Interdependency of Port Clusters During Regional Disasters

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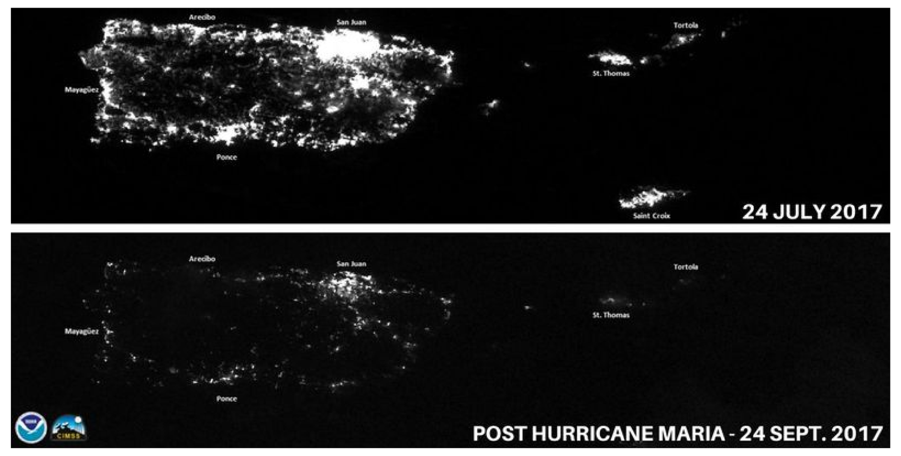
INTRODUCTION

Puerto Rico contains three major seaports. They are San Juan Port, the Port of Ponce, and the Port of Mayaguez. In 2017, these ports were disrupted by the wind and waves Hurricane Maria brought to the coast of Puerto Rico. Hurricane Maria devastated the island and it's 3.4 million residents. This storm registered as a category 4 hurricane that brought 155 mph winds and sheets of rain. Flooding damaged homes and left the entire island without power. Hurricane Maria was said to be the most devastating storm to hit Puerto Rico in 80 years. The ports along the coasts of the island suffered severe damage from the rising sea-levels and strong winds making landfall over them.



The performance of maritime transportation systems struggle to remain reliable and resilient during times of disruption. Major disruptions at a port may result from external threats such as storms, terrorism, labor disputes, and oil or hazardous material spills as well as multiple catastrophic events. The extent of the disruption and damage to a port, and the duration of the disruption depend on the severity of the threat, the degree to which the port is vulnerable to it, and the decisions that are made in responding to the disruption. Resiliency of a port is defined in terms of the severity of the impact of the disruption to a performance measure such as port capacity, as well as in terms of the duration of the impact on the performance measure.

PROJECT BACKGROUND

EXISTING RESEARCH

The ability of transportation systems to function when altered by a disruptive event is crucial for maintaining the national security and defense readiness of the United States, as well as the flow of essential goods. Much of the existing research on external disruptions to ports have been done on a small scale. Parr et al. created a simulation to generate various scenarios for the evaluation of three case study ports and estimate their resiliency. These simulated case studies were the partial closure of Port Everglades due to flooding, an oil/bio-hazard spill at the Port of New Orleans, and a labor strike at the Port of Long Beach [3].

These examples show that there is no consistent, quantitative approach to defining the resiliency of port clusters facing an external disruption. The cause and effect relationship ports in a cluster may face as one or more experience a less than desirable level of service can be applied throughout much of water bourn commerce. This research represents a step towards a systematic, objective means of measuring the resiliency of ports in a cluster.

PROPOSED RESEARCH

This research seeks to build upon the prior knowledge and expand the scientific understanding of regional disruptions to port clusters, areas of the country with multiple ports servicing the same region.

The contribution of this research is to empirically show how port clusters rely upon each other during disruptive events to increase the overall resiliency of water bourn commerce. The disruptions caused by Hurricane Maria in Puerto Rico, had both short-term and long-term impacts to the effected region. In the short-term, Puerto Rico experienced an inability for freight vessel to access any of the three port on the island territory, delaying much needed relief goods. Long-term, the economic impact and the recover process of this region will likely be affected by the devastating storm.

METHODOLOGY

AIS DATA COLLECTION AND PROCESSING

AIS technology was developed primarily for improving marine safety and maritime domain awareness [4]. The AIS technology uses the VHF radio spectrum to broadcast and receive real-time information concerning vessel identity, dimensions, position, speed, and headings, among other fields. All commercial vessels operating in or bound for U.S. waters are mandated to carry AIS technology by the Maritime Transportation Security Act of 2002 (46 USC 70113, 70114). The U.S. Coast Guard is involved in developing standards for AIS message formatting, and has established an archive of historical AIS data as part of its Nationwide Automatic Identification System program [1]. The archival AIS data for this study will be obtained through a commercial vendor.

