The Development of a Seasonal Event Matrix, a Case Study for the Mobile County Maritime Sector

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Abstract

Waterways and navigation operate within the context of complex systems complicated by changing seasonal patterns that are both man-made and climate-driven. Given the discussion on climate change adoption, linking seasonal patterns to discussions on sustainability may be of interest to various transportation stakeholders. By managing the categories around the three E's of Sustainability: Environment, Equity, and Economics, the Seasonal Event Matrix (SEM) was developed as a structured way to highlight these events, no matter how large or small. The SEM provides a framework for considering operational and monthly events that may be tied to climate change resiliency goals and understanding how events influence other actions through a navigation system. Using a mixed approach of published information and local knowledge, the authors created a matrix of routine, predictable events in Mobile County, Alabama. The paper concluded that such a matrix could be developed using published sources, but the model does need to be verified with local knowledge. The framework to collect and organize these events to assist port managers, operators, and other interested parties in identifying the essential events in a particular waterway sector, which capture the "rhythm of a place".

Keywords: maritime, weather, seasonal, risk, data, sustainability

1. Introduction

Navigation operations occur within a complex system, providing transportation services along ports, rivers, and waterways. That complexity is driven by the different factors influencing navigation, ranging from equipment failures, catastrophic disruptions (man-made or natural) to seasonal variability (water levels, precipitation, etc.). This concept was summarized as "a common interest for all shipping industry stakeholders is safe and accident free shipping", although the paper estimated that 80-85% of all marine accidents in the United Kingdom were related to human factors, the authors did not account for seasonality in the analysis.(Hasanspahić et al., 2021) Seasons matter as maritime disruptions can occur from wind, temperature or flooding. Some events are minor, while some are significant. These changing weather patterns are also part of the focus on addressing climate change and, for waterways, resiliency. With the increasing emphasis on sustainability objectives (including more utilization of inland navigation and decarbonization) and minimizing supply chain disruptions, there is a growing need to understand baseline navigation activities and how to manage the system more effectively. This process involves considering the impact of seasonality on waterways, including water levels, fishing habitats, and boating activities. Weather systems, such as winter storms and hurricanes, also influence the types of activities that occur, the

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associated risks, and the available capacity for navigation operations. In all things, every place has its unique rhythm and way of living as communities change throughout the year.

The maritime space, defined as ports and waterways, exists in the context of natural (climate) and man-made phenomena. Climate, described as the ongoing nature of weather within local geography, generates predictable seasonal patterns which drive weather, temperature, and rain. For inland navigation, this is further complicated by the water cycle, as rainfall moves through rivers, aquafers, etc., toward the sea. Humans can respond to and shape their environment by engaging in seasonal activities. Allan described it as "Ports operate within an environment that is driven by natural processes such as tides, currents, and climate, as well as marine biology, society, and man-made processes." (J. Allan & Allan, 2008) As such, seasonality influences many things at the port.

For example, the lower Mississippi River (Baton Rouge to the head of passes) in October can experience weather activities such as hurricanes, heavy fog, and low water conditions while experiencing the start of the grain export season. In April, the same section of the river may be experiencing high water and fog, but not hurricanes, while the grain season peak has finished. It is the same river system in some ways, but its conditions and potential events can change over a year. (If one compared this to a point further upriver, such as St. Louis, Missouri, there would not be a Hurricane Season or Marine Fog, as the timing of seasonal variability along longer river stretches may change.)

Table 1. Comparison of General Patterns on the Lower Mississippi River, Source: Authors

October			April		
Environment	Equity	Economics	Environment	Equity	Economics
Low Water	Limited Flood Risk Lock and Dam Inspections, Repairs	Draft Restrictions	High Water	Potential Flooding Events	Towing Assistance
Hurricane Season	Hurricane Response	Hurricane protocols			
Marine Fog Season		Vessel sailing restrictions may exist			
		Start of Grain Season			Northbound fertilizer shipments
			Seasonal Thunderstorms		Rain delays

Of the patterns listed in Table 1, these are known events and exclude such things as terrorist attacks, earthquakes, etc., although potentially catastrophic, do not occur on a predictable basis as the weather. However, weather patterns change within known parameters, although their duration, scale, and intensity may not be forecasted accurately. This concern leads to overstating the obvious; mariners need to know weather patterns to plan and execute their navigation plans accordingly. Many stakeholders are involved in navigation, such as carriers, cargo owners, and people concerned about the conditions of the associated navigation channels. The system's complexity in many ways means multiple stakeholders with different information needs beyond the maritime community.

Given the complexity of the interactions in the maritime domain, including natural processes such as tides, currents, climate, environmental concerns, other social goals, and man-made processes, there is a need for a structured approach to examining regular, predictable occurrences along waterways. Such a framework, created from various publicly available resources, can be fact-checked against local, tacit knowledge collected through user interviews/meetings but can be used as a baseline for other regional, seasonal discussions.

This paper proposes the development of a seasonal event matrix (SEM) based on data/inputs that provides insights into monthly operations and other regional activities that could influence navigation and its related stakeholders. The SEM matrix can assist stakeholders in understanding known seasonal events to develop the appropriate training, operations, and risk management strategies. This paper seeks to demonstrate that such a seasonal event matrix addresses seasonal weather patterns and is helpful for maritime domain awareness and possible linkages to climate change. By applying the seasonal event matrix to a particular port, the authors seek to demonstrate its usefulness for practitioners. The paper does this by:

- Reviewing the literature regarding maritime-related events,
- Discussing seasonality and casual events within the maritime systems,
- Developing a matrix combining different elements allows for examining known events and seasonal activities.

