METHODOLOGY FOR QUANTIFYING RESILIENCY OF TRANSPORTATION SYSTEMS

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ABSTRACT

The National Science Foundation’s definition of resiliency is “the ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events” (National Science Foundation). While this definition is informative and useful, it lacks a quantitative reference. There is a need for a method of quantifying resilience to better plan and prepare for system wide disruptions. The research effort described here provides a quantifiable measures of system resiliency, consistent with NSF’s definition. Fundamentally, a system disruption can be partitioned into five distinctive states: the stable pre-event state, the absorption state, the disrupted state, the recovered state, and stable recovered state. The proposed method identifies these states by measuring system output and quantifies each component on a value scale between zero and one. The resiliency measure then unifies these metrics to provide an overall assessment of resiliency, which accounts for the system’s ability to absorb, recover, and adapt.

This approach to quantifying resiliency is applicable to any real-world or simulated system with measurable outputs. This paper first documents the development of the resiliency quantification method and then applies the method toward four complex, real world, transportation systems undergoing disruptions. These case studies consisted of six maritime port, three airports, two localized refueling systems, and the Colorado Department of Transportation’s cyber network. Each system had a measurable drop in functionality due to a disruption. In general, the results of this research showed that the proposed method of quantifying resiliency can be utilized for any transportation system.

INTRODUCTION

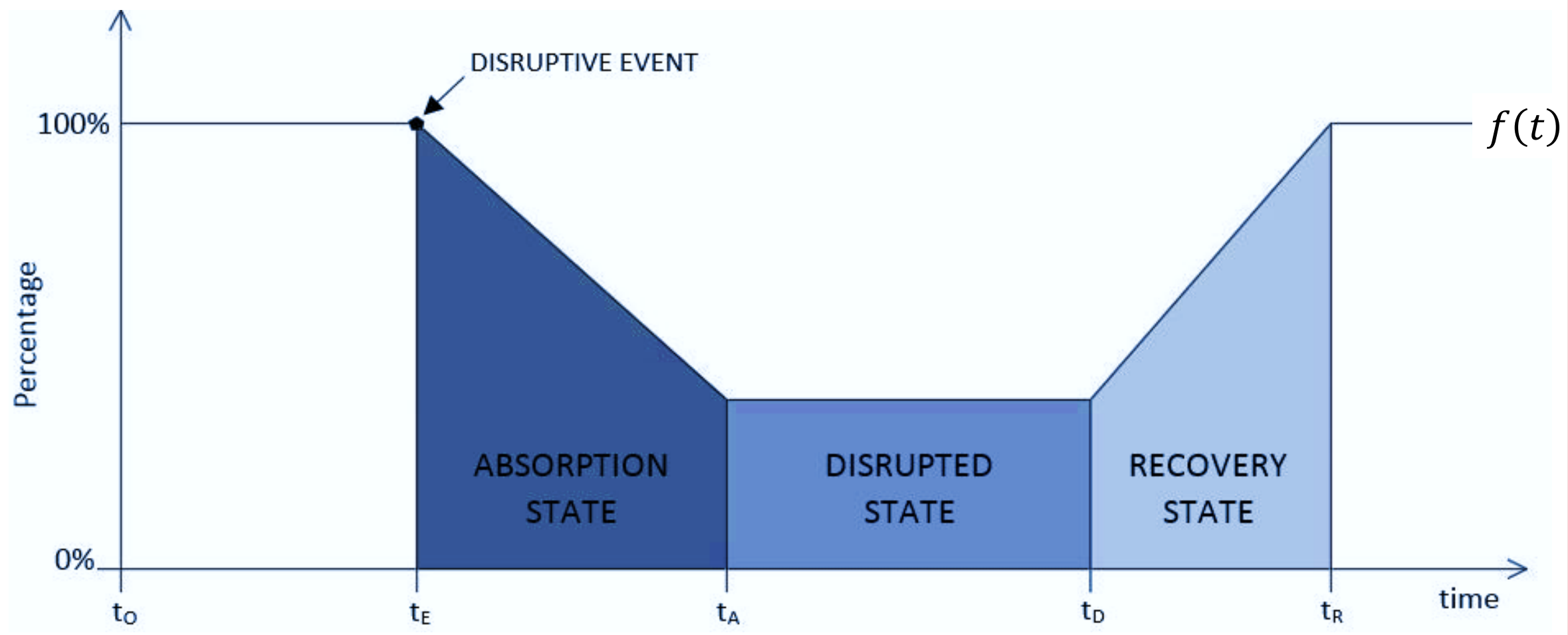
The need to enhance resiliency within the transportation systems and their management capabilities is vital toward providing safe, reliable mobility. Traditionally, civil infrastructure as included design limits that anticipating the reality of continually changing conditions. When these design limits are reached, the resulting disruption can and often does have a significant impact on the operations. Disruptions to the operations of transportation systems have generally been tolerated by the public as routine. Flight cancelation, delayed shipments, lane closure, power outages are tolerated as everyday occurrences to be expected with the movement of people and goods. Global climate change and an increase tendency toward urbanization are likely to increase the rate disruptions within the transportation system.

