

## ABSTRACT

Resilient infrastructure is imperative especially following natural or manmade disasters. The ability to move food, water, and relief supplies using multiple modes of transportation to areas recently affected by major disasters is oftentimes very difficult. Following Hurricane Maria's landfall on Puerto Rico in 2018, 10,000 shipping containers were stranded in just one port of Puerto Rico unable to traverse the island to reach those in need. The lack of resilient infrastructure caused a delay in repair to normalcy for the entire island and delayed supplies that were already late to their destination even longer.

The goal of this research is to model the elasticity of cargo arrival and departure under resilient infrastructure. The objective of this research is to determine the responsiveness of a mode of transportation to change under demand and restrictions. This model will be simulated in VISSIM by first modeling an individual port in Puerto Rico and then allowing this cargo to move along the major truck routes of the island and examining the dwell time and ultimate arrival time from the time it arrives in the port to when it reaches its destination. Its expected that a delay in final arrival time will still be seen; however, the delay time at the port and the delay time when the cargo reaches its final destination will not be linear. This research will help to bring improve well being to individuals of a society, increase public scientific literacy, improve national security, and enhance infrastructure for research and education.

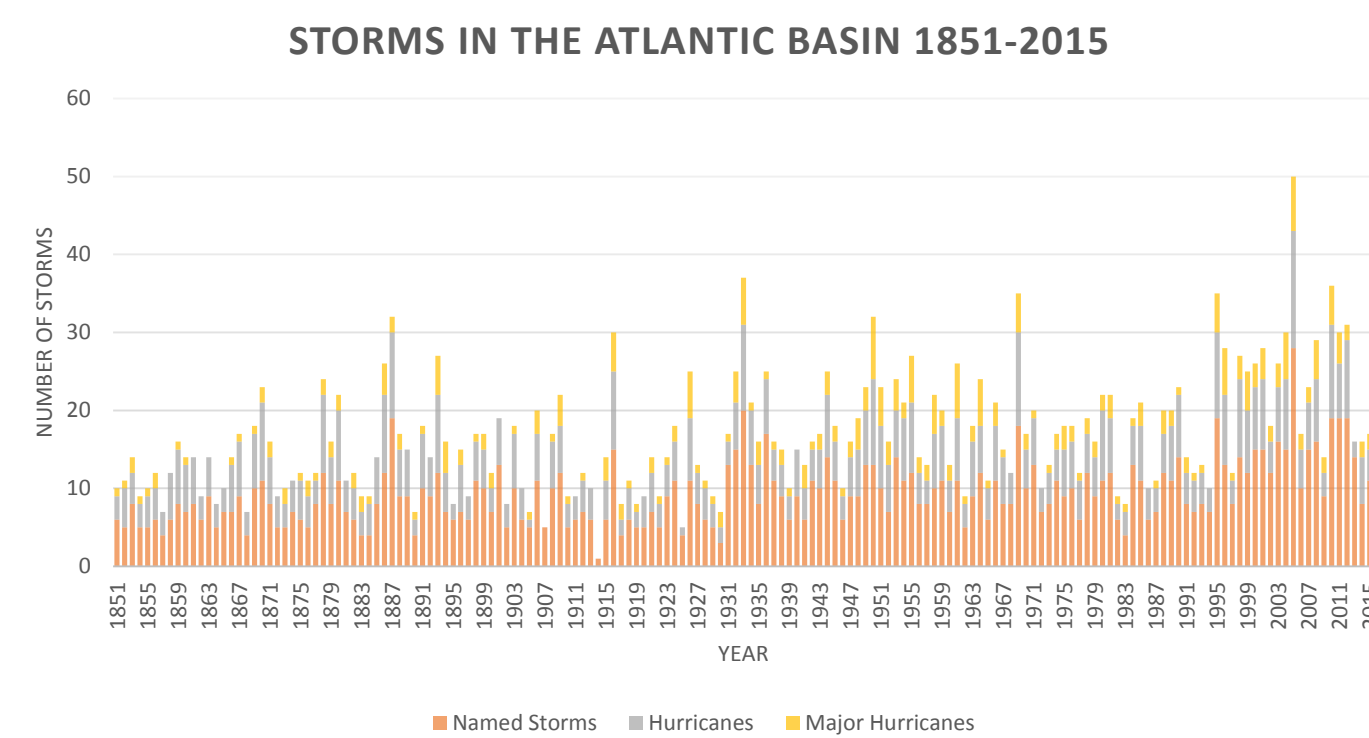
