Researchers create first large-scale model of human mobility that incorporates human nature

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For more than half a century, many social scientists and urban geographers interested in modeling the movement of people and goods between cities, states or countries have relied on a statistical formula called the gravity law, which measures the "attraction" between two places. Introduced in its contemporary form by linguist George Zipf in 1946, the law is based on the assumption that the number of trips between two cities is dependent on population size and the distance between the cities. (The name comes from an analogy with Newton's Law of Gravity, which describes the attraction of two objects based on mass and distance.)

Though widely used in empirical studies, the gravity model isn't very accurate in making predictions. Researchers must retrofit data to the model by including variables specific to each study in order to force the results to match reality. And with much more data now being generated by new technologies such as cellphones and the Internet, researchers in many fields are eyeing the study of human mobility with a desire to increase its scientific rigor.

To this end, researchers from MIT, Northeastern University and Italy's University of Padua have identified an underlying flaw in the gravity model: The distance between two cities is far less important than the population size in the area surrounding them. The team has now created a model that takes human motives into account rather than simply assuming that a larger city attracts commuters. They then tested their "radiation model" on five types of mobility studies and compared the results to existing data. In each case, the radiation model's predictions were far more accurate than the gravity model's, which are sometimes off by an order of magnitude.

"Using a multidisciplinary approach, we came up with a simple formula that works better in all situations and shows that population distribution is the key factor in determining mobility fluxes, not distance," says Marta González, the Gilbert Winslow Career Development Assistant Professor in MIT's Department of Civil and Environmental Engineering and Engineering Systems Division, and co-author of a paper published Feb. 26 in the online edition of *Nature*. "I wanted to see if we could find a way to make the gravity model work more accurately without having to change it to fit each situation."

Physics professor Albert-László Barabási of Northeastern is lead author and principal investigator on the project. Filippo Simini of Northeastern and Amos Maritan of the University of Padua are co-authors.

"I think this paper is a major advance in our understanding of human behavior," says Dirk Brockmann, an associate professor of engineering sciences and applied mathematics at Northwestern University who was not involved in the research project. "The key value of the work is that they propose a real theory of mobility making a few basic assumptions, and this model is surprisingly consistent with empirical data."

The gravity law states that the number of people in a city who will commute to a larger city is based on the population of the larger city. (The larger the population of the big city, the more trips the model predicts.) The number of trips will decrease as the distance between cities grows. One obvious problem with this model is that it will predict trips to a large city without taking into account that the population size of the smaller city places a finite limit on how many people can possibly travel.

The radiation model accounts for this and other limitations of the gravity model by focusing on the population of the surrounding area, which is defined by the circle whose center is the point of origin and whose radius is the distance to the point of attraction, usually a job. It assumes that job availability is proportional to the population size of the entire area and rates a potential job's attractiveness based on population density and travel distance. (People are willing to accept longer commutes in sparsely populated areas that have fewer job opportunities.)

To demonstrate the radiation model's accuracy in predicting the number of commuters, the researchers selected two pairs of counties in Utah and Alabama — each with a set of cities with comparable population sizes and distances between them. In this instance, the gravity model predicts that one person will commute between each set of cities. But according to census data, 44 people commuted in Utah and six in the sparsely populated area of Alabama. The radiation model predicts 66 commuters in Utah and two in Alabama, a result well within the acceptable limit of statistical error, González says.

The co-authors also tested the model on other indices of connectedness, including hourly trips measured by phone data, commuting between U.S. counties, migration between U.S. cities, intercity telephone calls made by 10 million anonymous users in a European country, and the shipment of goods by any mode of transportation among U.S. states and major metropolitan areas. In all cases, the model's results matched existing data.

"What differentiates the radiation model from other phenomenological models is that Simini et al. assume that an individual's migration or move to a new location is determined by what 'is offered' at the location — e.g., job opportunities — and that this employment potential is a function of the size of a location," Brockmann says. "Unlike the gravity model and other models of the same nature, the radiation model is thus based on a plausible human motive. Gravity models just assume that people move to large cities with high probability and that also this movement probability decreases with distance; they are not based on an underlying first principle."

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