METHODOLOGY OF RESILIENCY INDEX

DEFINITION OF RESILIENCY

According to the National Science Foundation, resiliency as the ability **“to prepare and plan for, absorb, recover from, or more successfully adapt to adverse events”.**

To find a quantifiable value for resiliency in correspondence to this definition, the functionality after the disruptive event has been broken down into three states. The absorption state, disrupted state, and recovery state. This model shows functionality vs time.



ABSORPTION STATE

System functionality between t_E and t_A can be used as a direct measure of absorption. In particular, the change in time with respect to functionality, i.e. the inverse of the slope, is an intuitive measure of the system’s ability to absorb. This value can also be normalized between zero and one, by the inverse tangent function. Equation 1 represents the system’s ability to absorb the impact the event. If the absorption state is 1.0, the disruption had no effect on the system. However, a sharp, negative slope indicates poor absorption and results in value closer to zero.

$$R_A = 1 - \frac{2}{\pi}\left|tan^{-1}\left(\frac{\mathrm{f(t_a)-f(t_e)}}{\mathrm{t_a-t_e}}\right)\right|$$

DISRUPTED STATE

The functionality during the disrupted state represents the system’s ability (or lack thereof) to adapt to the adverse conditions and overcome the disruption. While system performance is no longer decreasing, the inability to “bounce back” is measured in the disrupted state. Equation 3 provides a measure, between zero and one, for the system’s ability to quickly adapt to the new conditions which exist after the disruption.

$$R_D = 1 - \frac{t_e - t_a}{t_r - t_e}$$

RECOVERY STATE

Similarly, the system’s ability to recover, can also be measured by the inverse of the slope within the recovery state, $t_D < t < t_R$. Equation 2 quantifies the system’s recovery after a recovery action has been taken.

$$R_R = \frac{2}{\pi}\left|\tan^{-1}\left(\frac{\mathrm{f(t_r)-f(t_d)}}{\mathrm{t_r-t_e}}\right)\right|$$