## PROBLEM

On September 20, 2017 Hurricane Maria made landfall on Puerto Rico as a category four hurricane, the strongest storm to pass over the island in 85 years.<sup>1</sup> The island, whose infrastructure was already deteriorating, came out in an inhabitable state in many areas. It took until September 23<sup>rd</sup> for the Port of San Juan to reopen and allow 11 cargo ships to bring water, foods, cots, and generators.<sup>2</sup> On September 28<sup>th</sup>, eight days after landfall, 10,000 shipping containers containing food and supplies were still stuck in the Port of San Juan.<sup>2</sup> The lack of reliable infrastructure including the roads that travel inland held these supplies in the port, as they still remained impassible. Even before Hurricane Maria resilient infrastructure became even more of a need. Resilient infrastructure is more than clearing debris from roadways after a storm, it is providing the means to deliver the essential goods and supplies needed to safely and quickly recover, i.e. deliver the fuel trucks need to operate.

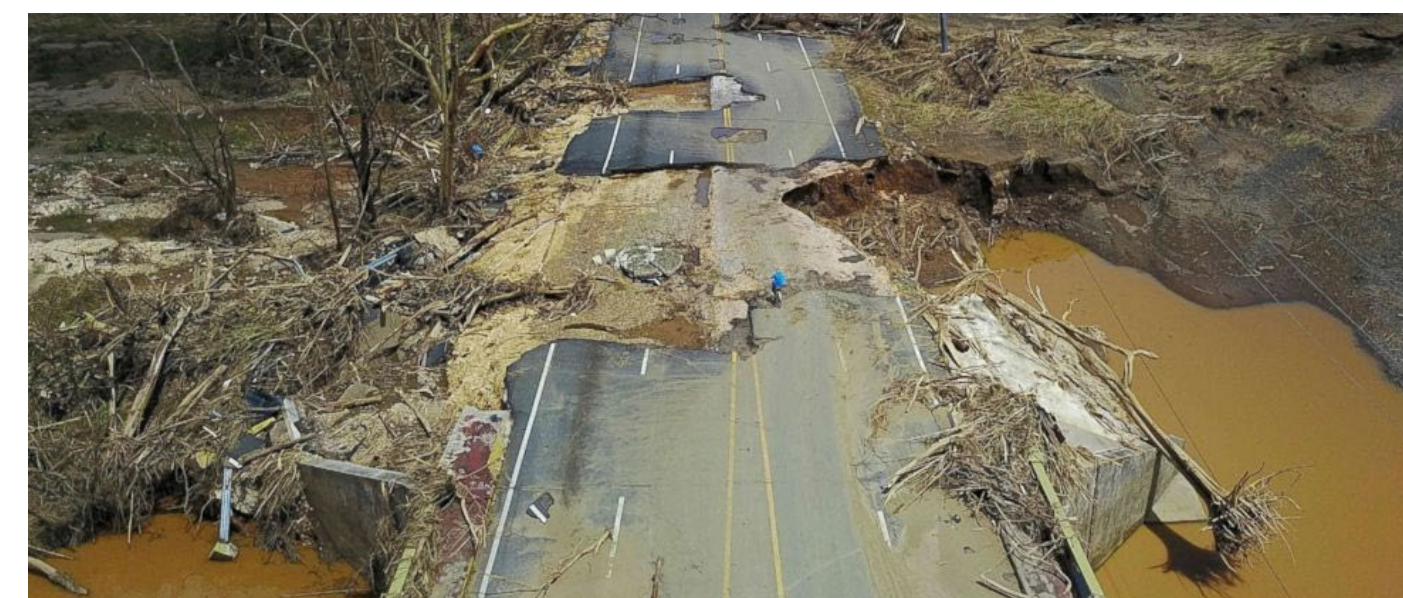


Cargo containers filled with supplies stuck in the Port of San Juan unable to leave due to lack of gasoline and damaged infrastructure following Hurricane Maria.<sup>3</sup>

In 2017, NOAA reported that 17 named storms formed in the Atlantic, 10 of which were hurricanes, and six of which were major hurricanes (category three or higher).<sup>4</sup> Since 1851, 27 storms have directly hit Puerto Rico, 11 of which were major storms.<sup>5</sup> In the past 20 years the number of major hurricanes in the Atlantic has increased 74 percent.<sup>6</sup> As the number of major hurricanes increases, the need to ensure resilient infrastructure to aid in preparation and repair efforts on an island with aging infrastructure is ever present. The National Science Foundation (NSF) defines resiliency as “the ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events.”<sup>7</sup>



