Ports
An industry guide to enhancing resilience
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ABOUT THE RESILIENCE SHIFT

The Resilience Shift (RS) was established in 2016 to address the recommendations of the Lloyd’s Register Foundation’s ‘Foresight review of resilience engineering’. The initial 5-year programme is funded by Lloyd’s Register Foundation, with Arup as host institution. Its aim is to inspire and empower a shift in critical infrastructure resilience thinking and practice so that engineered structures and infrastructure will be not only safer but also better.

DEFINING RESILIENCE

Resilience in infrastructure systems is the ability to prepare for identified shocks and stresses, to respond to and recover positively from those events that you cannot predict or avoid, and adapt to changing conditions. Resilience must focus on the ability of the system to continue to function, considering technical resilience alongside community and organizational resilience.

ACKNOWLEDGEMENTS

The authors would like to extend our gratitude to The Resilience Shift for the opportunity to highlight key resilience issues and opportunities in the port sector. We would also like to thank the interviewees who contributed their time and insights, which were invaluable for identifying critical barriers to resilience and potential opportunities for incentivizing resilience action across the sector. Lastly, we express our thanks to Helen Civil, Ibrahim Almufti, Jack Hogan, and the other reviewers whose feedback helped to refine the content better to meet the needs of port and shipping stakeholders.
Foreword

Building resilience of critical infrastructure requires decision-makers working in different industry sectors to understand what can be done, why it should be done, and how to put it into practice. Our work to date has told us that key stakeholders are often either unaware of the value that resilience can bring or are constrained by a lack of resources or support in terms of how to embed and enhance resilience.

This primer is a brief document introducing the elementary principles of resilience relevant to the ports sector and is part of a body of knowledge, tools and approaches that the Resilience Shift is producing, funding, and curating, intended to help those responsible for the financing, planning, design, delivery, operation and maintenance of critical infrastructure systems to shift practice. Our vision is to contribute to a common understanding across critical infrastructure sectors of what improves resilience and how it can be achieved in practice.

Building resilience into your infrastructure systems, across your value chains, will allow you to prevent or mitigate against shocks and stresses that you identify, and to respond better to those events that you can’t predict or avoid.

We’re delighted to have supported the team at Four Twenty Seven Inc. in producing this primer.

The Resilience Shift team
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Executive summary

In our increasingly interconnected world, supply chains span the globe and most have at least one link on a maritime ship. Ports serve as critical linkages between global economies, handling nearly 90% of internationally traded goods. To inform the expanding global conversation on resilience, this primer provides professionals in the maritime sector with insights on opportunities for (and barriers to) resilience. Developed with input from industry members, this document describes current benchmarks of resilience in the industry and provides recommendations for scaling up resilience actions.

In the maritime sector, resilience means that ports, and the organizations that depend on ports, can adapt to changing conditions and, when disruptions do occur, recover quickly and resume business stronger than before.

Resilience is not one-size-fits-all. The maritime industry is full of diverse actors, each with unique operations and facing a unique set of hazard impacts. However, by examining barriers to the uptake of resilience measures and good practices we provide a view on opportunities to scale up resilience actions across the sector.

“When you’ve seen one port, you’ve seen one port.”

Ports, and associated stakeholders can take actions now to build resilience to existing and evolving risks in a rapidly changing operating environment. Several of these actions are “low regret” measures that yield benefits under current conditions as well as a range of future scenarios and have relatively low costs compared to the potential benefits.
Our recommendations

**Figure 1**
Recommended resilience actions

- **Global action to define and standardize resilience**
- **Build the knowledge base to support a business case for resilience**
- **Establish an enabling environment that supports resilience decision-making**
- **Promote multi-stakeholder collaboration**
- **Engage stakeholders to obtain buy-in and support as well as collaboratively assess risks and identify resilience opportunities**
- **Integrate resilience into existing systems and processes**
- **Embed resilience in design**
- **Delineate clear resilience responsibilities**
- **Assess risks and opportunities leveraging existing resources**

See page 37 for details on individual organization recommendations and page 40 for sector-specific recommendations.
1 Introduction
INTRODUCTION

Marine ports are drivers of national, regional, and local economies as critical nodes in global supply chains, gateways for the movement of goods in and out of markets, and significant employers. In the United States, seaports handle over 99% of trade by volume and 65% of trade by value. Seaports also supported an estimated 550,000 jobs, and trade-related port activity generated over 23 million jobs in the United States in 2014. Marine shipping also plays a critical role in the global supply chains that underpin economic activity: its transport of goods accounts for 80-90% of international trade.

This primer is a brief document introducing the elementary principles of resilience relevant to the port industry. The industry is made up of diverse actors, each with unique operations and facing unique hazard impacts. Through exploring good practice and reported barriers to the uptake of resilience measures, we provide a view on opportunities to scale up resilience actions across the sector. This primer seeks to help those working in ports and associated sectors understand:

- the context for resilience of ports, including definitions, trends and vulnerabilities
- relevant stakeholders, and some of the barriers faced
- approaches used in practice to build resilience, with a focus on resilience to climate-related hazards
- the drivers and enablers that exist in practice to enhance resilience

It has been informed by interviews with industry stakeholders (a list of interviewees is provided at the end of the document), together with a review of reports from ports, shipping companies, industry groups, government and regulatory agencies, and research institutes. The interviewees were predominantly US-based, although the insights are relevant globally. In the preparation of this primer, resilience to physical climate risks such as hurricanes and sea level rise emerged as a common frame for resilience in this sector. As such, this primer places particular emphasis on physical climate risks. However, a holistic approach to resilience is important, recognizing that ports face a wide range of known and unknown shocks and stresses. Many of the findings of this primer are also relevant in a broader context.
2 Context
Resilience of ports is characterized by the ability to prepare for and adapt to changing conditions and withstand and/or recover rapidly from disruptions, with the aim of ensuring continuity of services and movement of goods to, from and through ports.\textsuperscript{4}

Effectively managing both acute and chronic risks would enable ports, and associated stakeholders not only to rebound to a previous state after a shock or other stressor, but to ‘bounce forward’ or achieve a state of greater resilience. Dependencies and linkages across critical infrastructure systems and planning and coordination among infrastructure partners all influence resilience.\textsuperscript{5}

**SUSTAINABILITY AND RESILIENCE**

The International Maritime Organization (IMO) defines a sustainable maritime transportation system as one that delivers “safe, secure, and efficient and reliable transport of goods across the world, while minimizing pollution, maximizing energy efficiency and ensuring resource conservation.”\textsuperscript{5} Sustainability efforts are closely linked to resilience, for example:

- Reduction in demand (e.g. through energy and water efficiency measures) can reduce exposure to disruption of regional infrastructure systems

- Acceptance of economic activities by local communities and other stakeholders will boost the social license to operate and create a more engaged and resilient community

- Enhanced business reputation through actions that create benefits for individual organizations as well as the community and ecosystem in which they operate.

**PORT CLASSIFICATION**

<table>
<thead>
<tr>
<th>LANDLORD PORTS</th>
<th>Comprise the majority of ports worldwide. The port authority owns the land and infrastructure and generates revenue from private sector tenants who lease and operate terminals.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PUBLIC SERVICE/OPERATING PORTS</td>
<td>Are owned and operated by the port authority, which is often a government entity.</td>
</tr>
<tr>
<td>TOOL PORTS</td>
<td>Similar to public ports, but use private operators to handle cargo.</td>
</tr>
<tr>
<td>CORPORATIZED AND PRIVATE SERVICE PORTS</td>
<td>More heavily privatized, with the public sector often just retaining a regulatory oversight role.\textsuperscript{6}</td>
</tr>
</tbody>
</table>
Essential functions

The main function of a port is management of cargo or passenger flows between water and land. Seaports vary significantly in terms of their management and ownership of land and infrastructure, service functions, the extent to which they handle cargo, and the types of cargo handled. Port authorities typically govern ports. Port authorities can be public, private, or a combination of public and private entities and tend to be classified by their function as either a landlord port, a public service/operating port, or a tool port.

