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Transit Sea Level Rise resilience is a fuzzy concept.

When it comes to researching the relationship between climate change and transit systems, one term is decidedly fuzzy: resiliency. Like its close relative, sustainability, resiliency is a process noun with powerful implications but a loose definition in the context of climate change research. The Oxford English dictionary defines it as a "the capacity to recover quickly from difficulties", but in the field of transit, "difficulties", "capacity", and "recovery" can each indicate a number of different things in the context of climate change. For instance, is a transit system that is forced to reroute itself to avoid Sea Level Rise (SLR) flooding technically recovered? Does saltwater damage to roadways count as a transit difficulty or a problem outside of the transit system's domain? Is a bus system that manages to serve a high number of residents after a natural disaster but not those who need it most capable? If we were told our local bus route had been negatively impacted by any of these challenges, would we call our bus system resilient? Unfortunately, the U.S. Department of Transportation does not offer a much better definition, stating that resilience is "an ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions."[1] The problem with fuzzy concepts, according to Markusen (2003), is that they allow authors to "get by with characterizations in which agents disappear, causal connections need not be made and processes rather than deliberative human acts are responsible for the built environment and the distribution of economic activity across space." Considering that the human-built world is about to face its greatest challenge yet in the form of climate change, a human-built disaster, it is of utmost importance that we connect actions with actors. In this spirit, I am going to break down the three core elements that define public bus transit resiliency as it relates to Sea Level Rise brought on by climate change. But before I do that, it is important to establish the threat of Sea Level Rise to transit systems.

The U.S. National Oceanic and Atmospheric Administration (NOAA) states that, "Globally, average sea level has risen eight inches since 1900"[2] as a result of melting glaciers and ice sheets, and thermal expansion of ocean water. Regarding the scale of this problem, NOAA cites a paper by Bromirski et al (2012) that suggests that the global sea level will continue to rise between 8 inches and 6.6 feet by 2100. Since six out of the ten biggest cities in the United States are very near or on coastlines, even the minimum expected SLR over the next 80 years could have a profound negative impact on the nation's largest public transit systems, including New York City's Subway[3] and Washington DC's Metro, both of which are largely underground. As the U.S Department

[1] US DOT: https://www.transportation.gov/mission/sustainability/adapting-climate-change
[2] NOAA: https://toolkit.climate.gov/topics/coastal/sea-level-rise#footnote1_gesxy47
[3] NYC Sea Level Rise Task Force: https://www.dec.ny.gov/energy/45202.html

of Transportation (DOT) puts it: "In addition to flooding infrastructure due to sea level rise, coastal cities are vulnerable to damage from storm surge, wave action, and/or inundation of their transportation infrastructure such as roadways, ports, bridges, rail, tunnels, shipyards, and navigational aids." It is very unlikely that most public transit systems would be able to avoid the damage affecting "rail" and "roadways."

That being said, it is not always obvious where SLR will have the most disastrous effects, and NOAA notes that there is a difference between global, regional, and local SLR. Indeed, there are some places that may witness their seas receding from the coastline for a time due to the land rising faster than the sea, while other places are subsumed faster as the land itself is also sinking. The latter phenomenon can be found in places like The Bay Area[4], Miami Beach, and Washington DC[5]. Manmade structures can also unintentionally impact tides and floodwaters by reducing wetlands - to disastrous effect, as seen in Louisiana[6] - without the direct help of SLR. For these reasons, researchers and planners have created tools such as the Transit Inundation Modeling Method (TIMM), which is a five-step process developed "with the goal of assisting transit agencies to begin adapting (to SLR) by identifying at-risk links and nodes based on various sea level rise inundation levels" (Oswald et al, pp.65). Furthermore, the guidelines in tools such as the TIMM suggest that SLR should not be thought of as a steadily encroaching shoreline, but as the source of a wide array of new challenges for coastal cities and their transit systems. As such, any municipal efforts towards transit resiliency should consider local factors before proceeding, because some links may be simply too vulnerable to be worth spending time and money building substantial resiliency infrastructure.