Table 1: Existing research data collected using AIS technology.

Cargo Type:	Number of Observations		
	Everglades	New Orleans	Long Beach
1. Oil / Chemical	335	2604	762
2. Timber / Cement / Asphalt	16	48	10
3. Reefer	0	11	25
4. Ro-Ro / Veh. Carrier	62	22	199
5. Heavy Load Carrier	606	0	0
6. Container / Bulk Carrier / Tanker	2239	4637	1385
7. Passenger	726	222	1391

For this study, vessel location information from onboard AIS transceivers will be used to generate average vessel dwell time within the port areas of interest and net vessel transits into and out of the port areas of interest. Dwell time is the continuous length of time a vessel spends within the port area or associated regions such as offshore anchorages [1]. This indicates the capability of the port to efficiently handle cargo flows at the terminals and beyond [5]. During a disruptive event, there is a decrease in port performance. Vessels are processed at a slower rate, causing an increase in overall dwell time in the area surrounding the port. The ability of ports to recover from a disruptive event determines their level of resiliency.

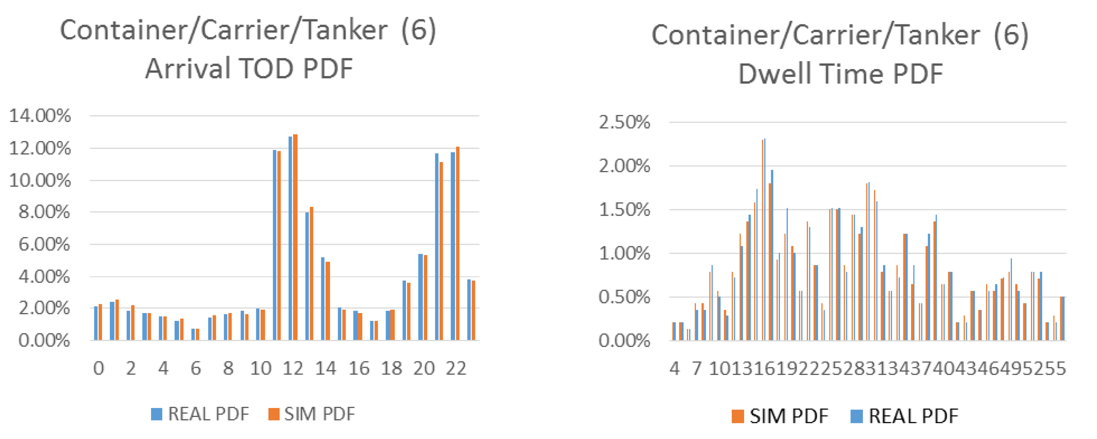


Figure 1: (a) Arrival times, (b) Dwell times for Long Beach displayed as a probability distribution function.

TIME-DEPENDENT RESILIENCY ANALYSIS

The time-dependent resiliency analysis plots will allow for systematic, objective means of measuring the resiliency of ports in a cluster. In an increasing service system, network output is positively correlated with service [1]. These plots will analyze each port's performance before, during, and after a disruptive event to determine their resiliency. A generic time dependent resiliency plot is shown in Figure 1 (a) for an increasing service system and Figure 2 (b) for a decreasing service system [7].

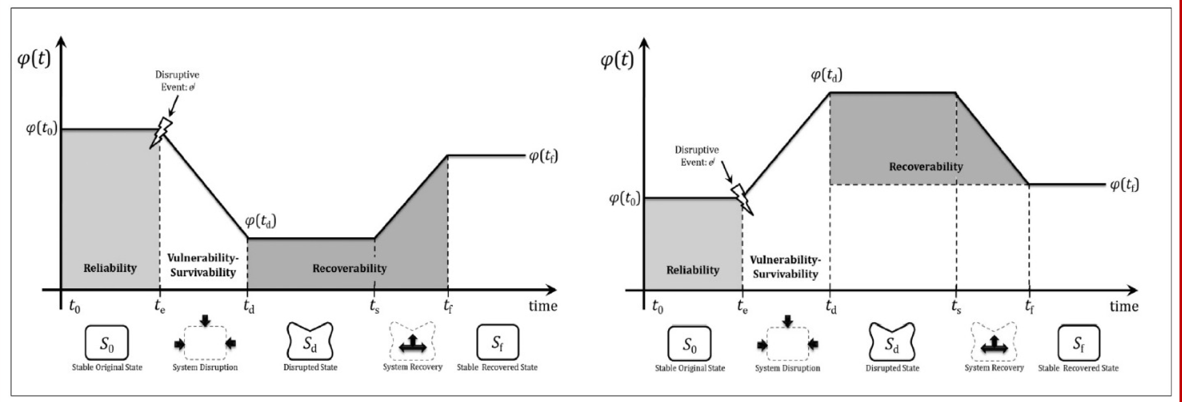


Figure 2 (a): Increasing Service System, (b) Decreasing Service System [7].