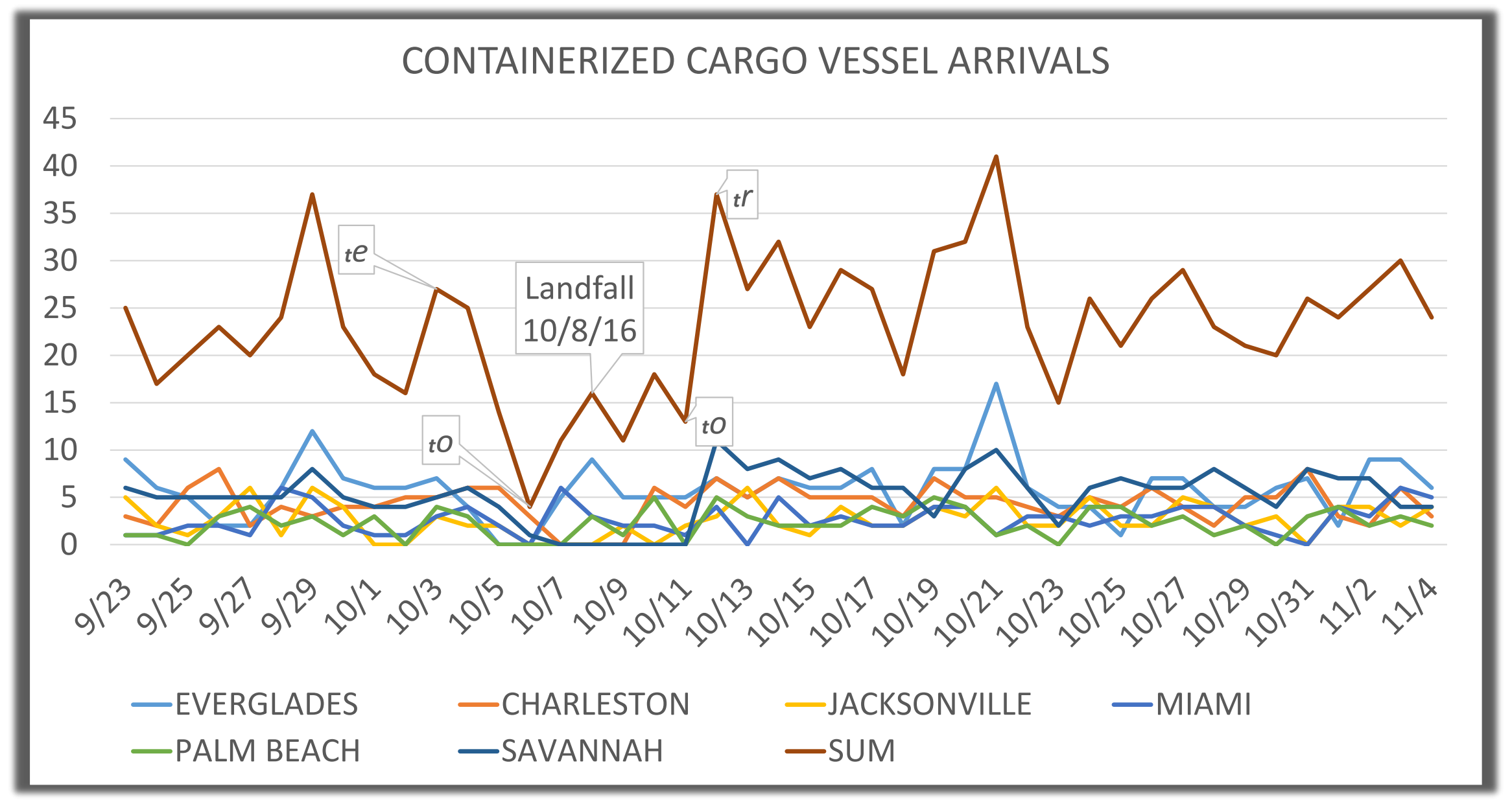
RESILIENCY INDEX

Resiliency is a measure of the systems absorption (Equation 1), recovery (Equation 2), and adaptability (Equation 3), then a quantifiable measure of resiliency is given as Equation 4.

