success or not can be tricky.

There are many different methods used by the public, private and social sectors of society to evaluate policy impact “which must be adapted to each specific case and each specific problem,” says Ernesto Amaral, a sociologist at the RAND Corporation in Santa Monica, California. When measuring the impact of a policy, he says, the ideal scenario is to compare a group that receives the policy with a ‘control’ group that doesn’t. It is a simple enough concept, but as the Hanoi-sewer story illustrates, even in cases in which a control group is available, policies do not have binary outcomes — a single policy can have multiple effects, good and bad.

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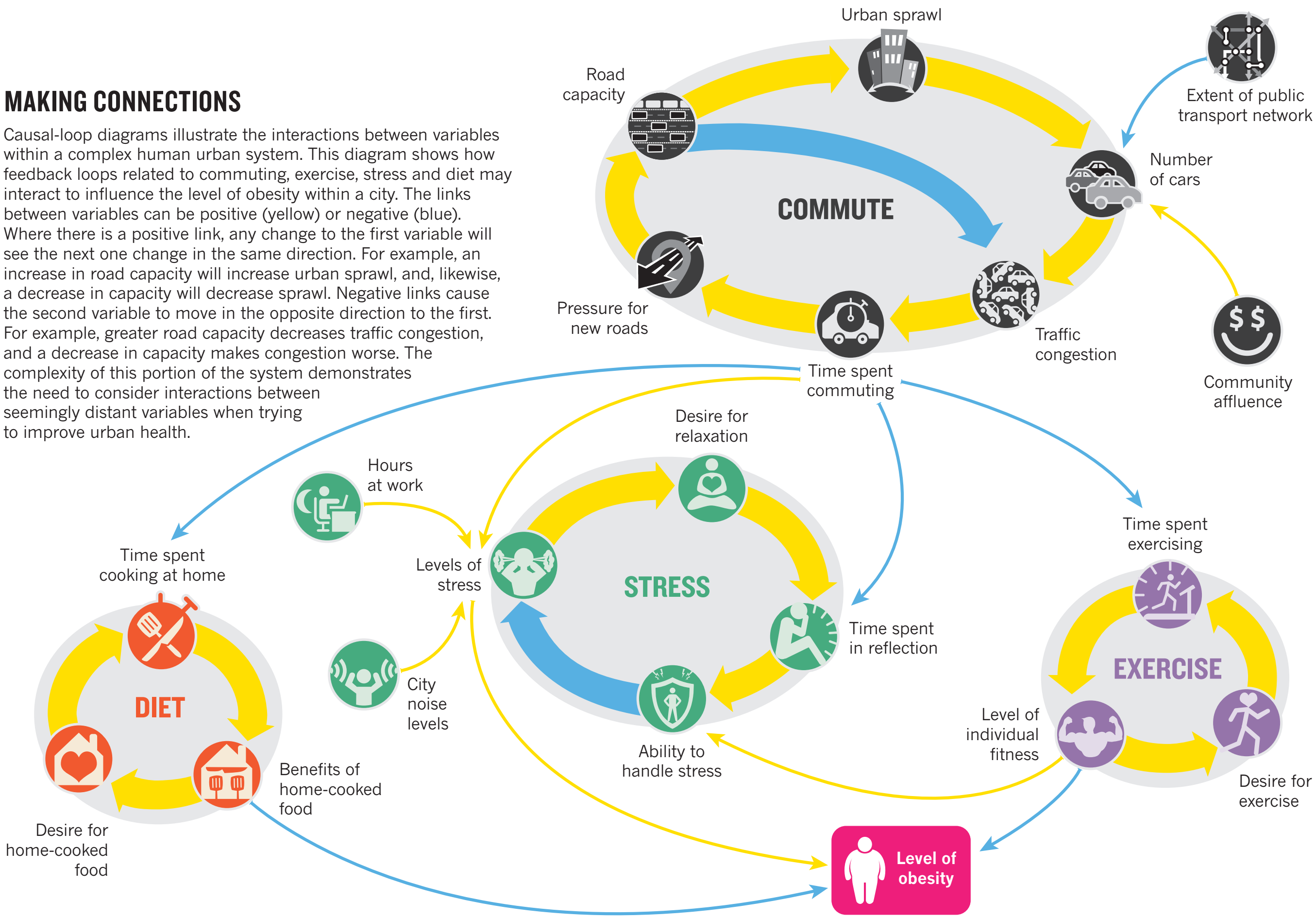
Another problem is how to demonstrate that a policy works when the outcomes might take decades or longer to appear. There can be multiple outcomes and the policymakers responsible for the initial intervention may have moved on by the time those outcomes occur. “It gets complicated to correlate back to the specific actions that actually caused them,” says Barry Newell, a systems dynamicist at the United Nations University International Institute for Global Health (UNU–IIGH) in Kuala Lumpur, Malaysia.

