

Taking a city's pulse with movable sensors

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Credit: Ad Meskens via Wikipedia

Suppose you have 10 taxis in Manhattan. What portion of the borough's streets do they cover in a typical day?

Before we answer that, let's examine why it would be useful to know this fact. Cities have a lot of things that need measuring: air pollution, weather, traffic patterns, road quality, and more. Some of these can be measured by instruments attached to buildings. But researchers can also affix inexpensive sensors to taxis and capture measurements across a larger portion of a city.

So, how many taxis would it take to cover a certain amount of ground?

To find out, an MIT-based team of researchers analyzed traffic data from nine [major cities](#) on three continents, and emerged with several new findings. A few taxis can cover a surprisingly large amount of ground, but it takes many more taxis to cover a city more comprehensively than that. Intriguingly, this pattern seems to replicate itself in metro areas around the world.

More specifically: Just 10 taxis typically cover one-third of Manhattan's streets in a day. It also takes about 30 taxis to cover half of Manhattan in a day. But because taxis tend to have convergent routes, over 1,000 taxis are required in order to cover 85 percent of Manhattan in a day.

"The sensing power of taxis is unexpectedly large," says Kevin O'Keefe, a postdoc at the MIT Senseable City Lab and co-author of a newly published paper detailing the study's results.

However, O'Keefe observes, "There is a law of diminishing returns" at play as well. "You get the first one-third of streets almost free, with 10 random taxis. But ... then it gets progressively harder."

A similar numerical relationship occurs in Chicago, San Francisco, Vienna, Beijing, Shanghai, Singapore, and some other major global cities.

"Our results were showing that the sensing power of taxis in each city was very similar," O'Keeffe observes. "We repeated the analysis, and lo, and behold, all the curves [plotting taxi coverage] were the same shape."

The paper, "Quantifying the sensing power of vehicle fleets," is appearing this week in *Proceedings of the National Academy of Sciences*. In addition to O'Keeffe, who is the corresponding author, the co-authors are Amin Anjomshoaa, a researcher at the Senseable City Lab; Steven Strogatz, a professor of mathematics at Cornell University; Paolo Santi, a research scientist at the Senseable City Lab and the Institute of Informatics and Telematics of CNR in Pisa, Italy; and Carlo Ratti, director of the Senseable City Lab and professor of the practice in MIT's Department of Urban Studies and Planning (DUSP).

Members of the Senseable City Lab have long been studying cities based on data from sensors. In doing so, they have observed that some traditional deployments of sensors come with trade-offs. Sensors on buildings, for example, can provide consistent daily data, but their reach is very limited.

"They're good in time, but not space," says O'Keeffe of fixed-location sensors. "Airborne sensors have inverse properties. They're good in space but not time. A satellite can take a photo of an entire city—but only when it is passing over the city, which is a relatively short time interval. We asked the question, 'Is there something that combines the strengths of the two approaches, that explores this city well in both space and time?'"

Putting sensors on vehicles is one solution. But which vehicles? Buses, which have fixed routes, cover limited ground. Members of the Senseable City Lab have fixed sensors to garbage trucks in Cambridge, Massachusetts, among other things, but even so, they did not collect as much data as taxis might.

That research helped lead to the current study, which uses data from a variety of municipalities and private-sector research efforts to better understand [taxi](#)-coverage patterns. The first place the researchers studied was Manhattan, which they divided into about 8,000 street segments, and obtained their initial results.

Still, Manhattan has some distinct features—an usually regular street grid, for example—and there was no guarantee the metrics it produced would be similar in other places. But in city after city, the same phenomenon emerged: A small number of taxis can circulate over a one-third of a city in a day, and a slightly larger number can reach half the city, but after that, a much bigger fleet is needed.

"It's a very strong result and I'm surprised to see it, both from a practical point of view and a theoretical point of view," O'Keefe says.

The practical side of the study is that city planners and policymakers, among others, now potentially have a more concrete idea about the investment needed for certain levels of mobile sensing, as well as the extent of the results they would likely obtain. An air pollution study, for instance, could be drawn up with this kind of data in mind.

"Urban environmental sensing is crucial for human health," says Ratti. "Until today, sensing has been performed primarily with a small number of fixed and expensive monitoring stations. ... However, a comprehensive framework to understand the power of mobile sensing is still missing and is the motivation for our research. Results have been incredibly surprising, in terms of how well we can cover a large [city](#) with just a few moving probes."

As O'Keefe readily acknowledges, one practical way to construct a mobile-sensing project might be to place sensors on taxis, then deploy a relatively small fleet of vehicles (as Google does for mapping projects)

to reach streets where taxis virtually never venture.

"You bias, almost by definition, popular areas," O'Keefe says. "And you're potentially underserving deprived areas. The way to get around that is with a hybrid approach. [If] you put sensors on taxis, then you augment it with a few dedicated vehicles."

For his part, O'Keefe, a physicist by training, thinks the result bodes well for the continued use of mobile [sensors](#) in urban studies, across the globe.

"There is a science to how cities work, and we can use it to make things better," says O'Keefe.

More information: Kevin P. O'Keefe et al. Quantifying the sensing power of vehicle fleets, *Proceedings of the National Academy of Sciences* (2019). [DOI: 10.1073/pnas.1821667116](https://doi.org/10.1073/pnas.1821667116)

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