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Editorial

B Urban Analytics and City Science

Unpredictability

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If I look back over 40 years of these editorials, what is striking is how new ideas about cities and their planning have emerged without premonition, ideas that at the time they were articulated had not even appeared on the horizon. When the journal was founded in 1974, the editor Lionel March and his colleagues which included myself, believed in the inherent predictability of the science that we were forging. We felt that the models and methods we were developing would enable us to make predictions about complex systems with some degree of certainty, so that we could use these forecasts to figure out how we might produce plans for 'better cities'. We were not particularly naïve in these sentiments because design was central to the role of models in planning and as many of us were trained as architects, we were conscious of our role in 'inventing the future' rather than just predicting it (Batty, 2018). Predictions and predictability were thus constructs that helped us to invent a better future, by at least steering the future away from what we might foresee as undesirable. Good predictions were judged to be essential.

Yet this certainty about the role of predictions and the need for them to be accurate has largely disappeared over the last 75 years. From the Enlightenment on, science was increasingly based on devising strong and robust theories that were improved inductively and validated deductively. Cracks do continually appear in the scientific edifice but it is these that motivate better science as theories are made ever more general and powerful. At least this is the goal. But throughout the 20th century, there has been a retreat from positivism. In 1935, Karl Popper (1959) argued in *The Logic of Scientific Discovery* that the system of scientific interest had to be entirely closed for science to be able to make accurate, hence immediately useful predictions. Popper's favourite example is the solar system whose form can be almost perfectly predicted by Newton's Laws, a closed system that to all intents and purposes could be treated as separate from the larger scale composed of other solar systems. I say 'almost perfectly' for there is always a chink in the armour of perfect certainty, in determinism, and even Popper's own theory of science is based on the notion that all we can do is falsify a scientific theory. The future is an unknown book, and this suggests that there is no such thing as an accurate prediction, anywhere, at any time. Perfect predictability is thus a norm to be aspired to but one which also enables us to determine a range of possible futures. Looking back over the last 75 years, our science has moved from a stance where we believed in 'good' prediction to a state of affairs where prediction is now 'difficult'. The recent Coronavirus crisis, almost entirely unpredictable if not in the emergence of a new virus then in its global economic and social impact of historic proportions, has turned our view about prediction into the 'impossible'. It is no longer merely 'difficult' to predict. We might assume that we can still hedge our bets a little, but our idea that small events in the shorter term might be easier to predict than larger events in the longer term, is no longer tenable.

Many people from many walks of life have come to the conclusion that prediction is impossible. In fact, we are strongly conditioned to believe that science has certainty. Our early formal experiences of it are cast in highly artificial contexts, in the laboratory where one can experience theory which is highly controlled, or as thought experiments that rely on the certainty of mathematical analysis. Our early years tend to be dominated by this kind of certainty. Even the most clear thinking scientists recognise a paradox in that our theories must be tested through their predictions but we know they will never withstand all possible tests. It is hard to break from this view. Those who still believe in the magic of science, only do so because they have not been at the forefront of reflecting on their own predictions. An increasingly number echo the author Margaret Attwood (2020) when she says: 'We live in such unpredictable times that you'd have to be an idiot to try to predict definitively the outcomes of some of the chaos and strangeness that we see developing around us.' To an extent as social change speeds up and as information technologies are continually reinvented, there is a certain logic to what she says but in retrospect, this has probably been true for all time.

Increasingly science is used to inform policy through models and this is as clear as it can be in the reaction to the Coronavirus crisis. Modelling epidemics is not generally regarded as problematic and it is one of the few areas where the determinants of how an infectious disease spreads are quite well-defined, at least in the hindsight of our knowing how an epidemic proceeds. If there is a disease where there are no deaths but one where people become infected (I), then the disease will spread through a population according to the numbers of persons who are infected by an already infected person. This contact is called the Reproduction number. If, for example, this number is *2*, meaning that each infected person passes it on to *2* of those who are still susceptible (S), hence not immune, the numbers infected will progress from the first so-called person-zero to *2, 4, 8, 16* and so on. This is a progression measured by 2^t, where t is the time at which the next group of susceptibles is infected by the disease. If we have a population of, say, 66 million, which is the current UK population, and if the infection is passed on in the next time period – the next day, say, the total of 66 million population will be entirely infected over the next 26 days. This is a very rapid spread but as soon as somebody is infected, they will spend some time with the disease, possibly initially infecting others, and then eventually become immune. At this point, they will recover (R) and no longer be part of the infected population. Thus, as the infection increases exponentially first affecting those who are exposed (E), at some point as the first to be infected recover, this will slow the progression. Eventually after the number infected peaks, this number will decline to the point where all are recovered and the virus disappears from the population. The curve of exponential growth and then decline mirrors what would happen if there were no attempts to reduce those exposed by using social distancing or self-isolation. In short, this is a pure epidemic model where the disease disappears as the population heads towards what is called 'herd immunity'. Of course in this example, there are no deaths and thus no policies which try and mitigate these by keeping deaths as low as possible.