$$R = R_A * R_D * R_R$$

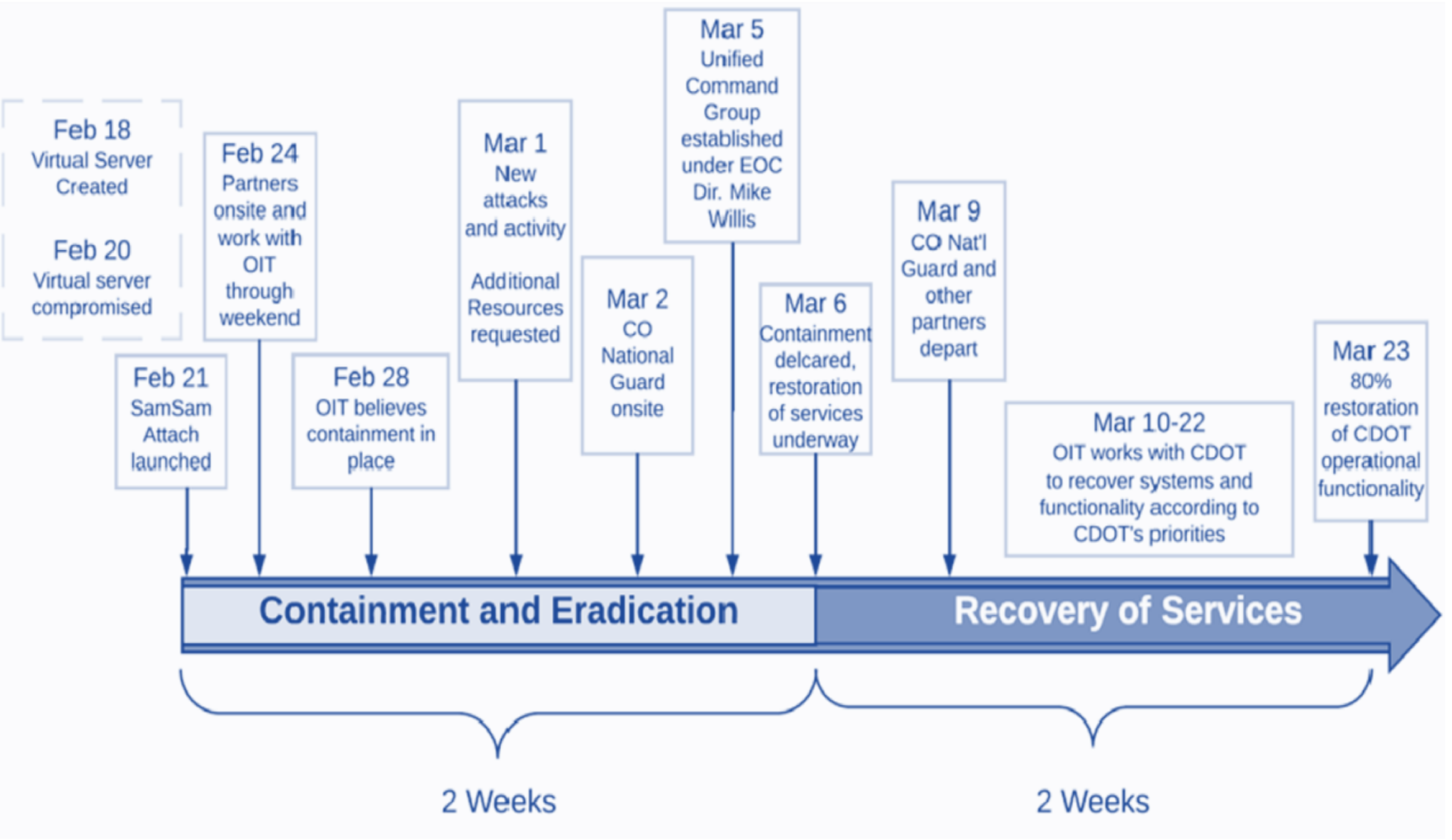
This formulation of resiliency suggests that a system must be able to absorb, adapt, and recover to be resilient and effectively bounce back, else $R = 0$.

RESULTS OF PORT RESILIENCY



PORT OF CALL	ABSORPTION	DISRUPTION	RECOVERY	RESILIENCE
MIAMI	0.156	1.000	0.874	0.136
EVERGLADES	0.177	0.800	0.861	0.122
W. PALM BEACH	0.126	1.000	0.874	0.110
JACKSONVILLE	0.500	0.600	0.705	0.211
SAVANNAH	0.295	0.500	0.942	0.139
CHARLESTON	0.205	0.600	0.895	0.110
AVERAGE	0.243	0.75	0.859	0.138
REGIONAL	0.161	1.000	0.90	0.145

RESULTS OF CYBERATTACK



Feb 18 Virtual Server Created

Feb 20 Virtual server compromised

Feb 21 SamSam Attach launched

Feb 24 Partners onsite and work with OIT through weekend

Feb 28 OIT believes containment in place

Mar 1 New attacks and activity

Additional Resources requested

Mar 2 CO National Guard onsite

Mar 5 Unified Command Group established under EOC Dir. Mike Willis

Mar 6 Containment delcared, restoration of services underway

Mar 9 CO Nat'l Guard and other partners depart

Mar 10-22 OIT works with CDOT to recover systems and functionality according to CDOT's priorities