2. Literature Review

Many common phrases about weather conditions exist in many cultures, especially in forecasting weather patterns ("red skies at night, sailor's delight" or "April Showers Bring May Flowers"). Mr. Gooley explains how nature wants to tell us what is happening now or in the immediate future.(Gooley, 2017) However, most people do not have the time or energy to sit and observe their local environment, but in a description of the relationship of seasons to human activity, there are many ways to frame this complex challenge. One could focus on process, regulatory control, area of activity, etc. Still, the evolving field of hydrosociology has focused on the differences in engagement with different sectors, such as agriculture and navigation, with water resources. The real challenge is that navigation discussions appear to be driven by two topics: addressing climate change through decarbonization strategies or encouraging resiliency. This paper will focus on resiliency, but rather a subset of that discussion, namely identifying seasonal patterns, both natural and man-made, that influence water/navigation systems. Such a focus is consistent with looking at weather through its relationship with humans, such as discussed in "Disaster by Choice" (Kelman, 2020) or the UN (United Nations)

The challenge is that we must consider these factors related to drivers – who or what occurs and how this changes the relationship with other users. In this required, equity mirrors stewardship as one aspect of natural resource management. Still, it also captures in its meaning environmental justice and other human aspects related to managing the waterway as a public space. This methodology means managing water resources and looking at the human desires related to the waterway, environmental concerns, and quality of life issues. The way to consider this is when "the environment (weather) is what is occurring", equity is how we regulate and define what occurs within that space, while economics is the human activities permitted to occur, in this case, navigation. This structure better aligns with the need to monitor and improve regional system resiliency.

For example, in Figure 1, a Heavy Participation event may lead to different things in a system. Heavy rains will lead to flooding, affecting human factors, such as mental and physical health, knowing that equipment must be secured, and the region, especially if people must evaluate. Operationally, people must consider what to ship, what mode, or whether the service will be available. Flooding can destroy hard infrastructure assets like docks, piers, or even power structures and roadways. Finally, there is the cargo itself, which could be lost if a barge sinks. Even after the flood levels decrease, there is a need to monitor, assess and determine a path to recovery. This one flood can lead to feedback loops to better understand, train and prepare for the next potential flood. Moreover, with the growing information of river information and the digitalization of vessels, it is possible to link vessel movements to water conditions. For example, estimating port resiliency indicates that such events can be modeled with existing databases to improve overall efficiency by understanding river conditions.(Dhanak et al., 2021) By using River Information Services, estimations on relationships with the inland river system could be modeled to evaluate relationships among various elements, such as available berths, channels, and lock availability.(Specht et al., 2022) Such systems are essential, but a waterway has more elements than channels, berths, and locks.

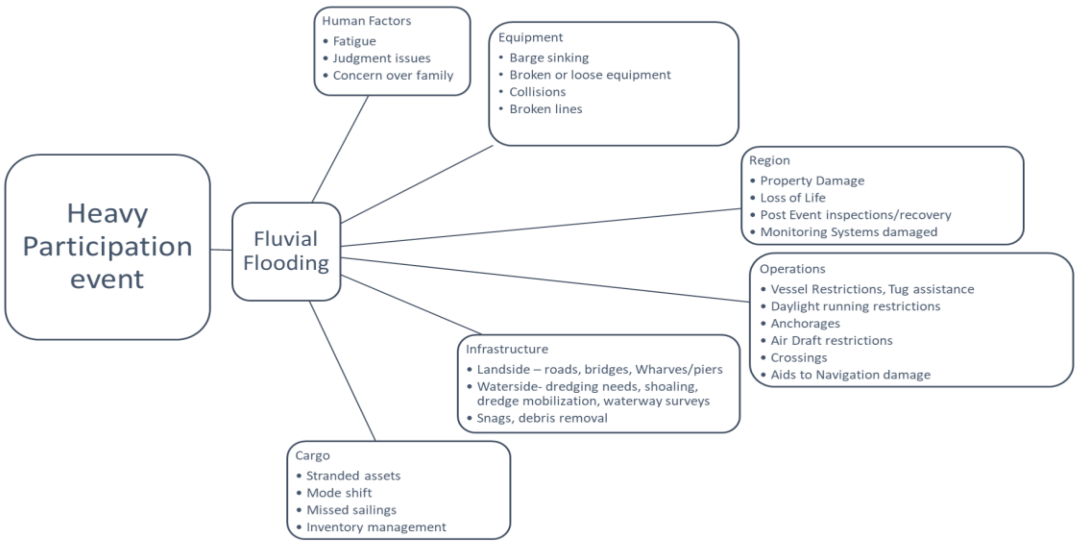

Figure 1. Some of the events that may occur during a flood event (source – authors)

In many ways, these casual chains can have implications for

- Human Factors- how people plan, respond, train, communicate, and work
- Equipment – Vessels, trucks, barges, basically, moveable or mobile assets
- Region – the broader region upon which the navigation system (city, county, etc.)
- Operations – how business occurs, such as communications or legal structures, but also the relationship among third parties (barges, labor, etc.), which includes regulators.
- Infrastructure – the physical assets, both land and waterside, that support navigation-related activities, such as cranes, pipelines, roadways, docks, etc.
- Cargo - the goods or related transportation service provided, often not owned by the firm engaged in transportation.