Port authorities (sometimes in combination with private sector tenants) manage infrastructure that supports maritime trade. Port infrastructure for maritime trade requires high levels of capital investment and includes seaports, inland ports, and terminal facilities that have piers, bridges, warehouses, distribution centers, and logistics centers, among other types of infrastructure.6 Port authorities also often manage other capital-intensive infrastructure like airports, bridges, tunnels, roads, and nearby coastal lands.8 Port services for ships include berthing, docking, loading, unloading, and maintaining critical infrastructure, such as by dredging of navigation channels. Ports often also provide freight services, like warehousing and transshipment. Ports handle commodities, energy products, building materials, and consumer goods.

The resilience of ports is highly interconnected with the shipping industry, and the landside freight and logistics. The system involves movement of goods to, through, and beyond the port itself.

The ocean shipping industry is undergoing monumental changes regarding the way goods are moved and the way business models are applied, and the biggest risk factors are staying ahead of the bow wave and staying relevant.

Source: Representative of North American port operator

Knowledge Sharing to Build Resilience Capability

The resilience of critical infrastructure is of great importance for ports and their associated industries. A host of interdependencies linked to supply chains mean that failure of any link in the chain can have a direct impact on the food security, safety and wellbeing of populations, as well as directly affecting a local economy and its businesses. The Resilience Shift hosted a Ports and logistics round-table in November 2018 with senior industry stakeholders gathered together to explore the issues and challenges of the sector in relation to critical infrastructure resilience. As well as leading to the development of this resilience primer for ports, further research was also commissioned into global supply chains, particularly in relation to food security.
Vulnerabilities

Hazards such as acute and chronic physical climate risks and earthquakes can damage or destroy port and shipping company assets and disrupt operations, potentially affecting costs, revenues, and regional and global supply chains.

Port of New York and New Jersey (NY & NJ) is the largest port on the East Coast of the United States. When Hurricane Sandy hit the East Coast in 2012, the port handled 5.4 million shipping containers and 37 million tons of bulk cargo per year and employed nearly half a million people in the region. The port was and remains an important economic driver in the region, also housing petroleum distribution, ferry transportation and recreation.

Before the hurricane, planning resources were limited – current climate science, including information on storm surge, was not available to port planners. Federal Emergency Management Agency (FEMA) flood maps were not up to date, and hurricane plans focused on wind, not on storm surge. Hurricane Sandy caused a 14-foot storm surge that inundated areas of the port and surrounding land. Unprecedented flooding beyond the 100- and 500-year floodplains described in FEMA flood maps significantly damaged physical infrastructure such as berths and piers, and had widespread, long-lasting impacts. Saltwater intrusion took out electrical equipment, power transformers and control systems, and power outages halted commercial activity for 10 days, with some terminals out of business for longer. Lack of electricity for the oil terminals caused fuel shortages, which further delayed recovery activities and affected the surrounding community. Impacts from the storm also affected other transportation connections, as 4,500 commercial trucks and hundreds of rail cars were lost.  

LESSONS FROM INDUSTRY:
IMPACTS OF HURRICANE SANDY ON THE PORT OF NEW YORK AND NEW JERSEY
Table 1 provides examples of direct and indirect impacts of physical climate hazards and earthquakes on maritime operations.

<table>
<thead>
<tr>
<th>HAZARDS</th>
<th>DIRECT IMPACTS</th>
<th>INDIRECT IMPACTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEA LEVEL RISE (CHRONIC)</td>
<td>• Nuisance flooding&lt;br&gt;• Damage to assets&lt;br&gt;• Reduced bridge clearance</td>
<td>• Damage to connecting infrastructure (roads, rail, etc.), disrupting port operations&lt;br&gt;• Port service delays&lt;br&gt;• Damage to port reputation and brand&lt;br&gt;• Higher insurance premiums from growing global losses and claims</td>
</tr>
<tr>
<td>EXTREME PRECIPITATION (ACUTE)</td>
<td>• Damage or destruction of assets&lt;br&gt;• Equipment damage or destruction</td>
<td>• Damage to connecting infrastructure (roads, rail, etc.), disrupting port operations&lt;br&gt;• Port service delays&lt;br&gt;• Damage to port reputation and brand&lt;br&gt;• Higher insurance premiums from growing global losses and claims</td>
</tr>
<tr>
<td>FLOODING (ACUTE)</td>
<td>• Damage or destruction of assets&lt;br&gt;• Road closures&lt;br&gt;• Silt accumulation in port channels, disrupting ship traffic</td>
<td>• Damage to connecting infrastructure (roads, rail, etc.), disrupting port operations&lt;br&gt;• Port service delays&lt;br&gt;• Damage to port reputation and brand&lt;br&gt;• Higher insurance premiums from growing global losses and claims</td>
</tr>
<tr>
<td>HURRICANES/ CYCLONES (ACUTE)</td>
<td>• Damage or destruction of assets&lt;br&gt;• Power outages</td>
<td>• Damage to connecting infrastructure (roads, rail, etc.), disrupting port operations&lt;br&gt;• Port service delays&lt;br&gt;• Damage to port reputation and brand&lt;br&gt;• Higher insurance premiums from growing global losses and claims</td>
</tr>
<tr>
<td>STORM SURGE (ACUTE)</td>
<td>• Damage or destruction of assets</td>
<td>• Damage to connecting infrastructure (roads, rail, etc.), disrupting port operations&lt;br&gt;• Port service delays&lt;br&gt;• Damage to port reputation and brand&lt;br&gt;• Higher insurance premiums from growing global losses and claims</td>
</tr>
<tr>
<td>HIGH SPEED WIND (ACUTE)</td>
<td>• Damage or destruction of assets including navigation and communication equipment.&lt;br&gt;• Toppling of containers in yards</td>
<td>• Damage to connecting infrastructure (roads, rail, etc.), disrupting port operations&lt;br&gt;• Port service delays&lt;br&gt;• Damage to port reputation and brand&lt;br&gt;• Higher insurance premiums from growing global losses and claims</td>
</tr>
<tr>
<td>EXTREME HEAT (ACUTE)</td>
<td>• Buckling and rutting of asphalt and rail lines&lt;br&gt;• Work stoppages or more shift changes for worker safety</td>
<td>• Changes in agricultural production resulting in shifting trade flows</td>
</tr>
<tr>
<td>WATER STRESS (CHRONIC)</td>
<td>• Power outages for thermal power plants, which require water for cooling</td>
<td>• Changes in agricultural production resulting in shifting trade flows</td>
</tr>
<tr>
<td>EARTHQUAKES</td>
<td>• Liquefaction&lt;br&gt;• Damage or destruction of assets</td>
<td>• Damage caused by moored vessels&lt;br&gt;• Operational and port service delivery interruptions</td>
</tr>
</tbody>
</table>

Table 1
Direct and Indirect Impacts of Natural Hazards for Ports (Source: Four Twenty Seven, Inc.)
LESSONS FROM INDUSTRY:
IMPACTS OF TYPHOON MANGKHUT 2018 ON HONG KONG

The Pearl River Delta is in a coastal location at the confluence of three rivers and is at risk of flooding from typhoons, land subsidence from the weight of new construction, tidal surges, and sea level rise. Critical infrastructure, including numerous ports and airports, is in vulnerable low-lying areas. Typhoon Mangkhut in 2018 shut down Hong Kong for two days, causing more than 3 million people to evacuate and causing an estimated loss of $627 million per day, according to Swiss RE. Advance Container Lines skipped all port calls to southern China because it estimated delays of up to four days as operations returned to normal. About 100 vessels per day normally arrive at Hong Kong International Terminals, but upon reopening, more than double the amount of vessels were scheduled to arrive.
3 Barriers to resilience across the value chain

Explosion on Hyundai Fortune in 2006 causing dozens of containers to fall into the ocean. There were no casualties. The resulting fire burned for several days. (Photo by yemin, Wikipedia)
Resilience value can be defined as the value achieved through ensuring that critical functions of infrastructure are delivered and maintained in ordinary as well as extraordinary circumstances. A range of stakeholders influence resilience decision-making in the different stages of the value chain for port operations, as shown in Figure 2.

