The expert view: systems and networks thinking for cities

Interviewer: Gareth Byatt – Principal Consultant, Risk Insight Consulting
Interviewee: Matt Winchur – Group EGM Operations Risk & Performance, Downer Group

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Matt,

Thank you for making the time to talk with me about urban systems and networks thinking, and what this means for urban infrastructure.

In our discussion, I may refer sometimes to some principles I use for urban development and management in my Urban 2.0 work, which are described below:

Urban 2.0 principles (by: G Byatt)

Could we start this interview with a brief outline of your experience and your current activities with Downer Group (which I know is a business that serves the transport sector and other sectors)?

Matt: *I'm delighted to be here today. I've spent my career in operational excellence, starting at [Toyota], then moving through major players like [UGL] (an Australian business working in the energy, transportation, resources, communications and Defence sectors) and [Lendlease] in Australia, and now leading Operational Risk & Performance as an EGM at [Downer].*

Around a decade ago, I embarked on a fascinating journey, delving into the science of cities for an innovative idea I had to try and create algorithms that could be used in digital twin models to describe city features. It's the learnings from this innovation effort that I'm keen to explore with you today.

Gareth: Thanks for this context, Matt. I appreciate the point you make about your research into "the science of cities", for the built environment part of the urban system in particular. What are the main points of this research?

Matt: *In my view, understanding the underlying network dynamics is crucial for comprehending how cities grow, thrive, adapt to risks, and also recover from disaster events that occur (such as extreme weather, major health problems such as pandemics or human-driven events).*

Drawing from the insights of Geoffrey West's book, [Scale], I want to emphasise the concept of looking at cities as complex networks. Just as biological systems use and rely on intricate networks – circulatory, nervous, and lymphatic – to efficiently deliver energy and resources to every cell, a city operates on similar principles. The interconnected web of infrastructure, transportation systems, communication channels, and social ties within a city function are its metabolism. This complex urban network dictates the pace at which information, goods, and people move, ultimately setting the fundamental tempo for innovation, economic activity, and overall societal processes within a metropolis.

Some key principles of network that need to be understood:

1. *The tentacles of a network extend everywhere across the system.*
2. *Networks have "terminal units" that are approximately the same size and have similar characteristics (e.g. the cells in our bodies).*
3. *Networks have feedback loops that, when acted on, can help us work towards optimisation.*

*Another concept I'd like to highlight is urban scaling. Extensive empirical data shows us that, despite geographical and cultural differences, urban infrastructure exhibits a predictable and **sublinear** scaling relationship with population size. The amount of physical infrastructure – be it the length of roads, the extent of electrical grids, or the network of water pipes – scales universally with an exponent of approximately 0.85. In other words, as a city's population doubles, its infrastructure needs increase by about 85% (not 100%), reflecting economies of scale inherent in urban networks.*

*Interestingly, while infrastructure demonstrates efficiencies of scale, human aspects (socioeconomic indicators) such as average wages, total wealth, the rate of patent creation, levels of crime, and educational attainment also scale predictably with population size – BUT these scale at a **super linear** exponent of approximately 1.15.*

So, as populations grow, these human aspects (positive and negative) grow faster. Cities also become more multi-dimensional as they grow.

Here are a few other governing rules to consider for cities:

1. *Kleiber's law (as applied to cities): Of all possible configurations a system can have as it evolves over time, the one that is realised is the one that minimizes its action.*
2. *Walter Christaller's Central Place Theory attempts to explain the size, number, and distribution of human settlements (or "central places") across a landscape. It suggests settlements primarily function as "central places" which provide goods and services to surrounding "market areas".*
3. *Marchetti's Constant is based on the observation that humans, across diverse cultures and throughout history, tend to allocate an average of about one hour per day to travel. This seems to be surprisingly consistent across human history.*

Gareth: Your description, Matt, of a complex urban network that dictates the pace at which information, goods, and people move makes me think in general how city design is a vital part of how to help people live well. It reminds me of discussions I have had with people such as Alain Bertaud about urban economics, and Adam Millard-Ball about street design.

Also, your point about Marchetti's Constant (the average time spent by a person for commuting each day) links with a discussion I have had with the transport consultant, Jarrett Walker. Whilst a lot is written about the benefits of public transport to help with making commutes as efficient as possible for citizens of cities and towns, its use, quality and effectiveness (including frequency – something for us to discuss later) vary greatly in cities and towns around the world.

Matt: *When it comes to transport, Marchetti's constant gives us a framework for understanding different and competing priorities that shape cities. The efficiency of transportation systems will influence city limits. The average person's walking speed of approx. 5 km/hr (3.1 miles/hr) can be linked to the diameter of a city centre and the proximity of services (infrastructure and others such as health and education). These will in turn determine the scaling factors that urban planners need to consider when planning new projects.*

Gareth: I carry out research into why public transport networks work well in some cities and towns, with a good balance of patronage / ridership and coverage achieved, but in other cities and towns their public transport networks do not work well. Do you have any thoughts on this, perhaps related to the "science of cities"?

Matt: *The work by the Future Cities Lab has asked similar questions; framed a little differently. They asked: 'How many people visit a given place?' and 'How often do they go there and from how far away?' They came up with a "visiting theorem" which states that the number of visitors scales with both distance travelled and visitation frequency.*

If, for example, an area of interest has 1,600 people that visit from 4km away once a month, it will have 400 people visit from 8km away. Similarly, around 400 people will visit twice from 4km away. This can be an interesting model to consider when we think about public transport usage and adoption.

Gareth: When it comes to the movement of people and how far people will travel and the frequency of this travel, energy / fuel is a big factor (and cost) for any type of transport. Do you have any thoughts on how energy and transport may evolve?
I remember seeing examples of public transport providing energy back to the grid, such as London Underground providing energy from heat generated by their trains in Islington (a borough of Greater London). We also hear about EVs being able to provide energy back to the grid.

***Matt:** I think there could be several advancements. For example, by embracing the view of transportation as a dynamic, interconnected network I envisage that electric vehicles will evolve to become mobile, intelligent batteries. These vehicles will no longer solely draw from the grid, they will actively participate in the grid including providing surplus energy when appropriate, following the natural ebb and flow of human movement in a city throughout the day. Anywhere people commute, they could supply local demands. This distributed energy model could significantly alleviate the burden on static energy infrastructure in cities (and towns).*

Gareth: Thanks for these thoughts about energy and transport, Matt. I know there is a lot of work going into how transport will evolve in future, including its linkage to energy and the grid.

I'd like to finish by asking whether you have any suggested reading or viewing material for people about urban environments in general – such as books, papers, articles or online videos?

***Matt:** I have found it interesting to review the work of four institutions doing some interesting work, which I hope others find of interest:*

1. *The Santa Fe Institute – agent-based modelling that describe how city properties vary in relation to their population size. They created simple rules for governing interactions between agents and algorithms for how they evolve over time.*
2. *University College in London (UCL) – measured the fractal dimensions of cities to determine their measure of complexity. They found values ranging from 1.2 to 1.8 (example paper here).*
3. *The University of Zurich – conducting computer simulations for a range of aspects of life (economic, climate, physical processes, etc.).*
4. *Future Cities Lab – adaptive mobility work.*

Gareth: Thank you very much for your thoughts and perspectives, Matt.