The acronym HEROIC is specific, as a response is often seen as dramatic, going beyond or engaging in some calls to a "higher purpose", but at the same time, a heroic reaction to an event can decay over time. [*]

The literature review's challenge is that there are both academic and practical resources. For example, the National Risk Inventory lists the following attributes within a waterway sector. There are eighteen natural hazards. Some of these, such as earthquakes, tsunamis, and volcanic activity, are not necessarily seasonal, but others are. The other categories are Avalanche, Coastal Flooding, Cold Wave, Drought, Hail, Heat Wave, Hurricane, Ice Storm, Landslide, Lightning, Riverine Flooding, Strong Wind, Tornado, Wildfire, and Winter Weather. Each of these has

[*] Human mental health remains an important consideration in managing crisis, including how to manage the initial disruption, and how people originally rise to meet the challenge, only to become discouraged.(Math et al., 2015) This heroic response was evident during the initial phase of COVID-21, as not only medical staff “flattened the curve”, but so too did the general population. Over time, COVID-21 fatigue become a mental health concern. (Joshua Gordon, 2021)

influenced navigation patterns; even Western U.S. wildfires affected shipping in the Portland area.(Peñaloza, 2020)

The challenge is what other elements to add to the matrix. Most of these events have been studied, such as Hurricane-related maritime losses in the Americas and Asia. (Bathgate et al., 2022; Chambers et al., 2018; Hashimura, 2013; Tian et al., 2023)

There is a difference in that some events are broader than the maritime space but can disrupt waterway activities. For example, estuaries may be more prone to certain events due to climate change due to their connection between the sea and land.(Kimmerer & Weaver, 2013) Other factors, such as cargo disruptions from congestion and supply chain disruptions, were highlighted by the equipment challenges throughout 2020-2022, as equipment available conflicted with seasonal cargo peaks.(Notteboom et al., 2020) or other system disruptions.(Pant et al., 2015) or limitations to the Danube to provide modal alternatives due to water levels(Nagy, 2022). Other items include typical high and low water activities, dredging activities, and mitigation for environmental species, significantly where these actions can influence navigation.

In this regard, a complete literature review of this topic, ranging from navigation activities, supply chain disruptions, changing weather patterns, and human interaction, reflex the system's complexity exceeds the length of this paper. Still, there have been various studies, such as on the Yangtze (Liu et al., 2019) or even general economic performance (Su & Wen, 2023), but even more detailed weather patterns can be shown in short-term forecasts. (Finkel et al., 2023) However, the focus on known events sometimes makes it easy to identify what to discuss, especially with vessel operators and maritime professionals. It also provides a framework for developing a methodology to bridge specific events with more general trends.

3. Methodology

Firstly, why develop a methodology? The challenge with creating such a framework is where to begin. The emerging field of Hydrosociology seems to offer one context, seeking to integrate many groups such as agriculture, water supply, navigation, and other activities. However, these tend to focus on water in the context of water resource management, and the field remains unclear concerning the correct taxonomy for quantifying system complexity.(Ross & Chang, 2020; Wesselink et al., 2017) The challenge is to look at one region in the context of seasonality, and the focus could be on examining specific known meteorological studies. For example, a central European study examined seasonal forecasting to assist vessel planners in analyzing waterway conditions, but it also included that there was a lag from the occurrence of a weather event until it was reflected in navigation conditions (Meißner et al., 2017) There model focused on metrological data and river levels. While monthly forecasts were estimated, specific hydrographical and meteorological elements were not addressed.

However, the starting part of most current discussions regarding maritime system disruptions tends to concern adapting to climate change or mitigating supply chain disruptions. These should not be seen as wholly separate functions. While estimating decarbonization implications are beyond this work's scope, it has led researchers to link current activities to climate change. For example, when considering navigation in the context of climate change strategies, Rohács & Simongáti identified the three E's of sustainability: a prosperous economy, a quality environment, and social equity.(Rohács & Simongáti, 2007) For an organizational structure, these broad goals should be part of any discussion concerning navigation and broad water resource discussions.[†]

[†] Most groups use Environmental, Social, & Governance (ESG) as their preferred term for sustainability discussions, especially as firms are adopting their procedures to address these goals.(North et al., 2023). ESG includes broad activities, such as reducing their environmental "footprints" (not just energy usage) but also decarbonation to reduce "fuelling" more energy into the world's atmosphere. However, the other side of the climate change debate is that weather patterns are shifting within the context of known weather phenomena. Any structural changes must be done through social and regulatory frameworks, external to any one entity. While retaining the sustainability goals, the 3E's accounts for the external and internal complexity of climate change procedures. This is not a new concept. Lange, in a study of Britain's droughts, suggested interdisciplinary groups should be used to examine the institutional and governance structures of the water sector.(Lange, 2020) The 3E's, allows for the incorporation of both control and complexity within the same framework.

The prosperous economy can be considered the domain of the port and the commercial maritime sector, focusing on maximizing throughput within the context of the maritime system. The two broad subcategories focus on waterway dependant activities, such as vessel operations, terminal facilities, etc. At the same time, commercial development includes landside activities, such as warehousing, industrial development, and supporting industries.

The second, quality environment, would include monitoring and improving the maritime system's environmental condition. Again, there are two broad categories, one focusing on regional conditions, which are related to overall weather conditions that affect an entire region and specific waterway conditions. Weather, and its implications on transportation, vary greatly. In some places, a particular event may be catastrophic, such as a 2021 snowstorm in Texas which the Federal Reserve Bank, Dallas, estimated that it cost the State over $100 Billion,(Garret Golding et al., 2021) The same cold snap in a different locations would not be "catastrophic". Thus, a monthly matrix should contain a metadata structure of broad categories of related activities but allow users to put specific items within the same categories relevant to their region.

