18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009
http://mssanz.org.au/modsim09

Understanding Connectivity of Settlements: Implications of the Power Curve

Kurt Seemann[1,2] and Dora Marinova[2]

[1]*School of Tourism and Hospitality Management, Southern Cross University, New South Wales*
[2]*Curtin University Sustainability Policy (CUSP) Institute, Curtin University of Technology*
Western Australia
Email: D.Marinova@curtin.edu.au

Abstract: Research on human settlements has traditionally focussed on one or a few descriptive or functional aspects, such as geographical characteristics of the locality, the economy, housing, transport, infrastructure, education or health, or created models with varying degrees of complexity that attempt to bring these elements together. This paper applies a different approach that is based in understanding connectivity within and between complex systems. It outlines a new growth area for settlement research and design which brings into play the concept of scale-free hierarchical networks with preferential tendencies, best described by the power curve. Using examples ranging from remote communities to developing countries, the concept helps explain among others, the economic connectivity within a globalised world. The paper also argues that understanding the implications of connectivity is a step towards predicting, evaluating and diagnosing the social, cultural and economic sustainability of settlements.

Keywords: *desert Australia, free-scale networks, human settlements, migration, small world, sustainability*

1. INTRODUCTION

Bell-shaped, Gaussian or normal distribution is the most commonly known and used statistical probability distribution in which the data observations cluster around a mean (or average) value. The list of normal distribution occurrences is almost endless, from size and weight of species to temperature ranges, to prices of goods and stocks, to measures of human health or intelligence. Being the most important statistical pattern of data, normal distribution in many ways is also shaping expectations and conditioning decision-making. In fact, knowing that 99.5% of all data lie within three standard deviations of the mean can be a good justification for a wide range of policy decisions and mechanisms that target the average case. Despite its pervasiveness, the normal distribution is in no means the only way of thinking about the world, and particularly about the sustainability of human settlements. In fact, what this paper argues is that it is the wrong way of thinking because of the importance of the power law.

According to Clauset et al. (2009), the power law is attracting a lot of attention recently as it leads to surprising consequences, both in the natural and human-made world. Mathematically a power law is present when a quantity x is drawn from a probability distribution:

$$p(x) \propto x^{-\alpha}$$

where α is a constant parameter of the distribution, known as the exponent. The exponent typically lies in the range of $2 < \alpha < 3$ (Clauset et al., 2009). Graphically the power law is represented by a long-tail distribution (see Figure 1) to which we refer as the power curve. The most common polynomial relationship used to describe this power curve is:

$$f(x) = ax^k + o(x^k)$$

where a and k are constants and $o(x^k)$ is an asymptotically small function of x. To put it in simply, what the power law says is that large is rare and small is more common or that the winner takes it all.

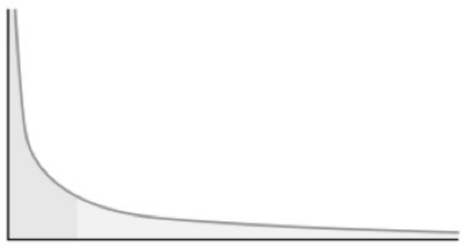


Figure 1. Power law distribution

x-axis denotes frequency, y-axis denotes the probability of a particular event

Examples of power law distributions include among others metabolic rate of species and body mass, (e.g. the evolution of metabolic networks of organisms, Singh et al., 2007), magnitude of earthquakes, income distribution, religious affiliations, fire sizes, occurrences of rare words in a writing (such as a book), academic citations, links to Internet sites and city-size distribution. The latter is often described as Zipf's law which states that a city's population is proportional to how it ranks in population size (Newman, 2005). The power law has mainly been the focus of statistical and mathematical analyses; however what is more important is what are its implications. Ijiri and Simon (1977) and more recently Mitzenmacher (2006) stress that it is essential to understand what are the practical purposes that arise from this robust and most interesting law.

One such application of the power law is the scale-free network. The remainder of the paper elaborates on this concept and examines its implications for understanding the connectivity between settlements. It is structured as follows. The section to follow explains the nature of scale-free networks and the type of connectivity they provide. This is followed by a discussion of examples of the importance of the scale-free networks. The final section concludes with the need to reconceptualise the dichotomy of a big world versus small world as the nodes of connectivity provided within the big world support the functioning and long-term sustainability of both, the small and the large human settlements.