<table>
<thead>
<tr>
<th>DIAGNOSE &amp; CONCEIVE</th>
<th>DESIGN &amp; DELIVER</th>
<th>OPERATE &amp; MAINTAIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIAGNOSE</td>
<td>OPTIONS</td>
<td>PROCUREMENT</td>
</tr>
<tr>
<td>Private Finance – e.g. Investors, Lenders / Banks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public Finance – e.g. Government Programs, Development Finance Institutions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Government – Regulators, Policymakers, Planners</td>
<td></td>
<td></td>
</tr>
<tr>
<td>International Maritime Organization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insurers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port Authorities and Shipping Companies – Leadership</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port Authorities and Shipping Companies – Risk &amp; Emergency Management, Sustainability, etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public Finance – e.g. Government Programs, Development Finance Institutions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port Authorities and Shipping Companies Service Providers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local Communities</td>
<td>Environmental Groups</td>
<td>Design, Engineering, Construction Firms</td>
</tr>
</tbody>
</table>

Figure 2

Resilience value chain and key stakeholders
Figure 3 below summarizes some of the barriers that limit the introduction of more resilience measures by these stakeholders.

<table>
<thead>
<tr>
<th>BARRIERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Existing business models focused on cost reduction</td>
</tr>
<tr>
<td>• Digitalization of the business model</td>
</tr>
<tr>
<td>• Changing business model for landlord ports</td>
</tr>
<tr>
<td>• Lack of data and guidelines</td>
</tr>
<tr>
<td>• Lack of enabling environment for resilience from government</td>
</tr>
</tbody>
</table>

**DIAGNOSE & CONCEIVE**

- Lack of enabling environment for resilience from lenders and investors
- Lack of resilience standards for design and engineering

**DESIGN & DELIVER**

- Limited pricing benefits to companies that proactively minimize their risk

**OPERATE & MAINTAIN**

*Figure 3*

*Key barriers to resilience for each value chain stage*
Examples of barriers in practice

**BUSINESS MODELS OFTEN FOCUS ON SHORT TIME HORIZONS**

At ports, planning cycles, typically five to 10 years, do not align with the much longer useful life of infrastructure, typically 30 to 50 years. Together with short-term planning for the use of port resources and competition with other business needs, these factors hinder the consideration of longer-term resilience.15

Changing business models for ports also present challenges. Long-term leases, traditionally used to fund capital planning for infrastructure builds and upgrades, are being replaced by shorter-term leases. Uncertainty of future revenues from leases makes capital investments today even riskier. Other business model changes, like increased digitalization and automation, while presenting opportunities for ports, also present cyber risk which can undermine resilience.

**RESILIENCE LACKS A CLEAR BUSINESS CASE**

Ports and shipping entities are unlikely to incorporate resilience measures until there is a better understanding how these can enhance operational performance and boost bottom lines.16 For these reasons, it is currently rare for port infrastructure managers to integrate resilience requirements into requests for proposals and other bid documents, which can help to embed resilience in later stages of the value chain.

Economic decision-making does not often prioritize environmental concerns.17 The lack of data on the financial impacts of hazards further exacerbates the challenges with resilience building. Until recently, ports and shipping companies lacked data and information:

- On climate hazards and impacts at a scale aligned with planning efforts
- In timeframes matched to investor horizons (e.g., 10-20 years in addition to 50 years)
- With a degree of certainty that could usefully inform capital planning based on a detailed understanding of where and how climate hazards could affect assets and operations.18

"The biggest challenge is there is not a full appreciation of the return on investment that you get for making those [resilience] investments."

Source: Caitlin Durkovich, Director at Toffler Associates

"There are several likely reasons for this lack of action [on climate change adaptation]. Primarily, ports do not have specific information about either the types of impacts that they can expect on their facilities or of the probabilities of different impacts occurring."

REGULATIONS AND POLICIES DO NOT PROVIDE A CLEAR MANDATE FOR RESILIENCE ACTIONS

In the United States, no central national port authority exists, and subnational incentives for maritime resilience have been implemented in only a handful of states. Moreover, federal mandates around port security issues, such as those relating to sensitive national security information under the purview of agencies such as the Department of Homeland Security, are opaque.

At the local level, there have been some instances where state requirements for vulnerability assessments have moved the needle on resilience. (See Section 5.) However, local governments’ ability to spur the uptake of resilience is contingent upon political will.

LENDERS AND INVESTORS LACK DEFINITIONS AND METRICS TO EVALUATE RESILIENCE

The current lack of definitions and metrics for resilience in the maritime sector makes it difficult to allocate for resilience across the capital stack for infrastructure investment projects. Moreover, lenders and investors enter at various stages of project financing, which affects how much influence they have over the incorporation of resilience in projects. Lenders (e.g. the International Finance Corporation) that engage in later stages of project development have limited ability to influence resilience considerations, particularly in terms of engineering design.

What constitutes a ‘resilient investment’ is not yet well-defined in the maritime sector. This makes it difficult for financiers to choose or provide discounted capital for more resilient projects.

RESILIENCE STANDARDS FOR DESIGN AND ENGINEERING HAVE NOT BEEN ESTABLISHED

Definitions of resilient infrastructure will become clearer over time, through ongoing global efforts to align definitions or create a taxonomy for resilience investments, including current work by the European Union (EU) Technical Expert Group on Sustainable Finance. Midway through 2019, the Technical Expert Group is expected to publish a set of recommendations for a taxonomy of investments to support sustainable growth, including climate-resilient investments. However, without translation of these definitions into resilience standards and building codes based on input from technical experts such as design and engineering firms, ports will continue to have difficulty evaluating thresholds at which natural hazards pose real risks and determining appropriate measures for reducing impacts.


INSURANCE DOES NOT REFLECT RESILIENCE REWARDS

Maritime insurance offers limited pricing benefits to companies that proactively minimize their risk and maintain good environmental, health, and safety records. Insurance underwriters can mandate that ships be moved to safe harbors during storm events; ships that are not in safe harbors during these events may not receive claims payments.20 However, improved understanding of how future risks will differ from historical data is needed for accurate underwriting going forward. These shortcomings are important to recognize as insurance can provide a major incentive for driving the uptake of resilience.
BEST PRACTICE FOR RESILIENCE IN THE PORTS SECTOR

Grounded ship Rena on the Astrolabe reef (Photo by New Zealand Defence Force)

Ships in Yaumatei Typhoon Shelter Area, Kowloon, Hong Kong (© Arup)
4 Best practice for resilience in the ports sector

Freight containers being moved at the Port of Colombo, Sri Lanka  
(Photo by Jgmorard, Flickr.com)
While efforts to build resilience are not consistently undertaken across the maritime sector, some maritime actors already assess risks and implement resilience actions. This section highlights good practices that maritime actors are implementing and discusses why these actions are effective. Actions include better integrating internal processes, data, and planning as well as leveraging external resources and stakeholders. Our research has identified the following key measures that can enhance resilience:

**ASSESS RISKS AND OPPORTUNITIES**

Recent guidance for developing physical climate risk disclosures calls for corporations to evaluate their supply chains, operations, and markets for exposure to hazards and potential impacts. Recommendations include:

- Assess and disclose locations of key suppliers and sales by country and segment
- Assess exposure to direct impacts in the short-term (2-5 years) to medium-term (5-20 years) using a probabilistic approach (focusing on low-probability, high-impact risks)
- Use of scenario analysis to evaluate both exposure in the long-term (more than 20 years) and exposure to indirect impacts. Port operations are likely to be highly sensitive to direct impacts of storms and cyclones and extreme rainfall, but they may also suffer market risks from indirect impacts on upstream suppliers or customers

See Table 4 in the resources section for further recommendations for physical climate risk disclosure, scenario analysis, and identification of opportunities and benefits.

Further descriptions and examples of best practice are set out below and on next pages.
LESSONS FROM INDUSTRY: ASSET DATA FOR RISK ASSESSMENT

For ports, risk assessments require reliable internal data on infrastructure, including location, height above sea level, age, maintenance costs, remaining useful life, and connections to and dependencies on other infrastructure. Obtaining a good record of existing infrastructure assets can be difficult, as ports often do not have a central repository for this type of information. When the Port Authority of NY & NJ undertook a vulnerability assessment between 2008-2010, it found that infrastructure asset information was stored in many different locations. Collecting information about each asset was time consuming because it had to be retrieved from internal staff with institutional knowledge. Once this exercise is conducted, however, processes can be institutionalized, and data stored in a usable format for future infrastructure resilience decisions.