The third category, social equity, is that waterway managers balance conflicting goals, such as water access, land use, infrastructure locations, or other activities. Policymakers monitor externalities, fund public assets, and regulate environmental programs. Equity has a view of stewardship that includes the management of the waterway to provide for both current and future use, while other users reflect non-navigation activities within the waterway area. For example, locks and dams are useful for flood management, generating recreational and safe navigation, and dredging activities ensure commercial operations occur. These facilities require maintenance checks and repairs, generally during low water conditions. At the same time, stewardship includes municipal water services and water management for other users, such as agriculture. Other users can be related to activities and local conditions that may result in localized traffic around the port area, such as restricting traffic near a waterside stadium or the inability to reach the port due to local celebrations such as carnival season.

As such, these 3E’s indicate the primary event and, by exception, some information concerning ownership and reporting responsibility while potentially tying specific actions back to sustainability discussions. Others support this broad categorization of waterways (L. Allan et al., 2007; Pande & Sivapalan, 2017), which suggests this may be a good starting point for developing categories to include in a standard structure.

Secondly, there should be additional subcategories for each of the 3E's. Some are listed in Figure 2 under the relevant 3E's, but elements from Figure 1 are also listed. Figure 2 shows potential sub-items under each of the 3E’s. As such, the developed subcategories reflect routine activities within a waterway. The included categories are not an exhaustive list but provide a format for identifying what may arise within a port/navigation area. So while linked to climate change resiliency, the baseline effects of climate change patterns could be extended to compare this to other performance metrics, as initially intended by Rohács & Simongáti to like actionable items. One could argue that any failure could force, through readoption, and improvement, a better, more sustainable system, but there is not the will or budget to rebuild everything simultaneously.

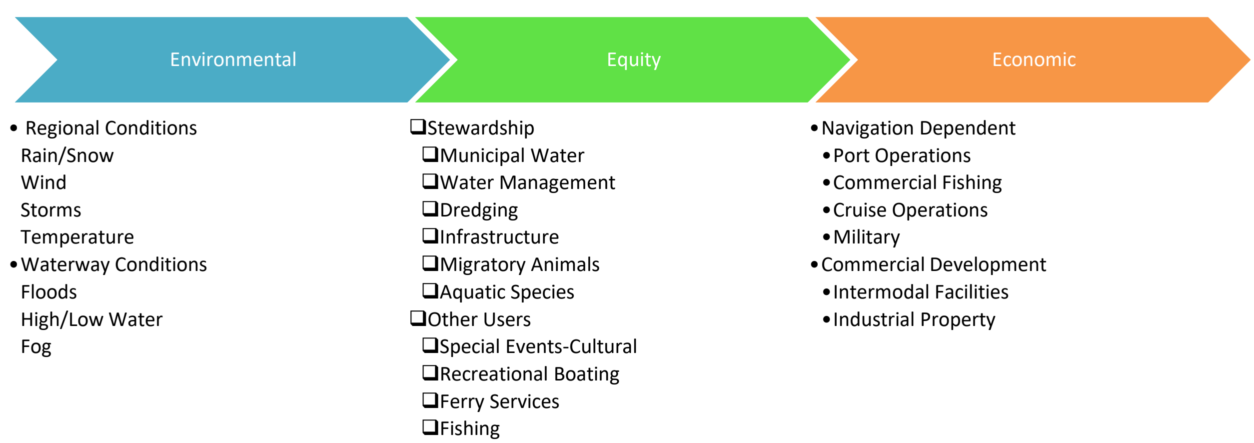

Figure 2. Categories of Water-Related Activities in a Region

These categories may be insufficient, but any events used should be temporally and geographically quantifiable. One key challenge in developing such an approach is capturing knowledge from different disciplines and communicating it effectively among various groups. A common framework is needed to link navigation operations to predictable monthly occurrences and assist stakeholders in understanding access and usage of waterways in relation to other general environmental and human activities. This matrix should be based on weather incidents, port operations, and ecological considerations and fact-checked against local, tacit knowledge collected through different user interviews and meetings.

Regarding the individual matrix, the information can come from any source, as no single resource categorizes all these divergent data streams. As such, the elements will rely on data integration from different databases or supplemented with local knowledge, what can be described as Type II knowledge concerning data integration versus primary research.(Gibbons, 1994)) For example, quantitative information on all of these elements may be available, but as data points for specific research or monitoring reasons, they may not be summarized or available in a format for a general practitioner, especially across different disciplines. In some structures, that limitation of data integration also suggests that the SEM Matrix be more limited in its area of research but broad in its scope to allow for such comparisons. Using a mixed methods structure thus allows data to be collected and shared.

One notable exception to the category is related to governance, often seen as a security or regulatory activity. Security/regulations provide the basis for operating with the waterway and thus are a known activity throughout the year. It should be listed as a distinct subcategory when there is an event, such as managing migratory species or hurricane season, where there are specific activities beyond normal operations. Often, the security and risk literature classifies all incidents are hazards, while the seasonal elements generate both socially positive and negative outcomes.

This structure provides a basis for discussing sustainability in the same context of operations. Developing the Seasonal Event Matrix (SEM) as a protocol could provide a manner to evaluate the integration among diverse groups that demand access/usage of waterways.