The first and most basic question to ask when told that a bus system is SLR resilient is whether any part of its physical infrastructure, from the buses to bus stops to depots, is at risk of damage from SLR. In the United States, this infrastructure is massive in its size (the amount of resources dedicated to it) and in its scope (the geographical area it serves). The U.S. is home to 500 major urban transit operators and bus ridership accounted for nearly half of all transit trips taken in 2014 (47%), comfortably outmatching its top competitor, heavy rail (36%). In 2016, Americans took 10.4 billion trips on all forms of public transportation.[7] Most importantly for this paper's purposes, however**,** is the Federal Transit Administration's 2013 report that found that "more than 40% of buses" are in "marginal or poor condition", compared to 25% of rail transit.[8] (This might explain why "the potential impact of climate change on transport is an area

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[4] City Lab: https://www.citylab.com/environment/2018/03/rising-sea-levels-and-sinking-ground-pose-a-double-threat-to-the-bay-area/555425/

[5] Washington Post: https://www.washingtonpost.com/news/capital-weather-gang/wp/2015/07/29/why-sea-level-in-the-d-c-region-is-rising-faster-than-anywhere-else-on-the-east-coast/?utm_term=.27dcce18e3ce

[6] New York Times: https://www.nytimes.com/interactive/2018/02/24/us/jean-lafitte-floodwaters.html

[7] American Public Transportation Association: http://www.apta.com/Pages/default.aspx

[8] Federal Transit Administration: https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/National_SGR_Study_072010%282%29_0.pdf

of research very much in its infancy" (Jaroszweski, 2014), as many operators could be too preoccupied with keeping their systems up and running to prepare them for the future). But how can interested parties (operators, planners, politicians, researchers) be sure that a bus system is physically resilient to sea level rise? This is not an easy question to answer. To begin, we would need to determine whether the damage sustained by buses was caused by sea level rise. This can be attempted by scanning weather and flood data from the U.S. Geological Survey, the Office for Coastal Management, and FEMA's Flood Map Service Center. As noted above, SLR is not a uniform line that steadily swallows the U.S. coastline, so each case would need to be taken into account individually. However, the DOT website offers a list of potential impacts of SLR that would be useful to look out for when approaching an idividual bus system's resiliency, including shortened infrastructure life as a result of storm surges, "asphalt degradation and shorter replacement cycles", and "higher maintenance costs for roads and bridges, due to… exposure to storm surge." While this list is meant to apply to all road transportation, a sister list targeting bus transit could be drawn up along these lines. This list could include looking at whether there has been an increase in saltwater damage to buses, indicating that they are more required to plow through flooded streets more often than before, or whether the routes needed to be changed due to regular flooding.

The second way to measure the SLR resiliency of a bus system is to look at its safety record. In a document titled "Sea Level Rise: Vulnerability Assessment", the Capitol Corridor Joint Powers Authority writes that climate change-related flooding will "hinder agencies' ability to achieve goals such as attaining a state of good repair and providing reliability and *safety*"[9] (emphasis mine). Again, the DOT website offers a few helpful primers for what researchers and planners should look for when analyzing the resiliency of a bus system, including "decreased driver/operator performance and decision making skills, due to driver fatigue caused by adverse weather", and "increased risk of vehicle crashes in severe weather." In one of the more in-depth papers on this subject, Jaroszweski et al (2014) note that some researchers have suggested "climate change will also affect the behavior of drivers, by either increasing or reducing the frequency with which drivers are exposed to a given weather hazard, hence altering their abilities to cope in these conditions" (pp.453). (Jaroszweski et al feel that more investigation into this claim is necessary). Between 2005 and 2015, transit buses accounted for 33% on average of all fatal accidents involving buses. In 2015, 261 buses were involved in fatal accidents in the United States.[10] A paper by Blower et al (2010) claimed that on average between 1999 and 2005, about 63,000 buses were involved in an accident every year.[11] However this study involved buses of all kinds, including school, transit, and charter. While the more transit specific data is not a huge sample size considering the number of buses operating in the country, it would still be valuable for

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[9]Capitol Corridor Joint Powers Authority: http://www.adaptingtorisingtides.org/wp-content/uploads/2015/04/CCJPA-SLR-Vulnerability-Assessment_Final.pdf

[10] Federal Motor Carrier Safety Administration: https://www.fmcsa.dot.gov/safety/data-and-statistics/large-truck-and-bus-crash-facts-2015

[11]Blower et al (2010): https://www.researchgate.net/publication/241809228_Type_of_Motor_Carrier_and_Driver_History_in_Fatal_Bus_Crashes

researchers to keep track of the causes of the fatal accidents, as they might indicate some of the factors noted in the paragraph above. A truly SLR-resilient bus system should have an explicit list of ways to guarantee a strong safety record in the face of more frequent storm surge and regular flooding.