GOOD PRACTICE EXAMPLE: COLLABORATIVE FLOOD AND STORM RISK ASSESSMENT

Evaluating physical risks also requires data on hazards like flooding, earthquakes, hurricanes, and sea level rise. In contexts where there are initiatives or regulations around climate change adaptation, ports can take advantage of more readily available climate data for vulnerability assessments. As part of the Australian Geological Survey Organisation’s National Geohazards Vulnerability of Urban Communities Project, the City of Gladstone undertook collaborative research to understand flood and storm risk for city infrastructure, with support from both federal and local government. The project actively engaged local economic stakeholders including the Port of Gladstone, which contributed to the research. The results of the report, ‘Community Risk in Gladstone: A Multi-Hazard Risk Assessment,’ informed the stormwater drainage system review and upgrade work at the Port.

GOOD PRACTICE EXAMPLE: TERMINAL MARITIMO MUELLES EL BOSQUE AND THE INTERNATIONAL FINANCE CORPORATION

The International Finance Corporation (IFC) conducted a study of climate risks to Terminal Maritimo Muelles El Bosque (MEB), a terminal operator in Cartagena, Colombia. As part of its vulnerability assessment, MEB examined potential impacts to a range of port activities, including navigation and berthing, goods handling, and vehicle movement within the port. The vulnerability assessment ultimately led to an investment of $10 million into a bridge linking the port to the mainland.


“Data is king and will inform decisions much more than other factors. Data-driven decisions will be more normal in shipping and will help to make risks more predictable and cheaper.”

Source: Representative of insurance entity
In 2016, the Port of Long Beach completed its Climate Adaptation and Coastal Resiliency Plan. Through the implementation of the plan the Port sought to identify vulnerabilities, hazard exposure, risks and adaptation strategies. The Port recognized the strategic business benefit of such an effort, noting that the project benefits include “a more resilient Port able to continue operations under changed conditions [and] a Port prepared and ready to adapt.” In developing the Plan, the Port examined the climate stressors of extreme heat, sea level rise, and storm surge, and evaluated six sea level rise scenarios, mapping inundation under each scenario. The Port completed an inventory of assets such as pier and transportation infrastructure, critical facilities, utilities, and breakwaters, assessing their vulnerability to climate hazards. The Port developed more than 50 potential strategies and held workshops with employees to evaluate and prioritize them. Finally, it chose and implemented five adaptation strategies that fall under three broad categories:

**Governance**
- Addressing climate change impacts through Port policies, plans, and guidelines
- Adding sea level rise analysis to the Harbor Development Permit process

**Initiative**
- Piers A and B study – combined impacts of riverine and coastal flooding

**Physical infrastructure**
- Terminal Island SCE electrical substation protection
- Terminal Island shoreline protection

Not all the adaptation initiatives undertaken by the Port were to harden infrastructure. Some measures are financially low-impact, but high-value, like mainstreaming climate change impacts into Port policies, plans, and guidelines.
ENGAGE WITH STAKEHOLDERS

Stakeholder engagement is vital to the success of any resilience-building effort. Port operators have extensive linkages with other actors, including shipping companies, inland freight distribution companies, electric power utilities, fuel distribution systems, local water systems, emergency management agencies, and the general public. These stakeholders operate with different lexicons and may make assumptions about each other’s operations absent a more formalized stakeholder engagement process.22

One of the biggest challenges is bringing together all the different stakeholders. You can make significant strides if you can start to bring these stakeholder groups together, and not just infrastructure operators but local governments. Bringing the community together is where you have to start because at the end of the day the community is the ecosystem responsible for the long-term health of the area.

Source: Caitlin Durkovich, (Director, Toffler Associates)22

GOOD PRACTICE EXAMPLE: MULTI-STAKEHOLDER ENGAGEMENT IN RESILIENCE ENHANCEMENT

Through the Georgia Coastal Regional Resiliency Assessment Program administered by the United States Department of Homeland Security, managers and stakeholders of critical infrastructure convened to evaluate vulnerabilities and develop resilience enhancement options. Outreach and data collection took place through facilitated discussions, stakeholder interviews, and assessments and surveys of infrastructure assets. Public and private regional partners that participated in the program include the Georgia Ports Authority, Georgia Department of Natural Resources, Georgia Emergency Management and Homeland Security Agency, City of Savannah, Chatham County, Georgia Power, The Home Depot, JCB, and Target among others.
EMBED RESILIENCE IN DESIGN

Design guidelines are an essential tool to set out the expectations required and to ensure consistency of approach.

GOOD PRACTICE EXAMPLE: EMBEDDING RESILIENCE IN DESIGN

The Port Authority of NY & NJ Engineering Department implements Climate Resilience Design Guidelines that require that “the design of all new construction and major rehabilitation projects is to be evaluated based on climate change variables,” like temperature, precipitation, and sea level rise. The application of these design guidelines varies for new and existing infrastructure, as new infrastructure investments present an opportunity to site new assets in more climate-resilient locations. The Design Guidelines consider factors like flood elevation, asset service life relative to future sea level rise projections, and asset criticality, and provides links to engineering recommendations and requirements.
DELINEATE CLEAR RESILIENCE RESPONSIBILITIES

Responsibility structures for resilience can differ significantly in their design, but must be understood by everybody in the stakeholder community.

GOOD PRACTICE EXAMPLE: CENTRALIZED EMERGENCY RESPONSE AT THE PORT AUTHORITY OF NY & NJ

During Hurricane Sandy in 2012, the Port Authority of NY & NJ experienced significant impacts on its infrastructure and operations such as the diversion of 25,000 shipping containers to other ports. The Port Authority centralized emergency response in the Office of Emergency Management with the creation of a Chief Security Officer following Hurricane Sandy. The Office of Emergency Management devises policies and processes to resume port activity during catastrophic events. It conducts preparatory tabletop exercises to bridge communication across operations departments, outlines roles for disaster events, and builds in redundancies across port systems. The centralization of resilience in one office is effective for the Port Authority of NY & NJ because the Port is a large organization that manages a diverse range of infrastructure types, from maritime infrastructure to roads to airport infrastructure.23
Resilience drivers and enablers

Raising awareness of the things that will drive uptake of the good practice measures outlined above is essential to ‘move the needle’ on resilience. The following drivers and enablers are discussed further in this section:

- Investor interest and emerging regulation such as the Task Force on Climate-related Financial Disclosures
- Recognition of the importance of business continuity

INVESTOR INTEREST AND EMERGING REGULATION

The Task Force on Climate-related Financial Disclosures (TCFD) calls for disclosure of material transition and physical climate risks and opportunities to enable investors, lenders, and insurance underwriters better to assess the potential financial impacts of climate change. The emergence of climate risk disclosure requirements and growing interest from investors, regulators, and credit rating agencies will raise expectations on maritime actors to engage in this process.

BUSINESS CONTINUITY

The maritime industry is driven by growth, so business continuity is the biggest incentive for the incorporation of resilience into port plans, operations, and asset management. Leaders in the maritime sector know that resilience can ensure continuous, efficient operations and protect reputation as a reliable service provider and brand.

GOOD PRACTICE EXAMPLE: MAERSK RESPONSE TO TCFD RECOMMENDATIONS

TCFD prompted Maersk to conduct a hotspot screening of its fixed assets to evaluate the financial risks posed by physical climate hazards. Maersk assessed the impacts of heat stress, water stress, floods, sea level rise, and storms on key ports and real assets globally and also examined the impacts of these hazards on specific assets and commodities. In the next phase of its climate resilience efforts, Maersk is exploring the potential value chain impacts of physical climate risks in key markets as well as engagement with priority stakeholders to identify opportunities to build the resilience of relevant value chains.

Port operators typically assume responsibility for long-term disaster and resilience planning, but short-term economic profits, and for some ports, economic development, normally drive port planning.