The authors took the Figure 2 listing to demonstrate if a SEM matrix could be developed and applied to a specific waterway. They converted it into a simple matrix, each category having a separate heading. The belief is that such a matrix would allow users to engage with the chart and see the relationship between seasonal and operational demands on the system. For example, not every waterway has ferry services, so that would not be counted as a separate event; however, if the ferry services run year-round but double capacity in the summer, that would be listed as a notable activity. Nor does every port have military operations, but some ports receive military cargo or support military operations. There is no need to exhaust this list, but the focus should be to report the top activities within a port region.

There is a recognition that events range from negligible loss to catastrophic failure, but the SEM matrix aims to look at the system, not to objectify every activity. Also, the SEM model does not try to capture all risks, especially asymmetric threats such as cyber-attacks, an active shooter, economic disruptions from a market collapse, or changing trade policies.

There is a need to understand how items can co-occur, and a focus on single-event occurrences may be misleading for understanding the system's complexity. There is an analytical overlay that may occur when studying complex systems, which over time, can often be ignored or underreported when estimating the contribution of a single event in the contest of many simultaneous events.

As such, the SEM matrix lists the following items: Rows, sorted by Environmental, Equity, and Economics, are tied to sustainability areas. Under each item are categories of potential events based on various data sources. The Columns reflect months when an event will most likely happen if it did occur and is linked to the HEROIC column, where casual relationships can be reported. A Notes space allows for indicating some particular circumstances, such as estimated economic activity, location, or related summarized information. Using the 3E's, a potential working monthly matrix may look like the following in Table 2. (The challenge in making something so simple is that people may not perceive the need to use the tool to collect and process information.)

The next step is to populate the matrix based on readily accessible databases. Focusing on readily available data aims to provide a quick overview of available resources and preclude the SEM matrix's development into something other than a baseline listing of known, predictable events that may occur by month in a port region. (While the SEM matrix may appear to be a risk matrix, there is no risk quantification for any event listed here. These are to show what may occur, by month, in a navigation area.) The HEROIC column is intentionally left blank so that users can report about the possible causal chain and provide feedback to understand better both relationships within the system and potential ownership/communication associated with that event.

There potentially exist more categories related to weather/environment than the equity and economic categories, especially as robust seasonal weather events exist. However, this does not mean that humans are not seasonal regarding our play or work, but our genes exhibit seasonal patterns. (Dopico et al., 2015)

Table 2. Sample Seasonal Event Matrix (SEM)

Event	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	DATA	HEROIC	Note
Environmental															
Event 1															
Event 2															
Equity–															
Event 1															
Event 2															
Economic–															
Event 1															
Event 2															

To complete the SEM matrix for Mobile, each of the 3E's categories are used to discuss key events and data availability. Part of the effort is to see what data is readily available so the work can be verified while providing some structure for local engagement to capture any tacit knowledge not reported in one of the listed data sources. Data indicates one data source for that seasonal event. The HEROIC elements should assist users in thinking through the corresponding relationships related to Human Factors, Equipment, Regions, Operations, Infrastructure, and Cargo.

4. Results

The authors created a SEM matrix based on Mobile County, Alabama, USA.[‡] Mobile County, located in Southwest Alabama, is home to the Alabama State Port Authority in Mobile, shipbuilding, recreational boating, cruise, and commercial fishing. The County borders Mobile Bay and has coastal areas on the U.S. Gulf of Mexico (Figure 3). The map, developed from the U.S. Geological Service, shows Mobile Counties location to both the Intercoastal Waterway along the Gulf Coast and the Mobile River, which is connected to other navigable systems (Tennessee-Tombigbee Waterway, Tombigbee, Alabama, and Black Warrior rivers).

The Alabama State Port Authority manages the Port of Mobile and has containerized, break-bulk, and bulk cargo operations facilities. Furthermore, the region includes connections to domestic waterways, such as the Gulf Intercoastal Waterway and the Tennessee-Tombigbee Waterway. The following map shows the relationship of Mobile to other regional navigation systems.(U.S. Geological Survey)

‡ The authors are willing to share the SEM Excel file if requested.

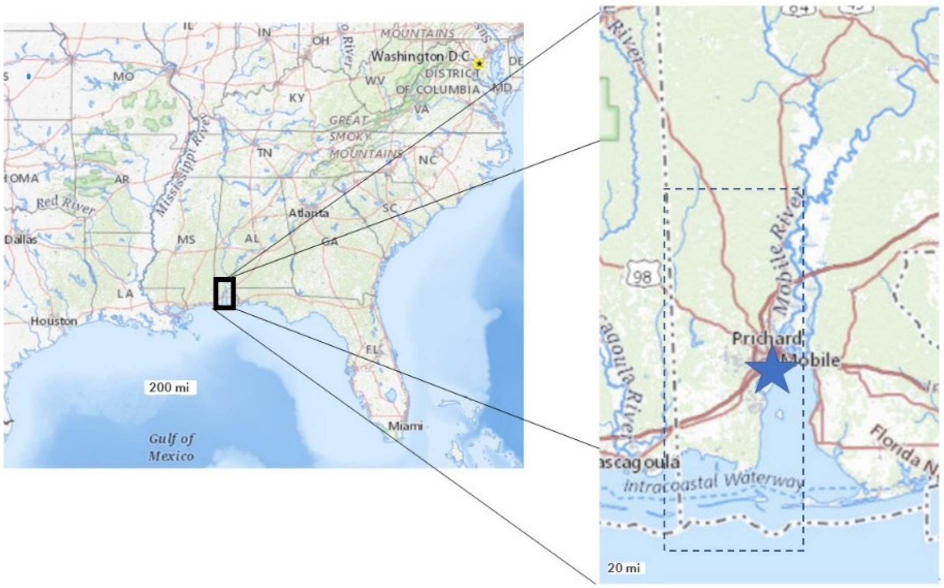

Figure 3. Map of Mobile County, Generated from U.S. Geological Survey, TopoBuilder from the National Map(U.S. Geological Survey).