Named storms, hurricanes, and major hurricanes in the Atlantic Basin from 1851-2015.<sup>6</sup>



Example of destroyed infrastructure in Puerto Rico following the landfall of Hurricane Maria in September 2017.<sup>8</sup>

## METHODOLOGY

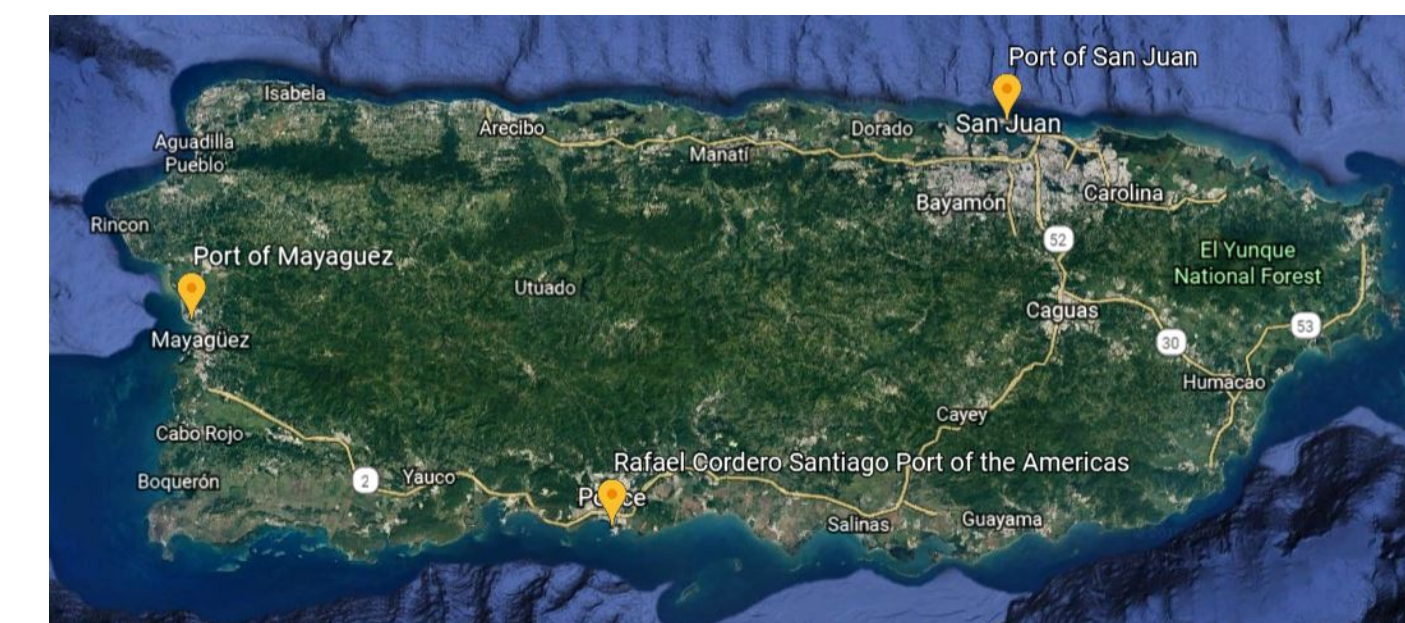
### Modeling of Hybrid Mesoscopic/Microscopic Network in VISSIM

A base model will be established under normal operations using data collected over a given timeframe. An Inverse Transform Sampling will be applied to simulate vessels within the port. Once vessel arrival and dwell times are estimated they can be analyzed using a Graphical User Interface. Simulated vessel operation will be examined and compared to historical data for calibration and validation purposes. A developed simulation model will allow the evaluation of various disruptive scenarios such as Hurricane Maria, flooding, and port labor disputes. This approach to analyzing port operations will be integrated with a landside model of surface transportation cargo distribution facilities.