2. SCALE-FREE NETWORKS

A scale-free network is a network whose degree distribution, or the number of connections from each node, follows a power law (Barabási and Bonabeau, 2003; Caldarelli, 2007). Mathematicians represent networks as graphs with nodes and links. Barabási (2002) shows numerous examples of the importance of networks and the links between hubs, including terrorist attacks or narcotic trade. The most important feature of a scale-free network (or any network for that matter) is the connectivity between its nodes. With many links, the network can exhibit fault-tolerant behaviour or robustness, that is a property which allows it to operate in a reliable way even if there is a (limited or randomly distributed) degree of failure. If a particular node is affected and becomes non-functional, the connectedness within the network can be restored through an alternative path, using a different combination of nodes and links. The World Wide Web is an excellent example to this point.

Networks also provide a powerful abstraction for social interactions, including interactions that are dynamic and evolving. Each node can be thought of as a person who has connections through acquaintance to other people and some people are much more connected than others. Human settlements are complex systems of people, resources, structures, the natural environment and are linked to other settlements and areas. They are also subject to outside forces which can affect the connectivity between nodes, such as natural disasters, war or military conflicts, border protection, political and commercial restrictions. Settlements can be described as such scale-free networks at a range of levels, for example:

- the city itself – houses, streets, suburbs, urban grid and public transport (see Figures 2, 5 and 6);
- human settlements within a region or a country (see Figure 3);
- the global network of human settlements (see Figure 4).

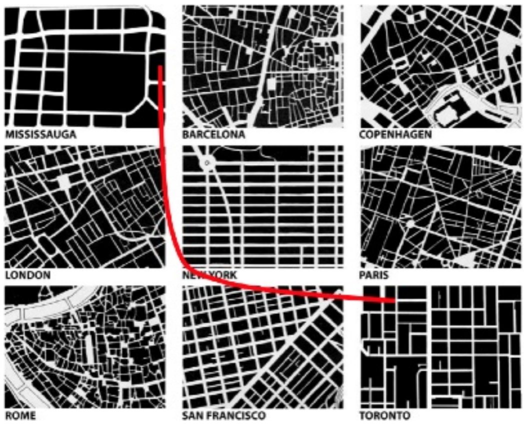


Figure 2. Street length patterns
Source: http://www.bricoleurbanism.org/wp-content/uploads/2008/01/urban-form_layout2.jpg

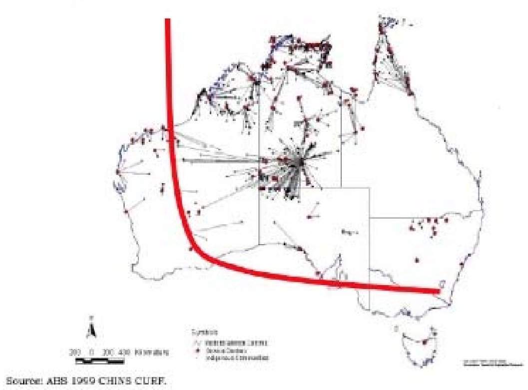


Figure 3. Provision of services in desert Australia

Figure 4. Electricity in human settlements around the globe
Source: http://media.rd.com/rd/images/rdc/mag0810/4-ways-to-look-at-a-map-05-ss.jpg

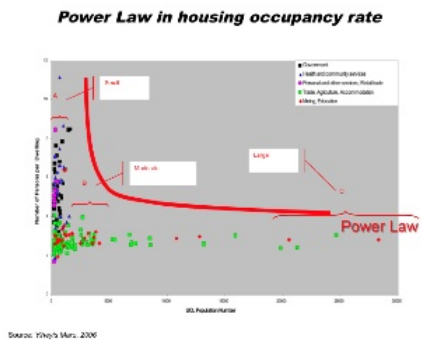


Figure 5. Housing occupancy rate
Source: Maru et al., 2006

Figure 6. Budapest public transport
Source: mappery.com/maps/Budapest-Public-Transportation-Map.thumb.jpg

What this paper argues is that the robustness of the connectedness provided by the scale-free networks is the key to the social and economic aspects of the sustainability of human settlements. The underlying power law lends weight to the view that the linked up system being observed emulates scale-free preferential networks with hierarchical tendencies and this pattern suggests inherent topology of human settlements with many predictive features, including robustness.

A scale-free pattern of connectivity between the nodes of a network has a very different nature to a normal distribution of links (see Figure 7). It essentially makes certain nodes highly more "favoured" than others as they have a much larger number of connections. If for some reason such a node is taken out, the network will fall apart and will become isolated non-connected islands. On the other hand, if the major hubs are functional, the robustness of the network will be maintained through the links from the remaining nodes.