HIGH LEVEL BUY-IN

When port leadership supports resilience measures it has an outsized influence on the uptake of resilience throughout the organization. An internal personality or personalities with influence and power to implement resilience can be powerful drivers. Leaders seeking to protect brand and reputation must be aware of environmental groups, the port’s economic stakeholders, municipal, state, and federal policies, customers, and local constituents. This is especially true in cases where port leadership, like a board of commissioners, is directly elected.

GOOD PRACTICE EXAMPLE: COLLABORATIVE FORUM TO CREATE BUY-IN FOR CLIMATE ACTION

The Los Angeles Regional Collaborative for Climate Action and Sustainability (LARC) has bolstered internal resilience initiatives at the Port of Los Angeles and Port of Long Beach. LARC’s membership includes government entities, regional authorities, planning agencies, academia, and non-profits. The network provides a forum to create buy-in for climate resilience and mitigation initiatives from city leadership, community members, environmental groups and other regional stakeholders. LARC also provides resources like consensus-based climate science and has helped to underscore the materiality of the issue for the ports and to raise awareness among leadership.
OWNERSHIP OF THE ISSUE AT THE DEPARTMENTAL LEVEL

Internal stakeholders can be drivers of resilience measures at ports. Resilience to disasters, including climate disasters such as hurricanes, are central to the work of port emergency management departments. Environmental departments are also tasked with building resilience by conducting vulnerability assessments, creating sustainability initiatives, and assessing and identifying measures that can build longer-term resilience. Engineering departments are crucial to implementing hard resilience measures.

ENABLING ENVIRONMENT THAT SUPPORTS RESILIENCE DECISION-MAKING

REGULATION

Government regulation can be an important lever in incentivizing port resilience. In the United States, federal mandates for security include the Maritime Transportation Security Act of 2002, which requires the U.S. Coast Guard to conduct vulnerability assessments and develop security plans for ports and ships. The National Infrastructure Protection Plan (NIPP) and Presidential Directives 7 and 21 provide frameworks to address cyber threats.27 The Department of Homeland Security has developed resilience policies and plans, but the information is not publicly shared due to its sensitive nature. No federal requirements exist for ports to address natural disaster planning.

In the subnational context, local- and state-level leadership and regulators are closely invested in the success of ports, whose operations are vital for economic activity and growth. Local governments incentivize resilience for ports through policy guidance, planning, providing climate data, and regulations that call for infrastructure to be resilient. In cities where resilience is incorporated into city and regional plans, ports have additional resources for resilience.

GOOD PRACTICE EXAMPLE: REGULATORY REVIEW OF RESILIENCE PLANS

The California State Lands Commission reviewed the Port of Long Beach Climate Adaptation and Coastal Resiliency Plan for compliance with California Assembly Bill 691, which requires land trustees to assess and address sea level rise. The Port relied on resources provided by the California Coastal Commission, an important regulatory body which provided the Sea Level Rise Policy Guidance, a framework for evaluating sea level rise risks and identifying strategies to address these risks.28 The State of California has also invested in the development of the climate data portal Cal-Adapt, which features forward-looking data on a range of climate hazards such as sea level rise and wind speed to facilitate climate risk assessments.29

Government as a lead experimenter is important. First mover costs are high, and if the federal government takes a strong role showing the sector that [resilience actions] can be done and taking away first mover risks, that will help incentivize resilience.

Source: Former US federal government official
FUNDING AND FINANCE
Governments provide support for ports in the form of funding and financing. National governments also provide resources for supporting and interconnecting infrastructure such as roads and rail. In the United States, the Federal Emergency Management Agency’s Port Security Grant Program, borne out of the 9/11 terrorist attacks, has funded over 8,000 infrastructure security projects, investing more than $2 billion over the last 16 years. The United States Maritime Administration (MARAD) has encouraged more resilient practices through its seaport investments and also provides loan guarantees under the Title XI Loan Guarantee program for shipyards, thus lowering the financial risk for maritime entities undertaking improvements and upgrades. Department of Transportation TIGER grants are available for port-related infrastructure projects. However, ports compete with other infrastructure types for this funding, and in a 2018 TIGER program funding round, only two of the 41 projects awarded went to marine port authorities. (See Section 7 for additional examples of United States government funding and financing support for port resilience efforts).

TECHNICAL RESOURCES AND SUPPORT
Though national governments do not generally control port authorities (with the exception of some instances in Europe), national governments provide support for emergency response and planning. In the United States, MARAD manages the National Port Readiness Network, coordinating emergency preparedness actions, and MARAD resources have been used during catastrophes to help manage port responses.

State and regional programs that incentivize resilience include requirements to conduct climate vulnerability assessments, coastal resilience planning, climate science initiatives, and regional collaboratives.

- The California government influences port decisions through the provision of sea level rise guidance through a key coastal regulatory agency (the California Coastal Commission) as well as of climate data that can inform ports’ physical climate risk assessments.

- In Virginia, the Hampton Roads region where the Port of Virginia is located is highly susceptible to inundation from sea level rise, as sea levels on Virginia’s coast have risen about a foot and half over the last 100 years. The Port has been involved in the City of Norfolk’s Flood Risk Management Study, the Hampton Roads Sea Level Rise and Resilience Intergovernmental Planning Pilot Project, and U.S. Department of Transportation initiatives to assess potential future impacts.

- In New York, the OneNYC plan describes resilience options, supported by climate data provided by the New York Panel on Climate Change (NPCC). The Port Authority of NY & NJ also leverages NPCC data in its infrastructure planning.
GOOD PRACTICE EXAMPLE: PORT RECOVERY UNIT

The U.S. Coast Guard’s Marine Transportation System Recovery Unit is a public-private mechanism for port recovery operations, with members including stakeholders from government and the maritime industry, formalized in 2006 partly because of significant recovery issues following Hurricane Katrina in 2004. Its objectives are to:

- Coordinate and facilitate port recovery activities
- Track and report the status of marine recovery
- Recommend courses of action to port leadership
- Resume safe, secure maritime commerce after port disruption
- Provide a forum for all stakeholders

Source: U.S. Department of Homeland Security

The MTS-RU had established open lines of communication and trust among its members and outlined clear responsibilities for disaster events ahead of Hurricane Sandy in 2016. These relationships and procedures were instrumental in the Port’s recovery efforts.

During Hurricane Sandy MARAD also sent ships to provide housing at the Port of NY & NJ, which defrayed hotel costs.
Opportunities for building resilience
First and foremost, ports are concerned with continued financial viability in the face of rapid market, technological, and policy shifts. Secondly, ports are focused on meeting regulatory requirements. Industry standards around resilience are scant, though there is some regulation around maritime safety and the groundwork has been laid to codify cybersecurity standards.

Various decision points where resilience considerations can enter include:

**Windows of opportunity following extreme events**
(see box on ‘post-disaster windows’).

**Regular planning processes**
for operations, maintenance, and capital investments such as infrastructure upgrades, new infrastructure projects, or disposal of existing infrastructure.

**Changes in the broader enabling environment**, like new regulations or policy requirements around resilience.

Local economic, policy, and cultural contexts shape opportunities for resilience and the nature of resilience actions. Resilience measures, drivers, and enablers presented in Section 4 are focused on the United States, but the examples provide useful insights into the types of actions that maritime entities can take to build and/or incentivize resilience.

*The Chinese are laser focused on efficiency and operations so they can compete and succeed in the world market. They’re growing quickly and recognize that they can only do so by looking at resilience, enhancing their ability to be productive.*

Source: Former US federal government transportation official
POST-DISASTER WINDOWS AS AN ENTRY POINT

Known to the Dutch as the Disaster, in 1953 1,800 people were killed when the sea overtopped existing protective infrastructure. The disaster led to the creation of the national program Delta Works and the eventual construction of the Maeslantkering, a sea gate with 70-foot storm surge barriers protecting the Port of Rotterdam.
Organizational level

Developing on the best practice, drivers and enablers identified in Section 4, the following actions are recommended at an organizational level:

- **Integrate resilience into existing systems and processes**

- **Embed resilience in design**
- **Delineate clear resilience responsibilities**
- **Engage stakeholders to obtain buy-in and support as well as collaboratively assess risks and identify resilience opportunities**

ASSESS RISKS AND OPPORTUNITIES LEVERAGING EXISTING RESOURCES

Building resilience starts with understanding which hazards pose a material risk and what the potential impacts of these hazards may be. Disasters provide maritime actors with firsthand experience and information about risks and vulnerabilities. But this reactive response is clearly not the best approach to gathering data on risk. Industry leaders undertake forward-looking exposure and vulnerability assessments, gathering necessary internal and external data for decision making.