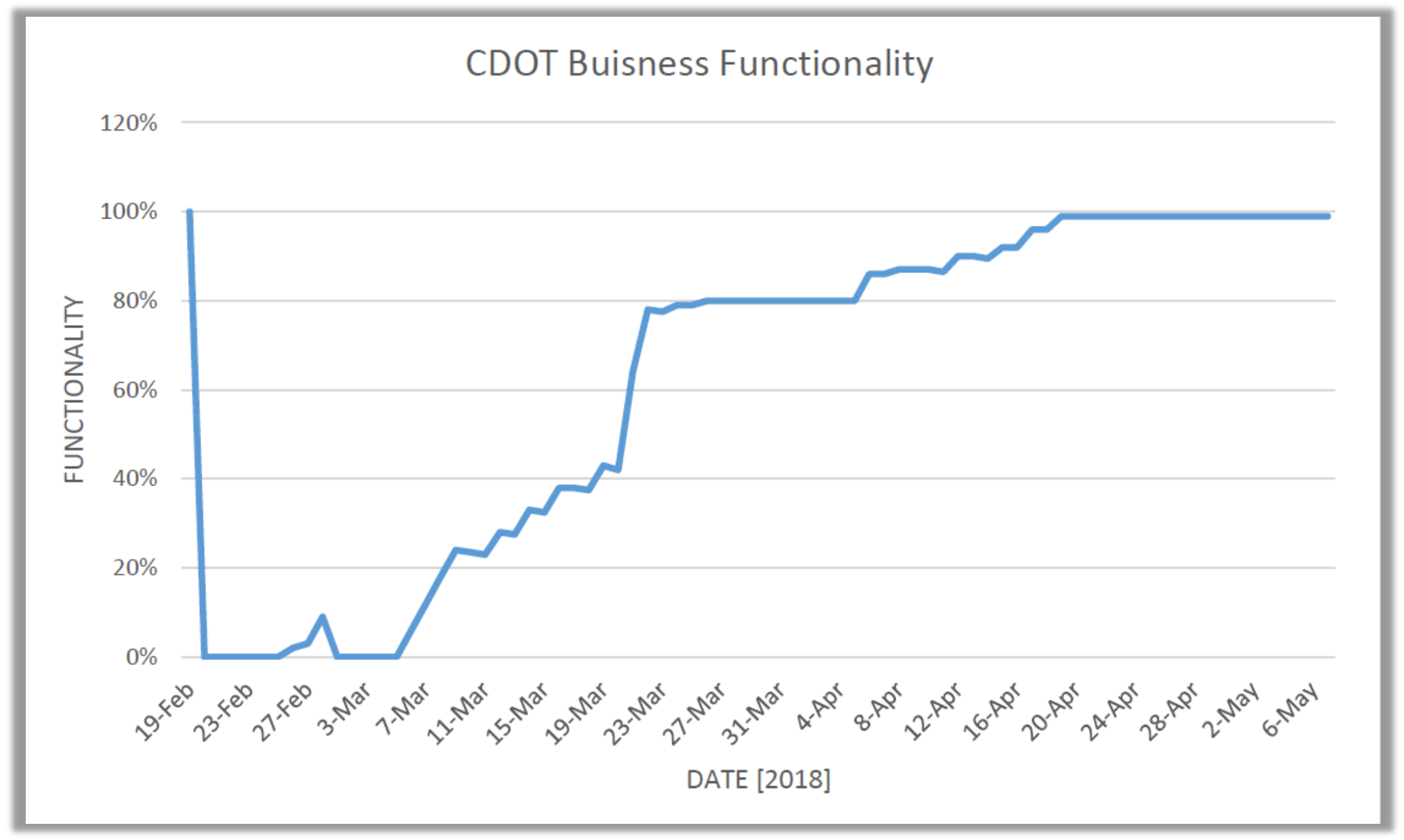
Mar 23 80% restoration of CDOT operational functionality