The Mobile maritime community plays a critical role in the regional economy and serves as a hub for transportation, trade, and commerce in the Gulf of Mexico region. The Port generated $85 billion in economic activity, handling over 58 million short tons of cargo, including automobiles, containers, and bulk exports[§]. (Port of Mobile, 2021) Mobile represents an "ideal" initial study area, as the port compares to other coastal ports that also handle domestic barge traffic and international cargo while located near an urbanized area. Finally, the United States Army Corps of Engineers (USACE) and the U.S. Coast Guard (USCG) have regional offices based in Mobile; thus, regional experts on waterway operations can be used to verify the information reported here and the associated knowledge gaps.[**]

Given its location and climate, one would not expect some of these events to occur, such as Tsunamis, etc. Still, other events may occur during specific seasons, such as Ice storms or Cold Waves. The FEMA National Risk Index suggests the following probabilities for Mobile County (Figure 4). The highest likelihood is lightning, followed by droughts and flooding. For emergency planners, this list is helpful. Still, as stated earlier, it lacks some of the details of the seasonal events that may influence navigation but can be understood by someone possessing localized knowledge.

[§] Over 52 million metric tons.

[**] Although the USACE and USCG were consulted, the SEM model is not endorsed by either agency.

Hazard Type	Annualized Frequency	Events on Record	Period of Record
Avalanche	--	--	--
Coastal Flooding	2.1 events per year	n/a	Various (see documentation)
Cold Wave	0 events per year	0	2005-2017 (12 years)
Drought	19 events per year	413	2000-2017 (18 years)
Earthquake	0.045% chance per year	n/a	2017 dataset
Hail	1.7 events per year	56	1986-2017 (32 years)
Heat Wave	0.8 events per year	38	2005-2017 (12 years)
Hurricane	0.2 events per year	43	East 1851-2017 (167 years) / West 1949-2017 (69 years)
Ice Storm	0.4 events per year	29	1946-2014 (67 years)
Landslide	0 events per year	0	2010-2019 (10 years)
Lightning	138.4 events per year	3,046	1991-2012 (22 years)
Riverine Flooding	3.6 events per year	87	1996-2019 (24 years)
Strong Wind	1.7 events per year	56	1986-2017 (32 years)
Tornado	1 event per year	47	1986-2019 (34 years)
Tsunami	--	--	--
Volcanic Activity	--	--	--
Wildfire	0.167% chance per year	n/a	2016 dataset
Winter Weather	0.2 events per year	9	2005-2017 (12 years)

Figure 4. National Risk Index for Mobile County ((Federal Emergency Management Administration)

A comparison of the report from the NOAA Storm Event Database summarized all storm events from 2015 to 2022, indicating there were 106 days with an event, of which four resulted in a human death and 42 with property damage.(U.S. Department of Commerce et al.)

Table 3. Storm Related Events in Mobile County, 2015-2022, From the NOAA Storm Event Database

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand Total
Coastal Flood							8			1			9
Flash Flood			8	5	6	10	2	22	5	4		1	63
Flood		1	3	1				1					6
Hail	1	2	1	1	6	5						1	17
Heavy Rain			1	1			1	1					4
Hurricane									3				3
Lightning	2					1	1						4
Rip Current				1			1	1					3
Storm Surge/Tide						4		2	3	4			13
Thunderstorm Wind	5	3	9	39	20	19	18	5	3	2	3	3	129
Tornado			5	4	1	4		1		10	1		26
Tropical Storm						4		2	3	4			13
Winter Weather	2											2	4
Grand Total	10	6	27	52	33	47	31	35	17	25	4	7	294

Based on the NOAA Weather report, from January 2015 to December 2022, there were 294 reported events during that time of year. Each event varied by the scale and economic loss; in some cases, multiple reports of the same event occurred at various locations within Mobile County. However, noting differences indicates the potential for cascading events from an emergency response perspective. As such, April through June remains the most active time for weather-related events, although hurricanes typically occur in August-October. As such, this table is a helpful start to examine broad regional and seasonal events but can be supplemented by additional information related to navigation to complete the Mobile SEM Matrix.

Environmental SEM Matrix

Mobile, Alabama, is classified as Koppen Sub Tropical Human Climate (cfa) (University of Idaho, 2020). This classification indicates a hot, humid summer but with milder winters. As expected in such a climate, the focus is on managing wind, rain, and heat, as the summers can be relatively hot and humid, and tropical systems drive rain events. The region's average temperature and perception were calculated from the National Weather Service (U.S. Department of Commerce). Mobile's driest month is October, but the region still receives four inches of rain, and rain-related events, as shown earlier, will be a large part of the region's seasonal patterns.

