Networks of urban vulnerability

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City is a complex system, composed of a multitude of interacting actors of different types. And while complexity is one of the main reasons for city's efficiency, it is also one of its major vulnerabilities. Urban systems are largely dependent on the functionality of their key components and one or several local failures can often cause substantial disruption to the entire system. In that relation understanding vulnerabilities of urban systems is critical for urban planning, transportation and public safety.

Vulnerability of the road networks for example is a well-studied area which saw a lot of advances including recent ones – in particular, approaches are developed to identify potential impact of disruptions happening to a certain node or link of the network [Ukkusuri, S. V., & Holguín-Veras, J. (2007). In Network Science, Nonlinear Science and Infrastructure Systems, Li, J. and Ozbay, K. (2012). Journal of the Transportation Research Board(2284)].

Disruptions can happen for a variety of reasons including infrastructural failures, planned interventions, natural or technogenic disasters or even terrorist attacks. But in most cases they create negative impact on urban mobility resulting in delays for urban population to reach their locations of interest. Major disruptions can even cause people to cancel their plans and change their destinations, but those scenarios are beyond the scope of the present study for now.

However, under certain conditions it can happen that a simultaneous disruption of two or more locations across the city (causing transportation system failures) can have a cumulative impact (delay) on urban mobility larger than the sum of their individual impacts taken separately, creating an effect one can call a disruptive synergy. One can represent this effect by constructing a vulnerability network with nodes representing urban locations, while edges are weighted according to the surplus of the projected cumulative delay to the expected urban mobility caused by a simultaneous disruption of this pair of nodes over the sum of their separate impacts.

In the present work we construct and study the vulnerability networks for NYC and several other major US cities. For that purpose, we leverage the information on available urban multi-modal transportation options on one hand and the expected mobility estimates on the other, based on the Longitudinal Employer-Household Dynamics (LEHD) and geo-tagged Twitter data. The last, despite its limitations is seen as a proxy for human mobility [Hawelka, B., et al (2014). Cartography and GIS, 41(3), Kurkcu, et al, 95th TRB Annual Conference, #16-3901] supplementing static LEHD data with temporal variations of the transportation demand.

In this analysis we ask a question: to what extent urban vulnerability networks for different cities exhibit common statistical and physical patterns and to what extent are those patterns city-specific? We also apply the vulnerability networks to discovering the structure of the city from a vulnerability standpoint, defining communities of locations, representing particular potential threat if disrupted together and compare those communities to the known patterns in urban infrastructure identifying new insights for urban and public safety stakeholders.