Using the time dependent resiliency function, Henry and Ramirez-Marquez (2012) [4] quantified resilience as the ratio of recover to loss. Therefore, resiliency at any time t_r after event e^j is calculated using the equation:

$$Я_{\varphi}(t_r|e^j) = \frac{\varphi(t_r|e^j) - \varphi(t_d|e^j)}{\varphi(t_0|e^j) - \varphi(t_d|e^j)} \; \forall e^j \in D$$

Eq. 1

where,

$Я_{\varphi}(t_r \mid e^j)$ = the resiliency of system S at time t_r resulting from the disruptive event, e^j.

$\varphi(t_d \mid e^j)$ = the performance of the system at t_d, corresponding to the time of maximum service loss.

$\varphi(t_0 \mid e^j)$ = the performance of the system at time t_0, corresponding to the original state.

D= the range of all disruption which could hinder service

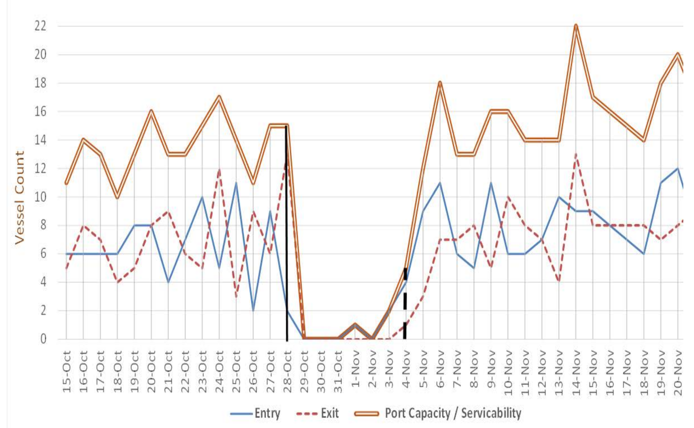


Figure 3: This is an example of a resiliency plot created for a case study that shows the operation dwelling times at Port of Long Beach

Time-dependent resiliency plots will be developed based on vessel throughput and dwell time for each of the ports within the Puerto Rico cluster. This visual will assist in the analysis and quantification of the performance of these ports before, during, and after the storm in both short and long term.

CLUSTER ANALYSIS

With the performance of each of the ports quantified with resiliency plots, the response and recover of the port cluster resulting from Hurricane Maria will analyzed holistically. It is expected that as one port decreases or increases in service, the other ports respond accordingly. At this point it is unknown how these port may react within a cluster and further analysis is needed. Once the resiliency plots have been developed and data analyzed, further methods for comparative analysis will be identified. This includes, but is not limited to the develop of a Monte Carlo simulation of the port. Fundamentally, Monte Carlo simulations work by estimating unknown values based probability distributions. Effectively, vessel arrivals and departures are random variables, however, they can be accurately estimated if enough observations are available. Therefore, using this statistical tool it is possible to generate random arrivals and dwell times that statistically match observed port operations. In effect this procedure allows for the generation of a "typical" day, week, or month of vessel traffic that is statistically indistinguishable from reality.

RESULTS

In general, the results of the research are expected showed the benefits of quantifying resiliency and how the information gained from such analysis can be beneficial when evaluating the impact of disruptive events on regional port clusters. The quantitative assessment of resiliency provides meaning, context, and relevance to port stakeholders which may not be readily apparent at face value. The interdependent nature of the transportation systems requires redundancies and therefore the impact of disruptive events must be viewed from a holistic approach. It not possible to see the entire regional impact of freight transportation by exploring the hindrance of one port. It is necessary to see the forest through the trees and develop methods and means to analysis these networks, systematically.

This research will also show that Automatic Identification System (AIS) data can be utilized to create new methods and metrics for the assessment of resiliency in maritime systems. This research may show, in quantifiable terms, reductions in performance resulting from a simulated disruption. On a broad level, research may represent one of first steps toward the development of standardized metrics for quantifying MTS operational resiliency. The use of AIS data, which collects information from nearly all commercial vessels on a semi-continuous basis, is a rich data source with many applications in disaster science. The methods developed and applied here incorporate an all-hazards approach to quantifying resiliency in navigable waters and can be applied across a range of temporal and spatial scales [1].

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