Table 4. Total Precipitation Normal, Mean Maximum, Minimum and Average Temperatures, for the Mobile Regional Airport, 1991-2020. Source National Weather Service, Department of Commerce

	Total Precipitation Normal		Mean Max Temperature Normal		Mean Min Temperature Normal		Mean Avg Temperature Normal	
Month	Inches	Centimeters	Fahrenheit	Celsius	Fahrenheit	Celsius	Fahrenheit	Celsius
January	5.66	14.38	61.5	16.39	40.7	4.83	51.1	10.61
February	4.47	11.35	65.6	18.67	44.4	6.89	55.0	12.78
March	5.44	13.82	71.8	22.11	50.0	10.00	60.9	16.06
April	5.71	14.50	77.8	25.44	56.0	13.33	66.9	19.39
May	5.39	13.69	84.9	29.39	63.8	17.67	74.4	23.56
June	6.55	16.64	89.4	31.89	70.8	21.56	80.1	26.72
July	7.69	19.53	90.9	32.72	73.1	22.83	82.0	27.78
August	6.87	17.45	90.8	32.67	72.9	22.72	81.9	27.72
September	5.30	13.46	87.5	30.83	68.8	20.44	78.1	25.61
October	3.95	10.03	79.7	26.50	58.2	14.56	69.0	20.56
November	4.60	11.68	70.2	21.22	47.7	8.72	58.9	14.94
December	5.45	13.84	63.5	17.50	43.0	6.11	53.3	11.83
Annual	67.08	170.38	77.8	25.44	57.5	14.17	67.6	19.78

Although FEMA lists Riverine flooding, it includes all riverine flooding, even on non-navigation channels. This data does not necessarily indicate levels on the main navigation channels nor how current velocity, sediment transport, or river height vary over time. The high water occurs in the Spring (due to heavy tropical storm patterns), while low water occurs in the fall. As such, these events were added to the matrix (Table 5).

Table 5. Environmental SEM Matrix for Mobile County

	J	F	M	A	M	J	J	A	S	O	N	D	DATA	HEROIC	Note
Environmental															
Avalanche															N/A
Coastal Flooding						x	x	x	x	x			NOAA Storm		
Cold Wave	x	x	x										Author		
Drought															Unable to find the Monthly Pattern
Earthquake															N/A
Hail	x	x	x	x	x	x							NOAA Storm		
Heat Wave							x	x	x				NOAA Storm		
High Water			x	x	x										
Hurricane						x	x	x peak	x peak	x peak	x		NOAA Storm		
Ice Storm	x	x											Author		Unable to find the Monthly Pattern
Landslide															N/A
Lightning	x					x	x						NOAA Storm		
Riverine Flooding		x	x	x	x	x	x	x	x				NOAA Storm		
Low Water							x	x	x						
Strong Wind	x	x	x	x peak	x peak	x peak	x peak	x	x	x	x		NOAA Storm		
Tornado			x	x	x	x		x	x	x	x		NOAA Storm		
Tsunami															N/A
Volcanic Activity															N/A
Wildfire															N/A
Winter Weather	x	x										x	NOAA Storm		
Termite Swarms					x								Author		Nuisance

Equity SEM Matrix

The equity category can cover things unrelated to weather or commercial navigation, such as waterways as a public good or a shared resource. Typically, navigation inspections occur, lock and dam repairs construction/repairs, and other items are related to the stewardship and management of the waterway system during low water periods. For example, during February, the people along the Gulf Coast celebrate Mardi Gras. Mobile's Mardi Gras has a $408 million economic impact on the City of Mobile every year, and more than 12,800 jobs in Mobile and Baldwin County are tied to the carnival season, mainly in the downtown area of Mobile.(Albrecht, Peter, 2020) While Mardi Gras does not lead to navigation system closures, it does influence workforce participation, localized congestion, and limited hotel availability.

While conservation and managing marine animals and other migratory species are essential, the author could not find any seasonal reports related to environmental stewardship.

Recreational boating is a year-round event in the region, although boaters tend to be on the water more in the summer. Also, there is a significant regional tourism trade and a growing demand to develop more properties and improve existing facilities adjacent to waterways. Still, the author could not find water-dependent tourism broken out by month.

From a water resource perspective, the USACE maintains navigation channels year-round but does many inspections and repairs in the summer and fall to accommodate lower water levels. The area has a large ship repair industry. Still, these vessels do not necessarily limit operational activities.

The Equity SEM Matrix is shown in Table 6.

Table 6. Equity SEM Matrix for Mobile County

	J	F	M	A	M	J	J	A	S	O	N	D	DATA	HEROIC	Note
Equity															
Cultural Events	Mardi Gras												Authors		
Recreational Boating					peak								Authors		
Endangered Species													Nothing available		
Low Water Repairs													https://www.sam.usace.army.mil/Missions/Civil-Works/Navigation/		Work performed year-round

Economic SEM Matrix

Navigation occurs to provide transport services. There are many users in the waterway system, including dockside workers, mariners, but also logistic planners and beneficial cargo owners. Like all things, there is a seasonal pattern to shipping. Sometimes those seasonal patterns are related to the commodities themselves, such as agricultural products shipped during times of harvest, and holiday shopping drives retail consumer spending, with associated pressures on containerized transport. Different demands for energy shipments are related to meeting regional heating and cooling needs.

So, the first question is, does the Port of Mobile see a strong seasonal pattern in its trade shipments? The United States Army Corps of Engineers (USACE) National Data Center reports tonnage information by waterways annually; only selected locks are reported monthly. Mobile County has no navigation locks, so monitoring barge traffic monthly in Mobile may be problematic. However, international trade data was accessed from the U.S. Department of Census. The information posted on USA Trade Online reports total trade, vessel, and air trade in tonnage and value.(U.S. Census Bureau). The Harmonized System, Port-Level Data, was used to estimate the monthly time series from 2015-2021.