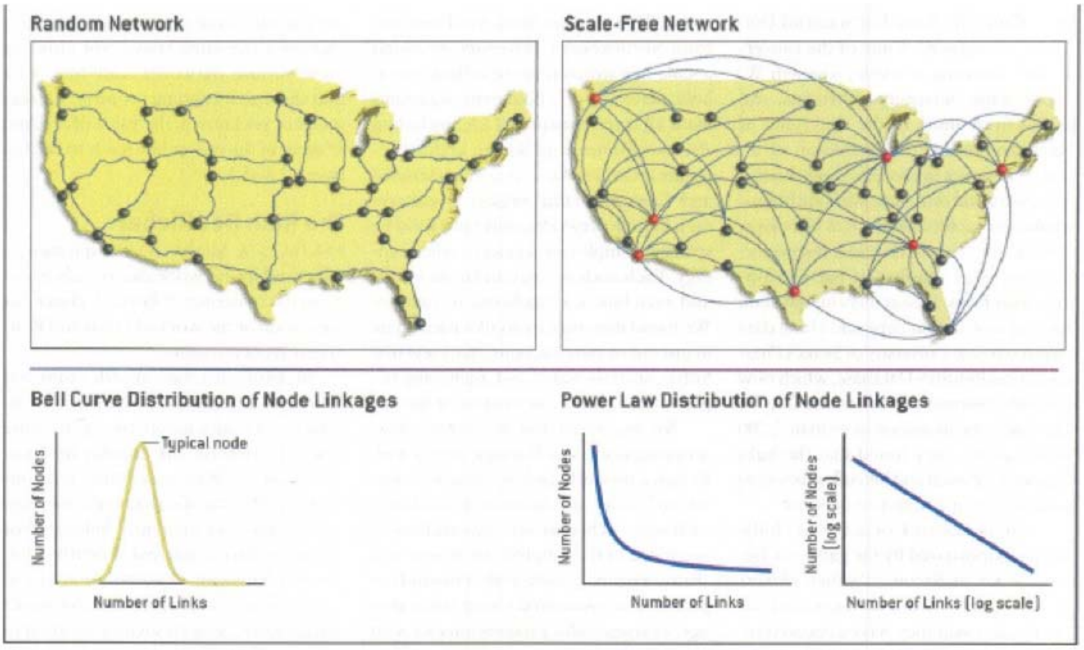


Figure 7. Random and scale-free networks
Source: Barabási and Bonabeau, 2003

Another feature of scale-free networks is that they be constructed "by progressively adding nodes to an existing network and introducing links to existing nodes with preferential attachment so that the probability of linking to a given node is proportional to the number of existing links that node has, i.e.

$$P\ (\text{linking to node } i) \sim \frac{k_i}{\sum_j k_j}\ ."$$

(Barabási and Alber, 1999: 509). Potential examples of this are Facebook connections, road networks or the electricity grid.

3. BIG WORLD, SMALL WORLD

One of the most interesting properties of the scale-free networks is the connectedness described as "small-world", i.e. that in some networks nodes may include shortcut links directly to major other hubs via a few degrees of separation. In a scale-free network of people, the small-world phenomenon describes how strangers can be linked by a mutual acquaintance. For example, the protest movement against globalisation and the World Trade Organisation builds its practical actions based on this concept (Watts, 1999).

Applied to the level of settlements, the small-world phenomenon alludes to the fact that even the smallest town is easily connected to the big towns or cities. What is important from a sustainability point of view is the nature of these connections. In the majority of the cases they are two-way connections, namely:

- through such connectedness the small town relies on this extended network of people who do not live there but are loyal to it and constantly connect it to the big world. In other words, the small town is bigger than it looks because of the myriad links it has with other settlements. This translates in information flows, financial remittances, visits by relatives and to familiar places (Guerin and Guerin 2008).

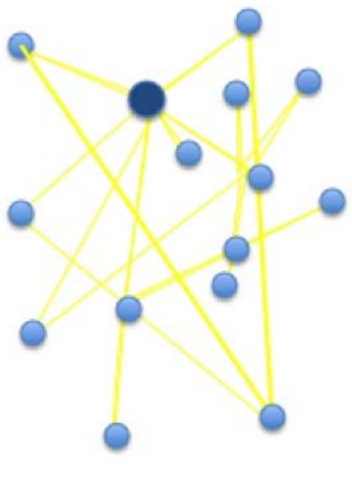
• the big settlements need the small-world connections for their existence as they justify its big-world importance as a node of multiple links. They provide economic and social services to the small settlements and their resilience is based on the capacity to do so.

In other words irrespective of their size, settlements need each other for their long-term sustainability. That exchange of services, information, people and finances can only happen if the channels of communication (that is, the connections between nodes) remain open, i.e. if the scale-free network is robust.

