Microgrid-enabled Resilient Port

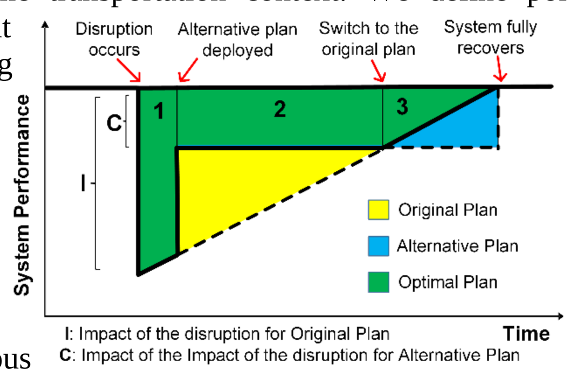
Jian Shi[1] and Gino Lim[2]
[1]Department of Engineering Technology, University of Houston
2 Department of Industrial Engineering, University of Houston

1. Introduction

Ports are intermodal hubs for freight and passenger transport, representing a nexus of critical infrastructure systems that connect communities via transport, energy, water, and communications networks. Ports serve as critical connection points of the backbone of global economies, handling nearly 90% of internationally traded goods. Ports also provide value-added services to commodities that they handle and act as bases for an array of marine and shore-side operations.
As the world depends more than ever on the critical services provided by the ports, their safe and reliable operation becomes critical for public safety and wellbeing. However, the location of ports makes them potentially vulnerable to natural disasters, such as coastal flooding, tropical storms, and hurricanes. In fact, a survey conducted by the United Nations Conference on Trade and Development (UNCTAD) in 2017 [1] showed that 72% of the responding port authorities have been impacted by extreme events, causing delays (60%), disrupting operations (76%) or causing physical damages (45%). Given the vital role of ports, understanding port disruptions caused by extreme events and building resilience into the global port and trade network becomes imperative [2].
In this talk, we discuss the definition and a modeling methodology for port resilience. We introduce an analytical framework to quantify resilience metrics and how they can be integrated in the port designing processes. We also show how microgrids, as an emerging smart grid technology, can systematically enhance the resilience of the port system.

2. Port Resilience

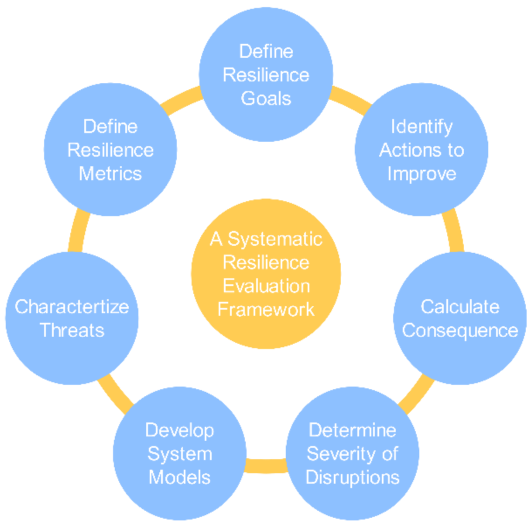
For the port system, we adopt the general definition of resilience from the Presidential Policy Directive (PPD) and modify it under the maritime transportation context. We define port resilience as "the ability of ports, and the systems that they are part of, to anticipate and respond to changing situations, as well as to survive and/or quickly recover from disruptions, with the goal of preserving the sustainability of operations and flow of cargo to, from, and through ports". According to this definition, it is evident that a port's resilience is deeply connected to the community and natural ecosystem that it is part of, as much as its physical infrastructure. Specifically, based on our previous



work [3], we propose a port resiliency definition involving the following factors: 1) readiness: the probability of disruption, 2) response: consequences of those disruptions, 3) recovery: recovery to the normal state after the disruption, and 4) criticality: the ability of the essential components of a port to perform in case of the failures and disruptions. Such a definition allows us to calculate the resilience of each component involved in the energy- and logistics-related port operations according to a set of parameters such as *impacts*, *repaired ratio*, *criticality*, *probability of* *component disruption*, and *component damage ratio*. Under the premise that the resilience of the overall port system is dependent on the resilience of every interconnected component, the overall resilience of the port can be determined. As illustrated above, a resilience triangle can be constructed for a system that is disturbed by a disturbance with the impact **I** on the network based on the proposed metric. It can be observed that the system performance loss decreases if an alternative plan is available while the disrupted component is being recovered.