Containment and Eradication

Recovery of Services

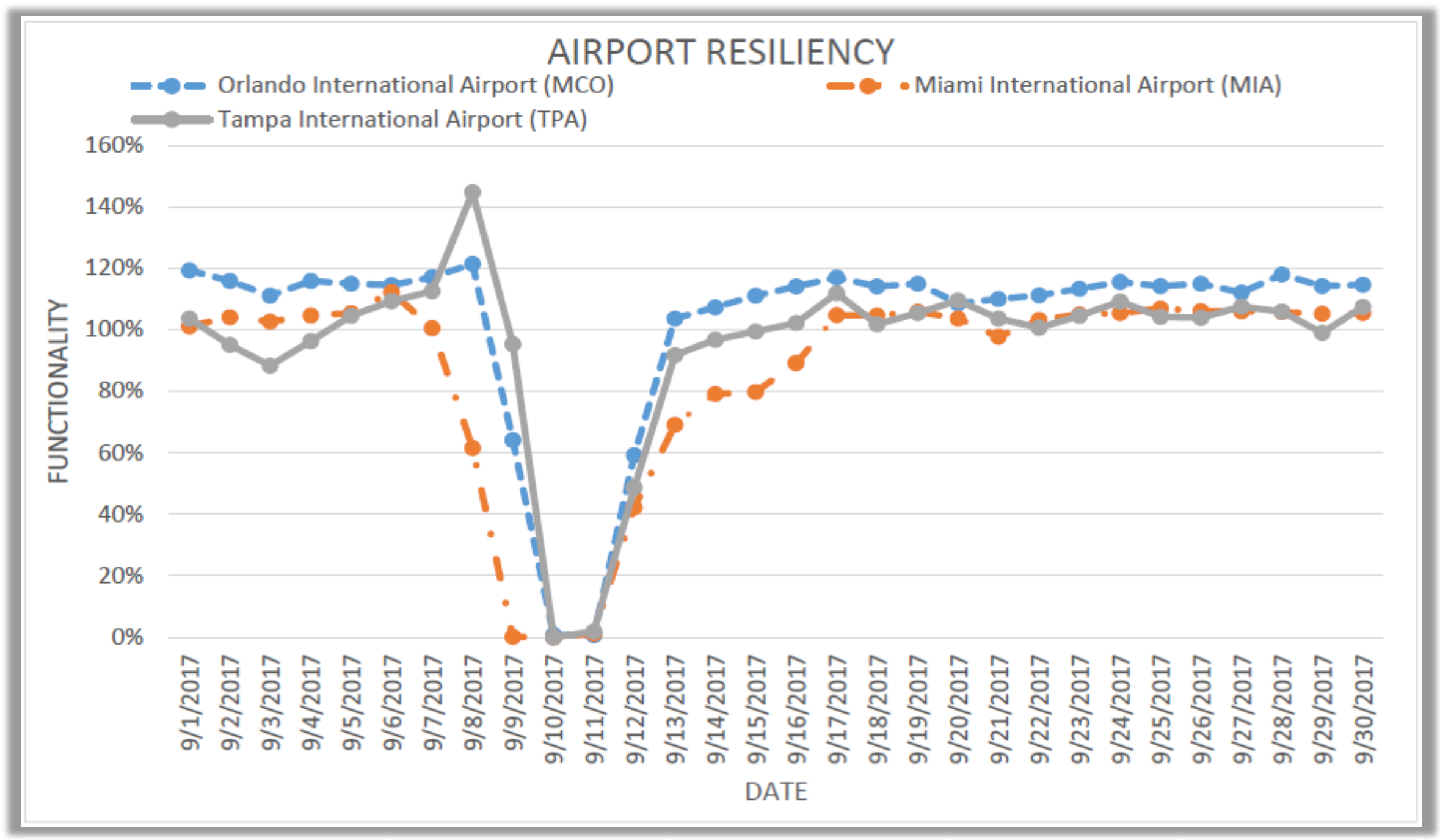
2 Weeks

2 Weeks



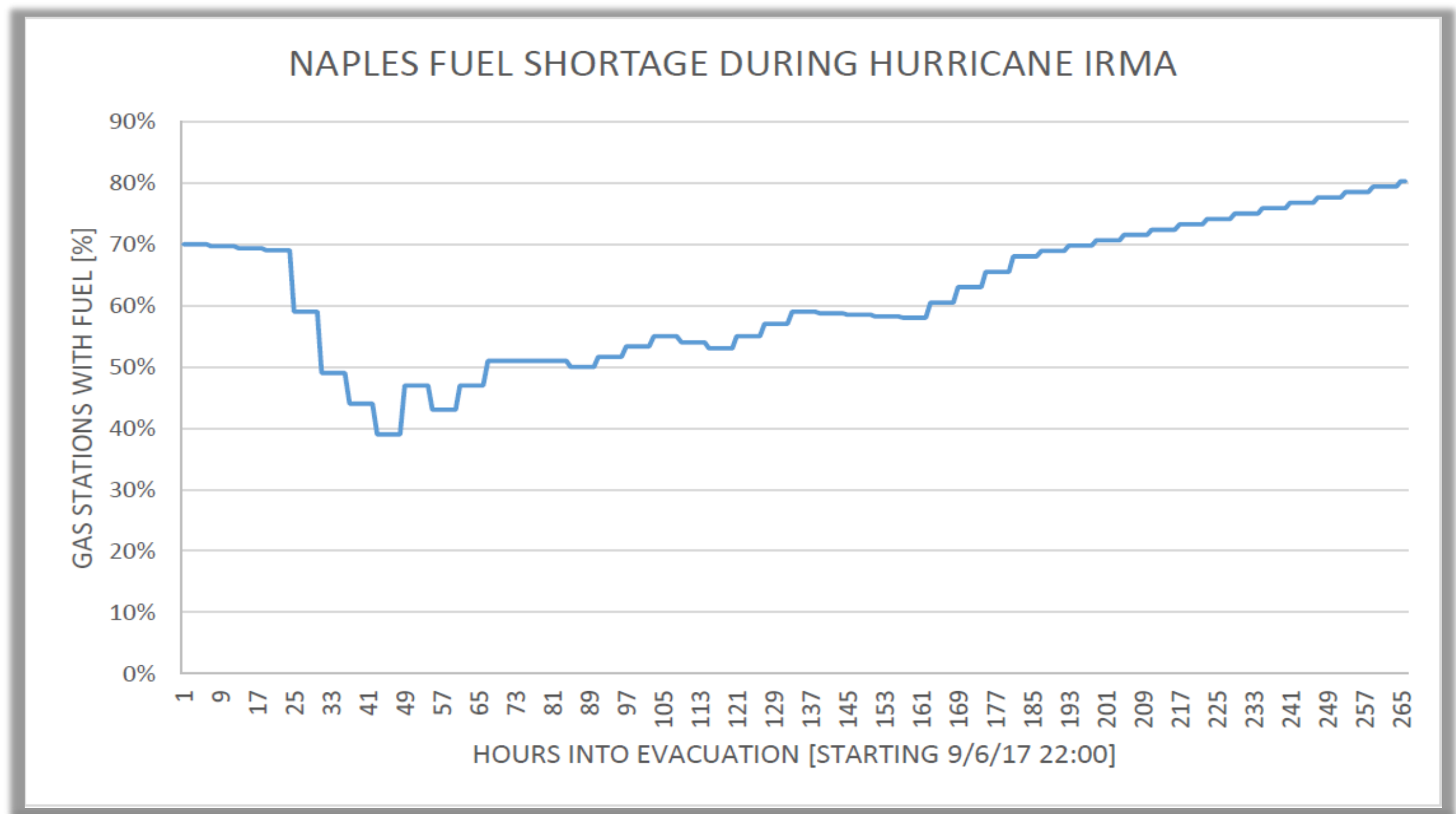
ABSORPTION	DISRUPTION	RECOVERY	RESILIENCE
0.00637	0.77966	0.7284	0.00362

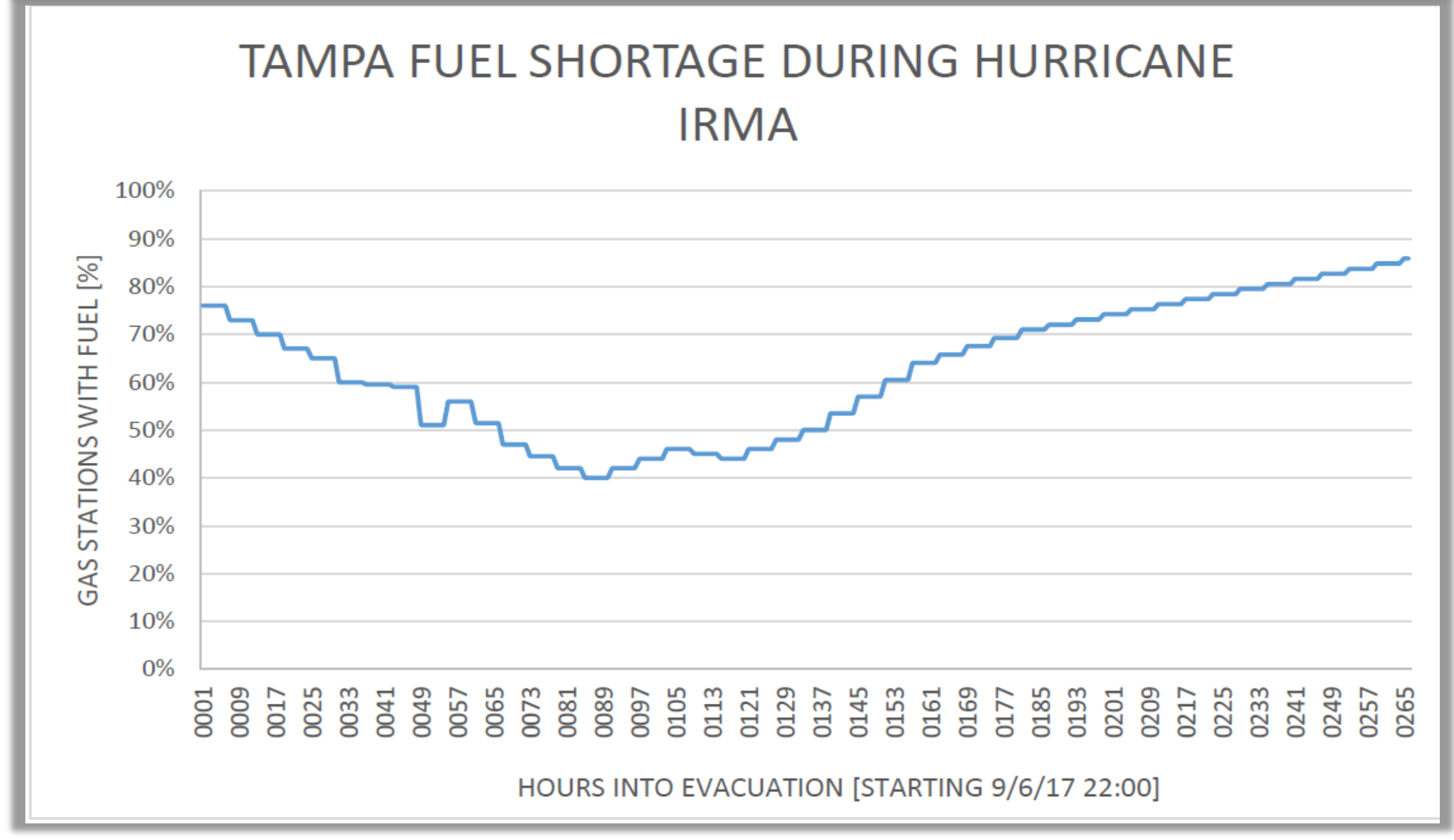
RESULTS OF AIRPORT RESILIENCY



AIRPORT	ABSORPTION	DISRUPTION	RECOVERY	RESILIENCE
ORLANDO (MCO)	0.0119	0.8	0.9878	0.0094
TAMPA (TPA)	0.0169	0.8333	0.9862	0.0139
MIAMI (MIA)	0.0126	0.8	0.9637	0.0097

RESULTS OF FUEL SHORTAGE





CITY	ABSORPTION	DISRUPTION	RECOVERY	RESILIENCE
NAPLES	0.3594	0.9702	0.1308	0.0456
TAMPA	0.7308	0.8317	0.2156	0.1311

CONCLUSION

This research presented a methodology for quantifying resiliency of transportation systems. Using the methodology developed in this research, any transportation system can determine their resilience to a disruptive event and determine where growth is needed to increase resilience. The resilience of a system during one disruptive event can be compared to the resilience of a separate disruptive event on the same system or an identical disruptive event affecting a separate transportation system. This methodology can also be adapted to predict the resilience of a transportation system to a future disruptive event through modeling approaches.