Another example of the importance of the small-world concept is the connectedness of migrants to their countries of origin. The large migrant labour force from China which is spread all around the world allows for shortcuts and flows of finances, capital and information to their native villages, towns and cities. This has supported their relatives in economic and political hardship and also allowed for a range of new opportunities when the communication channels are open. In addition, the network provides opportunities for other Chinese to become migrants by offering alternative links to the home environment. The small-world concept represents much more accurately the processes of globalisation and interconnectedness than attempts to study migrant networks as existent only in the foreign environment (see, for example, Hu and Salazar, 2005 for the role of Chinese business networks), as a conduit for investment opportunities (Leblang, 2008 and Javorcik et al., 2006) or as a boost to entrepreneurship (Light et al., 1990). It helps emphasise "that migration is embedded in a series of political, ethnic, familial and communal relationships and environments" and that migrating populations remain connected (Gold, 2005: 260). These networks cross national borders and link people at the level of human settlements. They explain the numerous findings by migration research (e.g. Crisp, 1999) that migrants find various ways to remain connected to their places of origin, co-nationals, people from the same ethnic origin across nation-state borders and indeed across the entire world. It helps understand "how migrants could, indeed, live both here and there" (McKeown, 2001: 1).

Similarly, the Eastern European migrants are providing their native settlements and countries the connectedness to the developed world. This is manifested particularly strongly in education, employment opportunities and investment. Within the European Union, the small-world model sheds light to what is a relatively recent and intense phenomenon of temporary, circular and return immigration, as distinct to permanent migration which was the case during the "iron curtain" times (Jiménez, 2009).

The small-world phenomenon defines the nature of social networks of the settlements in desert Australia. These arid zone settlements exist within the context of Australia's settlement system and share many of the broad trends and drivers that affect this country, e.g. increasing population flows toward capital cities, growth and volatility of the resources sector, challenging environmental conditions (Newman et al, 2008). However, arid zone settlements also exhibit markedly different features that are unique for outback Australia, such as low population density, high Indigenous population, remoteness from markets and high environmental variability. The typology of these remote settlements is rich and well represented by the power curve. Hence, even in dense big cities, small remote towns may have 1-3 degrees of shortcut access to key people in them (see Figure 8).



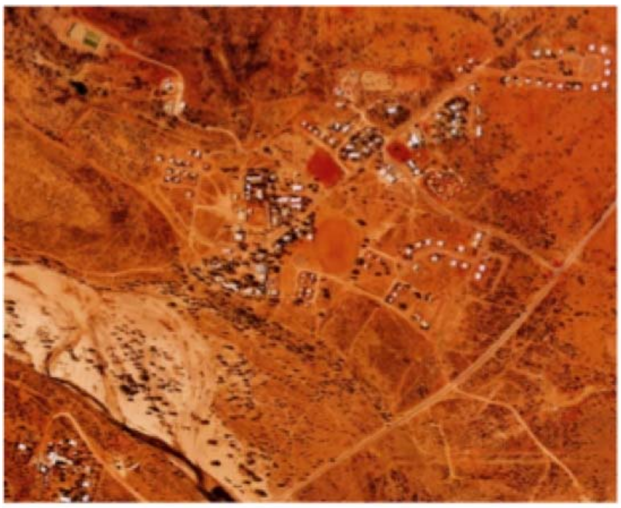


Figure 8. Small-world connectedness

4. CONCLUSION AND POLICY IMPLICATIONS

While most research so far has taken the traditional route and focuses on one or few key settlement measures (such as demography, economy, infrastructure provision, ecological footprint, health or education), such an approach may become fashionably dated as methods for settlement research matures. Systems methods which examine human settlements as complex adaptive systems have generated new concepts and entered a new era, that of understanding complexity and connectedness. What is expected to come next are predictive methods and evaluative/diagnostic approaches based on scale-free hierarchical networks with preferential tendencies. This is a new growth area for settlements research and design worth wider inclusion and examination

The insights that this research so far has generated in relation to informing policy can be summarised in the following few points:

• The robustness of scale-free networks is built on their connectivity and the ability to provide alternative links. If this is compromised, the networks will become dysfunctional and transform into isolated sections with little ability to provide a sound operational environment;

• The big world, small world phenomenon alludes to the importance of the variety of settlement sizes as they mutually reinforce each other. Any decision-making should be informed by the properties of the power law as the normal distribution concepts are difficult to apply to human settlements;

• Maintaining diversity and connectivity is a step towards predicting, evaluating and diagnosing the social, cultural and economic sustainability of settlements;

• In a globalised economy, the social and economic movement of people across borders can be understood in a network of connections between human settlements. This provides a much richer environment for explaining decision-making at the level of individuals, investment decisions, education and job employment opportunities, entrepreneurship and social aspirations.