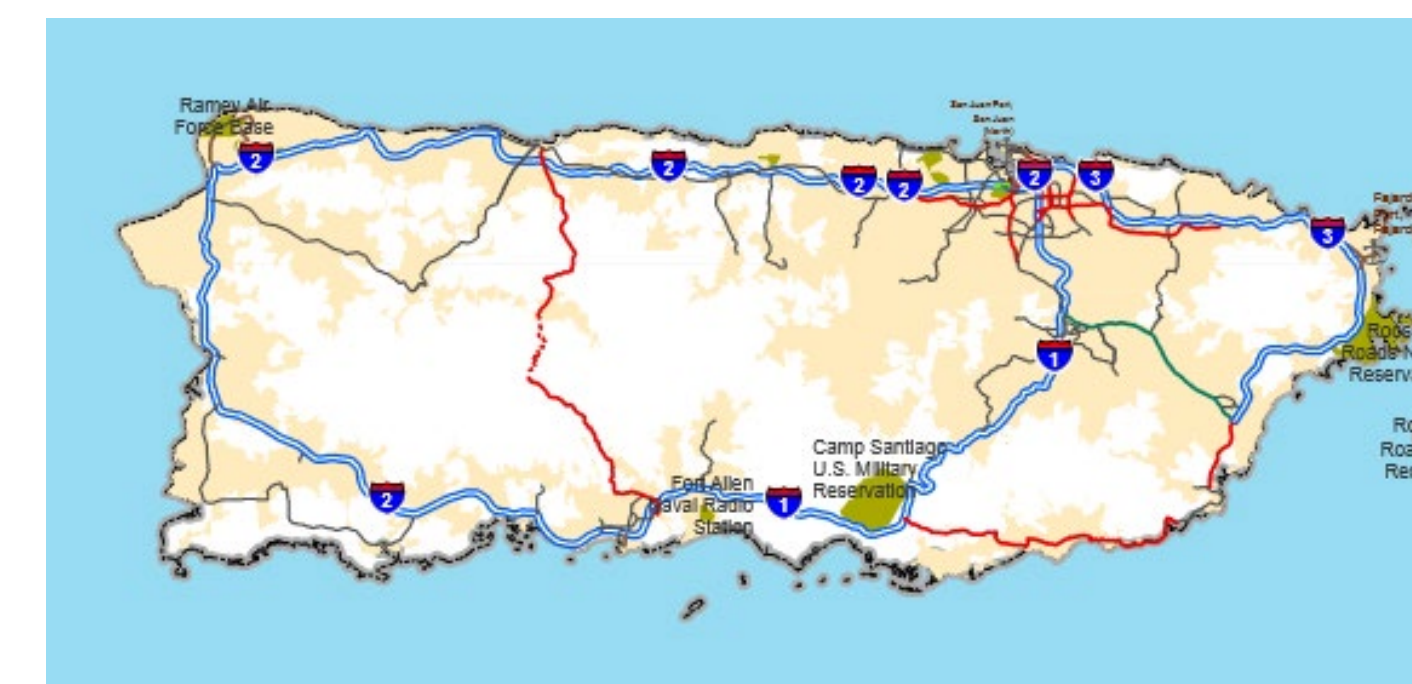


Example of VISSIM Network for a Container Terminal.<sup>9</sup>

An integrated microscopic traffic simulation platform will be used to model the surface transportation network. Within this platform, the developed port model will be integrated to link the travel modes within a unified architecture. Microscopic analysis will be conducted on the port facility and regional transportation network for the three major cargo ports, Port of San Juan, Port of Mayaguez, and Rafael Cordero Santiago Port of Americas. The three ports will be connected through the greater cargo distribution system and modeled at the mesoscopic level to encompass the integration of various modes, cargo, and ports of origin. Only through this level of incorporation can a holistic analysis of the elasticity of cargo connectivity resulting from a systematic disruption be achieved.



The three major ports within Puerto Rico that handle cargo, ferries, and cruise ships. (Google Earth, 2018.)



Federal interstates within Puerto Rico.<sup>11</sup>

## IMPLICATIONS

This research will have major impacts on society. By performing this research potential benefits can be achieved in public safety literacy, as well as the improvement of the well-being of individuals in a society. By enhancing emergency preparation and response times—i.e. allowing for the safe passage onto and off of the island and shipment of food, water, and preparedness and recovery supplies across the network in the days leading up to and following a major disaster this. It will help increase partnerships between academia, industry, and others by contributing research on a topic as important as resilient infrastructure from an engineering and academic standpoint. It will help to aid in new resilient infrastructure design and construction throughout the country and the world. It will also help to aid national security by providing data for the need for resilient infrastructure that can be applied to both natural and manmade disasters.

## REFERENCES

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