As discussed in Section 4, leaders in the sector are helping to define good practices for assessing exposure and vulnerability to physical climate risks. For a maritime entity seeking to better understand its risks and vulnerabilities to lay the groundwork for resilience actions, critical steps are:

1. Create a central repository of infrastructure information including location data (e.g. latitude and longitude, height above sea level and linkages with other infrastructure), data on remaining useful life, relevant structured finance indicators from project finance documents (e.g. capital expenditures, maintenance and operations costs), and a survey of damage from past events and the associated costs.

2. Gather climate data on physical climate hazards such as sea level rise, flooding, hurricanes/cyclones, extreme rainfall, heat stress and water stress, leveraging best available existing data and/or engaging relevant technical expertise.

3. Understand the likelihood of impacts from these hazards on physical infrastructure and operations through risk analysis.

Assessing risks will enable shipping companies and ports to respond to market pressures for improved disclosure of material climate risks. Resources are available to help maritime entities evaluate and disclose physical climate risks, such as the report “Advancing TCFD Guidance on Physical Climate Risks and Opportunities.”

The report provides guidance on scenario analysis as well as on which hazards, timeframes, and value chain aspects a company should consider examining.

INTEGRATE RESILIENCE INTO EXISTING SYSTEMS AND PROCESSES

These ‘soft’ measures are generally less expensive than hardening infrastructure and can be considered low-hanging fruit that enables proactive response to risks and leveraging of potential opportunities.

Maritime actors can incorporate resilience into emergency management guidelines, safety culture documents, business continuity plans, infrastructure operations and maintenance guidelines, and sustainability plans.
Ports and shipping companies can make management systems more resilient by building in redundancies, conducting tabletop exercises, and systematizing cross-departmental communications and collaboration. Ports can optimize insurance by better coordinating and aligning coverage across tenants. Examples of systems, processes, and plans where resilience should be incorporated include:

- Existing internal and external plans (e.g. transportation plans)
- Emergency response preparation
- Long-range planning for hazard mitigation (hazard-specific plans)
- Management systems’ training on specific hazards (e.g. climate hazards, earthquakes, cyber threats)
- Coordination with governments and supply chain linkages on hazards and resilience plans
- Research
- Purchase of additional insurance coverage
- Coordination of insurance policy provisions among port businesses.

**EMBED RESILIENCE IN DESIGN**

Maritime actors can embed resilience in design and operational stages of both greenfield and brownfield infrastructure across the stages of the value chain. New infrastructure builds present an opportunity to embed resilience into the design from the start of the project, such as considering future sea level rise before selecting a site for a new pier or choosing building materials that can withstand future extreme heat. In the project design stages (Diagnose and Conceive, Design and Deliver), opportunities exist to consider built infrastructure options as well as ecosystem-based measures such as protecting adjacent marshlands or mangroves that serve as a sponge for floodwater.

Key steps for embedding resilience in design include:

- Hiring experts or utilizing existing resources to gather usable climate data or other risk data
- Evaluating new or existing builds for risk based on asset location (e.g. in a floodplain or hurricane zone), anticipated service life (for long-lived assets changes in future conditions must be considered), and asset criticality
- Developing guideline documents that outline steps for engineering departments. Engineering guidelines should include examples of hard infrastructure measures that can be taken, such as architecture, civil, landscape architecture, mechanical, electrical, structural, and geotechnical options. Design and engineering measures to enhance resilience include considering hazard exposure when selecting sites, investing in higher wind-rated roofs, elevating roadways to accommodate sea level rise, incorporating water-absorbent landscapes, improving drainage, preserving trees for temperature regulation, and building in system redundancies.

**DELINEATE CLEAR RESILIENCE RESPONSIBILITIES**

Establishing an office or role dedicated to resilience can ensure that resilience is adequately considered throughout a maritime entity’s operations. A dedicated office of emergency planning, sustainability department, or chief security officer can organize tabletop exercises and facilitate cross-departmental dialogue so employees understand what to do in a crisis before it hits. Offices of emergency planning prepare employees for disasters, minimizing confusion during stressful events. A dedicated office also opens and maintains lines of communication with outside agencies that provide help in a crisis event.
Having established connections with outside resources like MARAD’s National Port Readiness Network or the Coast Guard MTS-RU helps speed recovery following disaster or crisis events and ensures operations recover fully. This office or role can also champion resilience issues with leadership, making the case for resilience when needed and helping to ensure allocation of budget to crisis preparation and response.

**ENGAGE STAKEHOLDERS TO OBTAIN BUY-IN AND SUPPORT AS WELL AS COLLABORATIVELY ASSESS RISKS AND IDENTIFY RESILIENCE OPPORTUNITIES**

Obtaining buy-in from key internal and external stakeholders is critical to resilience efforts. Ports often exist on large plots of land within the context of a city and community. By actively engaging with community and economic stakeholders, organizations can better understand and proactively manage risks “beyond the fence”. Awareness of the broader context of physical operating environments, for instance by engaging with regional collaboratives or neighboring critical infrastructure managers is essential, as is awareness of interconnections within value chains. Hazards in one part of the value chain often have knock-on effects further down the chain; thus, the structure of the maritime ecosystem requires collaboration around resilience efforts.
Sector-wide

Building on the best practice identified in Section 4, the following sector-wide opportunities to embed resilience are presented:

- **Define and standardize resilience**
- **Formulate a clear business case for implementing resilience measures**
- **Establish an enabling environment that facilitates risk assessment, risk reporting, and implementation of measures to address risks and build resilience**

GLOBAL ACTION TO DEFINE AND STANDARDIZE RESILIENCE

Facilitating broad implementation of resilience measures within the maritime sector requires developing a shared understanding of what resilience looks like, including principles and criteria for integrating resilience considerations into decision-making and a catalogue of resilience projects and technologies. The maritime sector can leverage existing industry associations to define resilience, create buy-in for industry resilience standards, and enable learning among industry peers. The maritime sector can also benefit from broader global efforts seeking to develop definitions for resilience and learn from individual actors’ good practices, identifying decision points to incorporate resilience and testing strategies to build resilience through pilot projects.

Uptake of sector-wide principles and criteria calls for a process that involves the perspectives and input of key sectoral stakeholders such as ports, shipping companies, policymakers, regulators / IMO, lenders and investors. Leverage existing efforts and forums that already successfully convene relevant stakeholders to advance a shared agenda can help to gain buy-in. Examples include the Global Maritime Forum which promotes cross-sectoral dialogues to tackle priority issues such as decarbonization and digitalization, and the Poseidon Principles, which are a set of guidelines under development for banks to integrate resilience and sustainability considerations in dealings with shipping companies. Industry associations like the Global Maritime Forum, Baltic and International Maritime Council, the World Association for Waterborne Transport Infrastructure (PIANC) and American Association of Port Authorities provide a forum for industry stakeholders to share experiences and good practices and coordinate on priority issues.

Voluntary certifications also provide opportunities for maritime actors to demonstrate good behavior and share good practices while supporting the standardization and uptake of resilience principles. For example, Green Marine is a member-driven organization that provides a rigorous and transparent certification process. The certification is based on agreed standards that seek to demonstrate improvement in maritime actors’ efforts to tackle sustainability issues year to year and is backed by external verification.
OPPORTUNITIES FOR BUILDING RESILIENCE

The Role of Industry Associations

Following Hurricane Katrina in 2005, the American Association of Port Authorities convened five workshops of the Emergency Planning and Disaster Recovery Working Group to devise best practices and a space to share experiences of past disasters among ports. This culminated in a manual containing best practices on disaster preparedness planning, "Emergency Preparedness & Continuity of Operations Planning Manual for Best Practices." This framework demonstrates a workable model that could be expanded or reimagined to incentivize resilience at scale.