When faced with having to evaluate such long-term effects, historical studies may prove crucial. “We can use history to understand what has happened as the result of actions in the past, and then project that into the future,” says Newell. An example of this type of research is a pilot project run by historian Katrina Proust in George Town, a city on the Malaysian island of Penang. Proust will lead an interdisciplinary team from the UNU–IIGH, including Newell. The researchers will apply the concepts of systems thinking and feedback dynamics to an analysis of almost 200 years of historical archive data — from 1786, when the city was established, to 1985, when the first bridge connecting Penang island with the mainland was completed. Proust hopes to model policy and decision-making behaviour by combining numerical data with well-documented, qualitative observations. The goal is to better understand the relationship between urban administration, planning and public health. “We’re looking at issues of health today, such as those related to dependence on motor vehicles,” says Proust, “as well as traditional urban problems of the tropics like sanitation and water quality.” In general, these types of small-scale, locally focused projects detect feedback effects

MAKING CONNECTIONS

Causal-loop diagrams illustrate the interactions between variables within a complex human urban system. This diagram shows how feedback loops related to commuting, exercise, stress and diet may interact to influence the level of obesity within a city. The links between variables can be positive (yellow) or negative (blue). Where there is a positive link, any change to the first variable will see the next one change in the same direction. For example, an increase in road capacity will increase urban sprawl, and, likewise, a decrease in capacity will decrease sprawl. Negative links cause the second variable to move in the opposite direction to the first. For example, greater road capacity decreases traffic congestion, and a decrease in capacity makes congestion worse. The complexity of this portion of the system demonstrates the need to consider interactions between seemingly distant variables when trying to improve urban health.



SOURCE: BARRY NEWELL

more quickly than large-scale global studies, because response times are relatively short and the people and variables within the system are better identified.

A COMMON LANGUAGE

By identifying the interactions within urban systems, it is hoped that real-world policy can be changed to improve the health of cities. "We want to scientifically understand and model complex systems in cities, to evaluate what the multiple components are and how they interact, in order to predict health and well-being in urban environments," says Franz Gatzweiler, director of the International Council for Science's Urban Health and Well-Being programme based at the Institute of Urban Environment in Xiamen, China. The programme supports research projects that use a systems approach to generate useful products for policymakers, because although projects such as Proust's can improve the understanding of systems, there are few examples of this type of approach being applied.

One group committed to this approach with some success is InWithForward, an organization based in Vancouver, Canada, that combines systems analysis and modelling with engagement of communities at the local level. They identify the shortcomings of existing urban policies by observing the system from the point of view of local individuals, and then work with these people to fill the gaps within the system. For example, by observing people with cognitive disabilities in Vancouver, the group discovered that although the medical care was adequate, most of these people had mundane and repetitive daily routines, and that their quality of life was poorer because of it. The organization's solution was to connect these individuals with other members of their community who could provide diverse opportunities and learning experiences — from art and music teachers, to carpenters and animal trainers. "Most of the data policymakers have available tells them where the problem is, but don't help to illuminate what the solutions would be," says Sarah Schulman, founder of the organization. Rather than major top-down changes, Schulman's approach focuses on creating new interactions and networks within the existing urban system, promoting a shared understanding among both policymakers and urban dwellers of how the system works, and what can be done to change things.

"Our capacity to act collectively is lagging."

But shared understanding is not a simple thing to achieve, especially between urban planners who tend to treat areas of the city separately. "We all talk different languages," says Gatzweiler. Different disciplines have their own vocabularies, and it is entirely possible for miscommunication to pass unnoticed. For example, despite physicist Newell and historian Proust working and living together (the two researchers are married), they only realized that they were each defining a term often used in their work entirely differently after five years on a particular project.

"Our capacity to act collectively is lagging," says Gatzweiler. Overcoming the silos into which different aspects of the city network are divided — water, transport, health and so on — is a central challenge of urban planning. In a system as complex as a city, no one person or speciality can see the whole picture; urban health is an interdisciplinary problem that requires collaboration across administrative and scientific barriers. Once again, Anderson's theory of complexity makes the way ahead clear. Rather than have each discipline focus on making inroads into problems by themselves, Anderson wrote, "we should recognize that such roads, while often the quickest shortcut to another part of our own science, are not visible from the viewpoint of one science alone."

Threats to urban health and well-being span disciplinary boundaries, and systems thinking offers a tool by which these boundaries can be bridged, says Gatzweiler "We need systems thinking and the co-production of knowledge in order to create healthier, wealthier cities, and people within them." ■

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