ACKNOWLEDGMENT

The authors wish to acknowledge the financial support of the Australian Cooperative Research Centre (CRC) Desert Knowledge for supporting the conceptualisation of this research. The views expressed here however do not necessarily represent those of CRC Desert Knowledge or its participants.

They are also grateful for the rich feedback and encouragement received from the seminar participants at the Curtin University Sustainability Policy (CUSP) Institute where some of the original ideas were presented in April 2009.

REFERENCES

Barabási, A.-L. (2002), Linked: The New Science of Networks, Perseus, Cambridge, Mass.

Barabási, A-L., and Albert, R. (1999), Emergence of scaling in random networks, *Science*, 286, 509-512.

Barabási, A.-L., and Bonabeau, E. (2003), Scale free networks, *Scientific American* (May 2003), 50–59.

Caldarelli, G. (2007), Scale-Free Networks: Complex Webs in Nature and Technology, Oxford University Press, Oxford.

Clauset, A., Shalizi, C.R., and Newman, M.E.J. (2009), Power-law distributions in empirical data, forthcoming in *SIAM Review*, http://arxiv.org/pdf/0706.1062v2 (accessed 29.04.2009).

Crisp, J. (1999), Policy challenges of the new diasporas: Migrant networks and their impact on asylum flows and regimes, Working Paper No. 7, UNHCR, Geneva, http://www.transcomm.ox.ac.uk/working%20papers/riia3.pdf (accessed 30.04.2009).

Guerin, B., and Guerin, P. (2008), Relationships in remote communities: Implications for living in remote Australia, *The Australian Community Psychologist*, 20(2), 74–86.

Gold, S.J. (2005), Migrant networks: A summary and critique of relational approaches to international migration, in Romero, M., and Margolis, E. (eds), The Blackwell Companion to Social Inequalities, 257–285, Blackwell, Malden MA.

Hu, X, and Salazar, M.A. (2005), Dynamic Change of Migrant Networks: How migrant networks change under changing environment?, http://www.cri.uci.edu/pdf/Hu.pdf (accessed 30.04.2009).

Ijiri, Y., and Simon, H.A. (1977), Skew Distributions and the Sizes of Business Firms, North-Holland, Amsterdam.

Javorcik, B.S., Ozden, C., Spatareanu, M., and Neagu, C. (2006), Migrant networks and foreign direct investment, Policy Research Working Paper No. 4046, The World Bank, http://ideas.repec.org/p/wbk/wbrwps/4046.html (accessed 30.04.2009).

Jiménez, J.P. (ed.) (2009), Migrations and transnational networks: Immigrant communities from Central and Eastern Europe in Spain, CIDOB Journal of International Affairs, No. 84.

Leblang, D. (2008), Familiarity breeds investment: Migrant networks and cross-border capital, Paper presented at the annual meeting of the MPSA Annual National Conference, Chicago, IL, http://www.allacademic.com/meta/p267009_index.html (accessed 30.04.2009).

Light, I., Bhachu, P., and Karageorgis, S. (1990), Migration networks and immigrant entrepreneurship, Institute for Social Science Research, Volume V, http://repositories.cdlib.org/issr/volume5/1 (accessed 30.04.2009).

Maru, Y., Chewings, V., Jones, M., and Breen, J. (2006), Mapping Socio-regions in Outback Australia, CSIRO and Desert Knowledge Cooperative Research Centre, Alice Springs, Australia.

McKeown, A. (2001), Chinese Migrant Networks and Cultural Change: Peru, Chicago, and Hawaii 1900-1936, University of Chicago Press, Chicago.

Mitzenmacher, M. (2006), The future of power law research, *Internet Mathematics*, 2(4), 525–534.

Newman, M.E.J. (2005), Power laws, Pareto distributions and Zipf's law, *Contemporary Physics*, 46, 323–351.

Newman, P., Marinova, D., Armstrong, R., Marley, J., McGrath, N., Raven, M., et al. (2008), Desert Settlement Typology: Preliminary Literature, Report No. 9, Desert Knowledge Cooperative Research Centre, Alice Springs, Australia.

Singh, S., Samal, A., Giri, V., Krishna, S., Raghuram, N., and Jain, S. (2007), A universal power law and proportionate change process characterise the evolution of metabolic networks, *The European Physical Journal B*, 57(1), 75–80.

Watts, D. J. (1999), Small Worlds: The Dynamics of Networks Between Order and Randomness, Princeton University Press, Princeton.