Many features however complicate this model. First the time spent by the person with the infection being infectious as well as the subsequent time to recover, hence acquire immunity, can change the parameters of this model dramatically. The death rate is also important and thus the severity of the disease is measured by the proportions of people who recover or not, by the speed of the recovery, and by the number of susceptibles at which an infected person passes the virus on to those who they contact, in this case the Reproduction number. All of these parameters can change as the infection progresses but in the last analysis, the model is fairly tractable and if the parameters from a past epidemic can be derived from data, it can

mirror exactly the behaviour that we observe. This of course is largely because we have no obvious way of avoiding an infection other than by changing our behaviour. There may, of course, be demographic issues which divide the population into different groups of susceptibles, mortalities, and infectives. As we begin to explore such epidemics in greater detail and in different environmental and social contexts, then the pure epidemic model becomes less and less tractable and subject to increasing error.

This then is the nature of using any model to make predictions about the future which have critical policy implications. No model can be tuned to replicate an epidemic before it has run its course. There are simply too many elements of the population that need to be taken account of and as in all social systems, much of the data may never be observable, even after the event. In the case of the current Coronavirus epidemic, it is clear that the virulence of the disease was much underestimated, at first in the West where there is much less experience and social control of such diseases. In the UK, there appeared to be some sort of acceptance that this epidemic would be more like an influenza outbreak with similar rates of recovery and death. But using parameters from various cases in China relating to the Reproduction number and the length of time when infected persons were asymptomatic, it appeared that any policy of unregulated diffusion of the disease would lead ultimately to herd immunity but with massive numbers of deaths. The model was then rerun with social distancing and self-isolation built in. This was shown to reduce the number of deaths very dramatically to the point where it might be possible to squeeze the virus out of the system, and to protect the health services until the point where some sort of vaccine could be invented and manufactured (Ferguson et al., 2020).

The problem however is that such models show such dramatic differences in terms of predicting numbers of deaths that we find it hard to weigh up the evidence. In some respects, this is true of all models in any context but in this situation, we might expect our confidence in the model results to be better than economic forecasting, traffic modelling and suchlike. However, when we stand back and reflect on what we know about science and modelling, we need to grapple with an essential dilemma. George Box, the eminent British statistician, said many times that: '. . . all models are wrong, but some are useful . . .' (Box and Draper, 1986). So if we know that our models will be wrong, then what do we do about them. In short, if our science does not lead to robust predictions, how do we continue to deal with such widespread unpredictability?

The answer to this dilemma must relate to what models we use, how we use their predictions, and indeed how robust they are to a manipulation of their parameters. In essence, as all models are wrong but some are useful, we need to employ several models, not simply one. In the UK example of dealing with the virus, it is not at all clear whether more than one model was used or whether or not this was subsumed under the umbrella of using the same model under different assumptions and different parameter regimes. It is not at all clear as to how sensitive is the predicted number of deaths under different scenarios. What we have to go on are predictions made with this particular model in different situations in the past and the results are not good. For example, notwithstanding the fact that the model has been developed over a 20 year period, it has been applied to several previous epidemics where very precise predictions of the consequent deaths have been made. Ferguson's team have explored many different epidemics using their SEIR model from Foot and Mouth disease in 2001 to Mad Cow disease in 2002, Bird Flu in 2005 to Swine Flu in 2009, and then to Ebola, MERS and Zika. The predicted numbers of deaths amongst human population for these epidemics were in the tens and hundreds of thousands but when the actual numbers who die were counted, these were a very tiny fraction of the individuals involved, in fact, in the tens and hundreds. Ferguson and his

team recognise this variability and comment 'We're building simplified representations of reality. Models are not crystal balls,' (Adam, 2020). But this implies that we need many models, not one. This follows directly from the fact that our science is not necessarily robust but the way we use it should be. In some domains, such as economic modelling, weather forecasting, and climate change, such alternative modelling strategies have been recognised and developed for a number of years. In fact, counter-modelling and multi-modelling were suggested for evaluating public policies many years ago by Greenberger et al. (1976). Modelling infectious diseases clearly needs to be underpinned by similar approaches.