Build the Knowledge Base to Support a Business Case for Resilience

A clear business case for investment will spur industry-wide resilience action. It takes time and experience to build the evidence base needed to bolster the business case for resilience.

Many decision points exist in the infrastructure life cycle for ports and shipping companies to make resilience decisions, such as retrofitting older infrastructure to be resilient or integrating resilient design features into new builds. Quantification of the risks and benefits that are derived from forward-looking resilience investments can help maritime stakeholders weigh the costs of inaction against the costs of proactive measures to address risks and build resilience. Climate risk impact modeling tools, research, and services as well as information on the costs, benefits, and payback periods associated with resilience projects or measures will provide a critical knowledge base.

Because this information is not yet widely available, maritime actors currently must rely on past experience with infrastructure damage or upgrades or on bespoke analysis provided by specialist engineering and climate analysis firms. The Resources section lists additional sustainability assessment tools for climate-resilient infrastructure.

It tracks a range of indicators including greenhouse gas and air pollutants, spill prevention, community impacts, and environmental leadership. Green Marine also helps organizations stay ahead of regulation and have a voice in sector progress and change. The issues Green Marine tackles are raised by member-driven working groups which survey trends and changes in the maritime industry. Green Marine's framework demonstrates a workable model that could be expanded or reimagined to incentivize resilience at scale.

In defining and standardizing resilience, the maritime sector can also build on relevant existing initiatives seeking to define resilient investments more broadly, such as those by the EU Technical Expert Group, the World Bank, and the IFC. The EU Technical Expert Group is actively working now to develop a process for identifying adaptation projects and activities. The World Bank and IFC are rolling out a rating system for lenders and investors to assess project-level climate resilience and risk. For each grade, the rating system stipulates minimum sector-specific methods, including climate information, that need to be incorporated into project design and operations. These metrics are expected to become publicly available in 2019 and can inform both ports’ development of infrastructure projects and investors’ evaluation of these projects.
ESTABLISH AN ENABLING ENVIRONMENT THAT SUPPORTS RESILIENCE DECISION-MAKING

Risks, vulnerabilities, and resilience options can be better understood through a more supportive enabling environment for resilience. In moving from assessing risks and vulnerabilities to planning for resilience, information on measures to fortify infrastructure as well as operational measures to build resilience is needed.46

Understanding the conditions under which a measure will be useful, as well as knowing its costs, benefits, and implementation process will help to evaluate and select appropriate resilience measures. National and regional government programs, regional collaboratives, engineering, procurement and construction firms, and academic institutes, are critical components of the enabling environment to support resilience.

National governments can help to reduce the reputational and financial risk of being an early adopter of resilience measures by providing a clear regulatory environment as well as funding for research and pilot projects of new technologies.

National programs like the Regional Resiliency Assessment Programs by the United States Department of Homeland Security build a knowledge base of best practices and measures taken to build resilience across the country. FEMA preparedness grants help offset costs, and some national governments build in funds to support the maintenance and upgrades of critical infrastructure. Loan guarantees from the United States Maritime Administration help reduce first mover costs, as they did for TOTE, Inc., which was an early mover in converting liners to liquefied natural gas fuel.47

Beyond funding and loan guarantees, governments can also provide necessary research and development assistance for precommercial technologies.

United States Department of Transportation University Transportation Centers (UTC) provide research funding for state-of-the-art transportation technology and training for transportation professionals.48 MARAD’s Maritime Academy provides support in this area through various educational programs for port operators and shipowners.49 The Transportation Research Board of the National Academies of Science, Engineering and Medicine also contributes research for the maritime transport industry.

At the local level, governments can incentivize resilience actions through regulations that require the integration of resilience considerations. Requirements include embedding resilience in procurement bid documents and local building code and design standards.

PROMOTE MULTI-STAKEHOLDER COLLABORATION

At the regional level, collaboratives ranging from Rotterdam to California have played an important role in bringing together cross-sectoral stakeholders to share information and lessons learned while sometimes also fostering collaboration on collective resilience priorities.

In Rotterdam, collaborating across industries and government is common practice. The city participates in a multitude of global climate resilience-focused projects, including C40, 100 Resilient Cities, and the Global Center on Adaptation. The drive for Rotterdam to innovatively address resilience is not only about self-preservation; its continued participation in these global forums incentivizes the city to share its expertise and continue to prioritize climate resilience throughout the city.
Conclusions

Maritime actors can and must take action now to enhance resilience. As investors, rating agencies, and regulators increasingly call upon ports and shipping companies to take account of risks, actors that assess and address the resilience of their systems proactively will have a competitive advantage.

A proactive approach to risk management and building resilience will also enable ports and other maritime actors to stay ahead of the sectoral shifts in business model, logistical, and technology trends that are redefining the industry.

By demonstrating their leadership on resilience issues, maritime actors will effectively contribute to both their own and broader systemic resilience, helping to ensure the communities and economies of which they are an integral part thrive even in the face of changing risks.
Supplementary information
List of Acronyms

EU  European Union
FEMA  Federal Emergency Management Agency
IFC  International Finance Corporation
IMO  International Maritime Organization
LARC  Los Angeles Regional Collaborative for Climate Action and Sustainability
MARAD  United States Maritime Administration
MEB  Maritimo Muelles El Bosque
NIPP  U.S. National Infrastructure Protection Plan
NJ  New Jersey
NPCC  New York City Panel on Climate Change
NY  New York
PIANC  World Association for Waterborne Transport Infrastructure
TCFD  Task Force on Climate-related Financial Disclosures
TIGER  Transportation Investment Generating Economic Recovery
UTC  United States Department of Transportation University Transportation Centers

Interviewees

Justin Luedy, Environmental Specialist, Port of Long Beach
Michael Christensen P.E., C.M., Deputy Executive Director, Facilities Maintenance and Utilities Group, Los Angeles World Airports; former Deputy Executive Director, Port of LA
Molly Campbell, Advanced Leadership Fellow, Harvard University; former Director of the Port Department, Port Authority of NY and NJ
Michael Parker Global Industry Head for the Shipping, Logistics and Offshore, Citigroup
Michael Lowder, Principal, Michael W. Lowder & Global Associates; former Director, Office of Intelligence, Security and Emergency Response, U.S. Department of Transportation
Chris Bhatt, Head of Sales, Global Marine, Aon
Caitlin Durkovich, Director at Toffler Associates; former Assistant Secretary for Infrastructure Protection, Department of Homeland Security
Captain Robert Wagner, Senior Associate Toffler Associates; former U.S. Coast Guard
Vladimir Stenek, Senior Climate Change Specialist, IFC
Eleanor Kirtley, West Coast Program Manager, Green Marine
David Matsuda, Principal at Matsuda & Associates; former Administrator, MARAD
Philip J McMahon, CPCU, ARM, Account Executive, Paul’s Agency
# Relevant Resources

**Table 4**

Recommendations for disclosing physical climate risks and opportunities and scenario analysis