As I have noted in several of my journals and labs, when it comes to measuring how bus transit systems in the United States are being affected by SLR, it is crucial to understand the relationship between transit users and their buses. As noted by Jaroszweski et al (2014), there is a high "expectation (among) the public for efficient, safe, and effective transport every day of the year and under all but the most extreme meteorological conditions" (pp.449). A bus system must at least address this trend if its operators and political leaders are aiming to make their transit SLR resilient. The reason for this is that bus transit relies partly on ridership and political support to sustain itself, whereas private auto transit is largely seen as essential to maintain. If SLR has a measurable negative effect on public buses, then it can be assumed that bus systems will become less reliable if their operators do not spend the money to make them more resilient. If the increasing unreliability of buses is not checked, then operators will see their system lose riders and the political and financial support for their system will follow. Political support for public transit is already tenuous, as some believe that rideshare services and automated vehicles will soon outmode transit.[12] Rather than maintain a non-competitive, unpopular and undependable bus transit system, municipalities will most likely choose to shut the program down. This has troubling implications, as public bus transit is not only an important tool for lessening damage to the climate by reducing greenhouse gas emissions, but also as a vital emergency service tool during the natural disasters scientists are expecting to see more of in the gulf states.

There are more than a few major US cities that have set up climate resilience offices in their city halls, including New York,[13] New Orleans,[14] Miami,[15] and Boston.[16] This practice also appears to be growing, as Bassett et al notes in their case study that evaluated 20 completed climate action plans: "In none of the localities in our study did a traditional city planning commission appear to play a role in leading climate action planning." Interestingly, resilience plans and initiatives are often focused on more that the threats of climate change, but approach "comprehensive resilience priorities across environmental, social, economic, and infrastructural improvement goals" (New Orleans). Many of these same cities are also members of the 100 Resilient Cities Program,[17] which "supports the adoption and incorporation of a view of resilience that includes not just the shocks… but also the stresses that weaken the fabric of a city on a day to day or cyclical bases." – a more developed concept of "resilience" that can easily applied to bus transit.

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[12] Slate: http://www.slate.com/articles/business/metropolis/2016/12/cities_are_cutting_transportation_service_because_they_think_uber_will_fill.html

[13] City of New York: http://www1.nyc.gov/site/orr/index.page

[14] City of New Orleans: https://nola.gov/resilience/

[15] Miami-Dade.gov: http://www.miamidade.gov/planning/resilience.asp

[16] City of Boston: https://www.boston.gov/departments/environment/climate-ready-boston

[17] 100 Resilient Cities Program: http://www.100resilientcities.org/about-us/

In the current political climate, in which one of the two major parties in U.S. politics continues to be skeptical of the threats of climate change, it is significant that these offices and approaches can be found in cities of every political stripe and character. In Florida, where Governor Rick Scott created an unwritten policy in 2011 that asked Florida Department of Environmental Protection employees to refrain from using phrases such as "climate change" and "global warming", former Jacksonville Mayor Alvin Brown defended his resiliency plans, saying "At the end of the day, we want to make sure we're always prepared do deal with any situation that can impact the quality of life for a generation."[18] This attitude is vital not just for building a city that is more capable of surviving and thriving in the face of climate change, but also for encouraging researchers and planners to be more effective at shedding light on the field's fuzzy concepts for the public. While the concept of "resilience" has been a useful lightning rod for political leaders seeking to protect their cities from threats like sea level rise, ending the fuzziness of the term will help to ensure that their methods are held to a more rigorous standard.

[18] Inside Climate News: https://insideclimatenews.org/slideshow/11-us-cities-are-leading-climate-resiliency