3. A Resilience Analysis Process

To model, quantify, and analyze port resilience, an iterative analytical framework is adopted as illustrated to the right. The proposed framework can be broken into the following seven steps:



1) Define resilience goals: in this step, we aim to determine to purpose of the study (evaluate vs. improve). We also identify the scope of analysis, the current resilience practices, as well as the stakeholders to be included in the study.
2) Define resilience metrics: based on the resilience goals outlined in the previous step, we can determine the specific metrics necessary to characterize and quantify the resilience performance of a system (i.e., port)
3) Characterize threats: in this step, we identify threats to the system and the associated uncertainties. Historical data can be utilized in this step to help us model the threats more accurately.
4) Develop system models: in this step, we focus on identifying a numerical system model, so we can capture the performance of the system under the identified threats. This model includes the infrastructure models as well as their interdependencies. For a port system, we consider four types of main infrastructure systems: transportation (freight or passengers) infrastructure system, energy infrastructure system, water infrastructure system, and communication infrastructure system.
5) Determine severity of disruptions: using the threat model and system performance model, we can quantifiably determine how the system is impacted by the identified threats, including the elements impacted and the level of disruption.
6) Calculate consequences: in this step, we calculate the aftermath of events based on the resilience metrics. In this way, the resilience can be assessed.
7) Identify actions to improve resilience: as the final step of the process, we focus on evaluating improvements and enhancements that be applied to the system to improve its resilience. Some representative actions include infrastructure improvements, policy and operational changes, as well as requesting additional resources for recovery. Progress can be tracked over time once the identified improvements are performed.

4. Microgrids as a resilience resource

Microgrid is one of the technology-based solutions to enable a prosperous, sustainable, and resilience future for the ports. A microgrid is a relatively small-scale localized energy network that features an effective integration of high penetration level of Distributed Energy Resources (DERs), such as renewable energy resources, energy storage devices, and controllable loads. A microgrid can operate both in island mode (i.e., disconnected from the main utility grid) or in connected mode. The secure, high-quality, and green energy that microgrid can provide opens up opportunities for technology integration, capacity expansion, sustainability enhancement, and business continuity to further improve the port's smartness.

There are many very recent and ongoing efforts around the world to incorporate microgrids into the port design. Take the United States for example, Port of Los Angeles (POLA) invested $27 million in 2018 in microgrid development and distributed clean energy resource technologies. Port of Long Beach (POLB) has been evaluating the feasibility of developing microgrid to serve the port's needs for energy reliability, power quality, and economic stability. Port of San Diego was awarded $5 million grant from California Energy Commission in 2018 for the installation of a renewable-energy-based microgrid to provide back-up power to port-operated facilities and support military deployment activities.

The results obtained from our preliminary study [4] showed that microgrids can contribute to various aspects of port operations and infrastructures, including three times increase in the use of renewables, 54% improvement in emission reduction, zero downtime for critical loads, cost savings, and energy dependency.

5. References

[1] UNCTAD, 2017. Port Industry Survey on Climate Change Impacts and Adaptation, UNCTAD Research Paper No. 18.

[2] Verschuur, J., Koks, E. E., & Hall, J. W. (2020). Port disruptions due to natural disasters: Insights into port and logistics resilience. Transportation research part D: transport and environment, 85, 102393.

[3] Najarian, M., & Lim, G. J. (2020). Optimizing infrastructure resilience under budgetary constraint. Reliability Engineering & System Safety, 198, 106801.

[4] Molavi, A., Shi, J., Wu, Y., & Lim, G. J. (2020). Enabling smart ports through the integration of microgrids: A two-stage stochastic programming approach. Applied Energy, 258, 114022.