<table>
<thead>
<tr>
<th>Recommendations for the disclosure of physical climate risks</th>
<th>SUPPLY CHAIN</th>
<th>OPERATIONS</th>
<th>MARKETS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Hazards</td>
<td>Assess exposure to heat stress, extreme rainfall, drought, cyclones, rising sea levels, wildfire and other industry-relevant and/or locally specific climate hazards across the corporate value chain</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Timeframe</td>
<td>Assess exposure to first-order (direct) impacts in the short to medium term (2-5 and 5-20 years) using a probabilistic approach; use scenario analysis for long-term risk (more than 20 years) and possible exposure to second-order (indirect) impacts.</td>
<td></td>
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<tr>
<td>3. Level</td>
<td>Location (country or city) of key supplier facilities and a measure of their importance</td>
<td>Location (country or city) of critical business facilities (such as production or support systems) and key distribution or logistics sites, as well as a measure of their importance</td>
<td>Breakdown of sales by country and by segment</td>
</tr>
<tr>
<td>4. Impacts from recent extreme weather events</td>
<td>Decreased production capacity due to supply-chain interruption</td>
<td>Reduced revenues, including situations where a significant number of staff members are unable to get to work</td>
<td>Reduced revenues from lower sales due to the consequences of extreme weather events</td>
</tr>
<tr>
<td>5. Impacts of weather variability</td>
<td>Increase in supply-chain costs due to changes in the availability of commodities</td>
<td>Increase in opex (energy costs, negative impacts on the workforce)</td>
<td>Reduced revenues from lower sales due to variability in the weather</td>
</tr>
<tr>
<td>6. Future risks of climate change</td>
<td>Suppliers or commodities likely to be affected by climate change</td>
<td>Number of sites and business lines exposed to relevant impacts of climate change</td>
<td>Markets or sales likely to be affected by climate change</td>
</tr>
<tr>
<td></td>
<td>Value-at-risk (VaR) from 1:100 or 1:200 and annual average loss projections from disruption to key supplier(s)</td>
<td>Projected change in production, revenues, opex or capex due to climate change</td>
<td>VaR from 1:100 or 1:200 loss projections from impact on key customer(s) or markets</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VaR from 1:100 or 1:200 impact on operations or production</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Annual average losses from projected impacts of climate change</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Physical climate risk management and climate resilience strategy</td>
<td>Supply-chain risk management strategy</td>
<td>Insurance and risk management instruments and total cost of risk (net risk exposure after risk management)</td>
<td>Logistics, distribution and sales risk management strategy</td>
</tr>
<tr>
<td></td>
<td>Engagement with suppliers to help identify, assess and manage climate-related physical risks</td>
<td>Planned improvements, retrofits, relocations, or other changes to facilities that may reduce their vulnerability to climate impacts</td>
<td>Engagement with distributors and key customers to help identify, assess and manage climate risk</td>
</tr>
<tr>
<td></td>
<td>Engagement of suppliers with local and national governments to identify, assess and manage these risks</td>
<td>Engagement with local or national governments and local stakeholders on local climate resilience</td>
<td></td>
</tr>
</tbody>
</table>
### Recommendations for the disclosure of physical climate opportunities

<p>| | |</p>
<table>
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</table>
| **8. Opportunities** | Identify opportunities inherent in managing existing and emerging physical climate risks  
Identify opportunities based on adapting to market shifts driven by a changing climate |
| **9. Timeframe** | Assess and disclose opportunities using an adequate timeframe, according to the industry and the type of opportunity:  
- snapshot of current context (shortest timeframe)  
- business planning timeframe  
- asset lifespan (longest timeframe) |
| **10. Level** | Disclose physical climate opportunities at the segment level  
Disclose climate resilience benefits at the facility level for critical facilities |
| **11. Metrics for climate resilience benefits** | Disclose benefits of climate resilience investments using the same metrics that are used for the disclosure of physical climate risks  
In addition, whenever possible, assess and disclose public co-benefits from climate resilience investments (in other words, the wider economic benefits of managing physical climate risks) |
| **12. Metrics for business opportunities** | Disclose qualitative information on the lifecycle of a new commercial opportunity, including:  
- the development stage of an endeavour  
- the business area and connection to company's core business  
- the size of the potential market  
- the approximate timeframe for commercial viability |

### Recommendations for scenario analysis disclosures

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>13. Climate scenarios</strong></td>
<td>Consider current and ‘aspirational’ greenhouse gases concentration pathways and related warming projections as a basis for scenario analysis of physical climate risks and opportunities</td>
</tr>
<tr>
<td><strong>14. Motivation</strong></td>
<td>Integrate scenario analysis of physical climate risks and opportunities into existing planning processes to ensure strategic, flexible and resilient businesses and investments</td>
</tr>
<tr>
<td><strong>15. Scenario building</strong></td>
<td>Avoid standardised scenario analysis in order to have a more comprehensive range of outcomes</td>
</tr>
<tr>
<td><strong>16. Data</strong></td>
<td>Consider data from a wide variety of sources and scales when developing scenario analysis of physical climate risks and opportunities</td>
</tr>
<tr>
<td><strong>17. Scientific uncertainty</strong></td>
<td>Take account of scientific uncertainty inherent in climate data and in scenario analysis of physical risks and opportunities</td>
</tr>
</tbody>
</table>
| **18. Scenario analysis and disclosures** | Disclose qualitative information that is relevant to the company and its investors  
- Consider scenario analysis of physical climate risks and opportunities as an initial step towards building climate resilience |
<table>
<thead>
<tr>
<th>Agency or Department</th>
<th>Program Name</th>
<th>Exclusive for maritime?</th>
<th>Amount per year (unless otherwise noted)</th>
<th>Use of Funds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Department of Homeland Security - FEMA</td>
<td>Preparedness grants</td>
<td>No</td>
<td>$2.5 billion[^42]</td>
<td>Grantees (state and local governments, tribal groups, non-profits, ports, transit systems, etc.) can use grants for planning, equipment purchase, training, conducting exercises, personnel and operational costs</td>
</tr>
<tr>
<td>Department of Transportation – MARAD</td>
<td>Federal Ship Financing Program (Title XI)</td>
<td>Yes</td>
<td>$2 billion currently outstanding in loan guarantee portfolio[^45]</td>
<td>Loan guarantees to private companies for ship construction and modernization of shipyards</td>
</tr>
<tr>
<td>Department of Transportation – MARAD</td>
<td>Capital Construction Fund</td>
<td>Yes</td>
<td>No set amount – tax deferral program</td>
<td>Tax deferral program allowing vessel owners and operators to defer federal income taxes for construction, reconstruction or purchase of vessels[^46]</td>
</tr>
<tr>
<td>Department of Transportation</td>
<td>TIGER (Transportation Investment Generating Economic Recovery) grants</td>
<td>No</td>
<td>$500 million</td>
<td>Funding for any public entity in the U.S. for road, rail, transit, bicycle, port and multi-modal projects[^47]</td>
</tr>
<tr>
<td>Department of Transportation</td>
<td>Marine Highway Program</td>
<td>No</td>
<td>$5 million</td>
<td>Promotes short sea transport, or the use of marine transportation where landside transportation is currently used instead[^48]</td>
</tr>
</tbody>
</table>

[^41]: Assessments of critical infrastructure, including regional analysis of surrounding infrastructure.
[^42]: $2.5 billion.
[^43]: $390 million.
[^44]: $100 million.
[^45]: $2 billion currently outstanding in loan guarantee portfolio.
[^46]: No set amount – tax deferral program.
[^47]: Funding for any public entity in the U.S. for road, rail, transit, bicycle, port and multi-modal projects.
[^48]: Promotes short sea transport, or the use of marine transportation where landside transportation is currently used instead.

- U.S. National Oceanic and Atmospheric Administration PORTS system: https://tidesandcurrents.noaa.gov/ports_info.html
- Voluntary sustainability ratings for climate resilient infrastructure:
  - Infrastructure Sustainability Rating Tool (Australia)
  - CEEQUAL (UK)
  - ENVISION (US)
  - SURE Infrastructure Resilience Standard


16. Lowder, Michael (Principal, Michael W. Lowder & Global Associates; former Director, Office of Intelligence, Security and Emergency Response, U.S. Department of Transportation), Interview by Yoon Kim and Lindsay Ross. Phone interview, February 5, 2019.


22. Durkovich, Caitlin (Director, Toffler Associates). Interview by Yoon Kim and Lindsay Ross. Phone interview, December 14, 2018.

23. Strunksy, Steve, “Port authority puts Sandy damage at $2.2 billion, authorizes $50 million to power wash PATH tunnels,” (NJ Advanced Media, 2013).


35. Luedy, Justin (Environmental Specialist, Port of Long Beach. Interviewed by Yoon Kim and Lindsay Ross. Phone interview. December 13, 2018.


42. Kristiansen, Tomas. “Big banks incorporate climate considerations into shipping loans.” (ShippingWatch, October 10, 2018). https://shippingwatch.com/secure/carriers/article10914903.ece


Due to navigation errors near the Astrolabe Reef, the Rena ran aground near Tauranga, New Zealand, resulting in an oil spill. (Photo by New Zealand Defence Force)