Many approaches to grappling with unpredictability in science do not have the resources to develop several different approaches to the same problem but in the case of disease transmission, and the policies that have been tested using the model, there has been another difficulty – the separation of 'the science' from 'the policy'. What has emerged is a strange dependence of the policy-makers on the scientists with the scientists articulating the fact that their advice is 'neutral' when it comes to policy. Much of policy seems to depend on the science but there is no recognition that this science might be flawed, is inevitably flawed, of course, if the arguments in this editorial are taken to heart. Because the policy of locking down a whole society to squeeze out the infection is so controversial, then the idea of throwing everything on the 'science' appears somewhat perverse. This whole approach is not scientific in the context of the physical and natural sciences for it rests on much more controversial perspectives related to behaviour. In fact, although this epidemic is intrinsically physical at the level of how the virus attacks the body, everything else around its transmission is manifestly environmental, social and economic and the notion of how self-isolation and social distancing affect transmission is very largely a behavioural issue. Epidemic models do not have appropriate and well-tested mechanisms to deal with such non-pharmaceutical interventions.

In these editorials, I have introduced these broader questions of prediction and predictability several times as our interest and knowledge about them have changed. We now accept that cities are inherently unpredictable in that we are unable to predict how individuals with high degrees of freedom will behave under very different conditions. We may be able to discern aggregate patterns that are generalisable and offer some possibilities for good prediction but for the most part, this is difficult and controversial. The problem with cities is that we continually invent and reinvent them thereby changing the conditions in which they operate. In terms of epidemic modelling, then the nature of how an epidemic evolves with respect to the basic epidemiology is a good deal more stable than systems that are formed by interacting ill-defined economic and social activities and individuals. Once this is put in the context of everything else that is happening in the city or society, then our understanding of an epidemic is equally confounding. As I argued in a previous editorial (Batty, 2020), the rapid emergence of an epidemic which was largely unanticipated is an example of something that we will never be able to predict, notwithstanding that we might prepare for it (Batty, 2010). It is not quite a 'Black Swan' in that we have seen them before (Taleb, 2007) but they are inherently unpredictable in any temporal context. They are predictable in the small in terms of virus transmission but hugely unpredictable in the large in the way we respond to them. As in the case of many systems, when we narrow or broaden the system and its environment, its degree of unpredictability changes.

The dynamics of change in cities exists on all scales and it has long been assumed – almost as a rite of passage – that the short term is easier to predict than the long term, largely because the short term is nearer in time to what we know in the past and the present whereas the long term is in a distant future. We know that there is likely to be more substantial change in the long term future but as we learn more about how cities change, the short term

future appears as equally volatile and difficult to predict as the long term. In this sense, there is little difference in the impact of change other than in the kind of change that occurs over different time periods. The degree of change is not a function of the time over which such change takes place. In the last half century, our focus on change has moved from the idea that systems such as cities appear to embrace it slowly and smoothly to one which is quite the opposite: that change is always volatile, never smooth and that we have to tear back the illusion that change is absorbed easily with little disruption in cities. This is rarely the case for change is masked by the inertia of the social and physical structures that we build and evolve that give the appearance of longevity. In fact these are under continual scrutiny as we attempt to adapt what we have built in the past to the demands of the contemporary present and of course to the norms and aspirations that we have for both the near and far future.

Layered on top of all of this is the notion that we have raised often in these editorials, that cities are becoming more complex as they evolve and as human populations acquire ever more technologies that continually provide them with new sets of opportunities. In this sense, nothing is predictable. The recent pandemic is likely to force us into new ways of dealing with the physical space of cities in terms of the way we connect with one another – social distancing and self-isolation may well turn into principles of spatial distancing that change the way we think of moving and locating in cities, to cities with lower densities where the local and the global mesh in ways that we have yet to invent. We may well ask the question as to why such changes have not been incorporated into cities already for plagues and pandemics are not new. But the fact they have not is simply a recognition that the world has changed, has become more complex, that our values have changed and will continue to do so. Unpredictability is now the norm. Many have said this before but we need to embrace it in ways that makes us deal with the future rather differently from the way we have dealt with it in the past. It was Arthur C Clarke (1982) who in his novel *2010: Odyssey Two* said all human plans are '... subject to ruthless revision by Nature, or Fate, or whatever one preferred to call the powers behind the Universe ...', a mantra for our time.

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