When considering monthly trends concerning navigation, the Port of Mobile experiences seasonal trade patterns, with imports higher in the fall months and exports in the Winter and Spring (Table 7). (The tonnage, not value information, were used for the calculation.)

Table 7. Average Monthly International Cargo Activity in the Port of Mobile, 2015-2021 Source U.S. Census International Trade(U.S. Census Bureau)

	Exports		Imports		Total	
Month	Vessel Tonnage	Vessel Value	Vessel Tonnage	Vessel Value	Vessel Tonnage	Vessel Value
Jan	8.87%	8.32%	7.48%	8.35%	8.73%	8.34%
Feb	8.23%	7.92%	7.05%	7.13%	8.12%	7.34%
Mar	9.28%	8.57%	7.55%	8.43%	9.11%	8.46%
Apr	8.12%	7.76%	8.67%	7.89%	8.17%	7.86%
May	8.19%	7.87%	8.15%	8.55%	8.19%	8.37%
Jun	9.01%	8.12%	7.93%	8.21%	8.90%	8.19%
Jul	7.32%	7.81%	9.52%	8.90%	7.53%	8.61%
Aug	8.17%	7.52%	9.52%	8.99%	8.30%	8.60%
Sep	8.06%	8.60%	8.69%	8.27%	8.12%	8.36%
Oct	8.29%	9.04%	9.35%	8.71%	8.40%	8.80%
Nov	7.50%	8.64%	8.27%	8.18%	7.57%	8.30%
Dec	8.97%	9.84%	7.82%	8.38%	8.86%	8.76%
Grand Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Carnival Cruise Lines operate a cruise service; however, there seems to be little information on actual cruise operations and passenger trends by month. In 2022, Carnival will run cruises from March to October.(City of Mobile)

The National Oceanographic and Atmospheric Administration (NOAA) publishes annual fisheries in Alabama but does not report monthly fisheries landing information for Mobile County. However, in 2019, fishing generated over $465 million in state-wide economic activity.(National Marine Fisheries Service, 2022)

In many ways, the lack of nationally published data monthly for various economic activities highlights the importance of collaborating national reports with localized knowledge, especially related to maritime activities.

Table 8. The Economic SEM Matrix for Mobile County

	J	F	M	A	M	J	J	A	S	O	N	D	DATA	HEROIC	Note
Economic															
Cargo Level	Exports						Inbound Containers					Exports	U.S. Trade Data		
Fisheries													Unknown		
Cruising			x	x	x	x	x	x	x	x			City of Mobile		Cruise Vessels depart from the Mobile City Docks

The SEM Matrix should be complete/confirmed by various localized users, including pilots, terminal operators, port managers, emergency managers, government officials, and waterway operators. It is also essential to have broad users, as not all risks will be the same for all users within a port area, as a container terminal may have different operational concerns than a petroleum facility. Larger vessels will put more pressure on bollards than smaller vessels. The HEROIC subcategories further help users think through the casual relationships of these seasonal events, such as heat waves that may influence human factors or cargo demand to support air condition usage. However, there are a few caveats.

- Local users may not understand the need for such a tool, as they have localized knowledge concerning their perception of these seasonal events.
- There remain challenges related to data gaps in mixed, multidisciplinary studies, especially those related to broad events and possible causal relationships. The challenge is that more information is becoming digitalized in the public domain. That does not mean local stakeholders have the time and desire to remain updated on these new information sources. Furthermore, these gaps are essential for certain things, such as fisheries. For example, Alabama has a list of endangered species, but it is unclear how these species, especially the aquatic ones, influence navigation.(Burnett, 2021)
- There should be some concern to guard against information seen as confidential/proprietary. Furthermore, while this structure provides enough information to be helpful without causing a burden regarding data collection and dissemination, it may be an issue for certain ports/waterways.
- Domain experts may see such a structure as of limited use, and their detailed information is more robust than the overview provided. However, this challenge is the hardest to address, as the SEM Matrix is designed for the practitioner to understand causal relationships and changes over time of known events while providing a framework for discussions on system operations.
- There are always concerns regarding updates. Once a regional SEM Matrix is completed, it could be reviewed periodically, especially regarding system resiliency and climate change, especially if regional climate models were developed to baseline seasonal events and any changes in associated duration, frequency, or other attributes can be estimated to avoid potential local confirmation bias.

The SEM matrix presented in the paper may be a helpful tool for assessing monthly and seasonal factors in a waterway or port. In addition to providing a framework for assessing potential risks, the SEM matrix can also help to improve communication and collaboration among port stakeholders.

5. Discussion

Many published studies on hydrosociology, navigation, climate change, and resiliency exist, but no consistent framework exists for discussing the relationship between human activities and waterway environmental relationships.(Madani & Shafiee-Jood, 2020) The challenge, as stated earlier, the SEM Model is an approach to integrate various navigation and waterway users in a single structure that allows for understanding seasonal patterns. In this regard, the model is more about creating a framework enabling multiple users to examine elements systematically related to water resources but does not preclude others from developing more robust quantitative profiles associated with changing weather/storm duration, frequency, or intensity. The model's flexibility allows local users to incorporate their information, which may provide a framework for comparisons across diverse systems.

When evaluating modal diversion to waterways, these elements, such as identifying known events that may influence inland navigation operations, could provide further ground for linking users to researchers. Additional work could better qualify the casual loops within a system, such as the duration of flooding events to dredging requirements or the seasonal marine species environmental regulations on vessel movements.

From a data collection aspect, River Information Services may provide additional insights for developing temporal information about waterway usage/conditions. As such, transportation planners and system operators may have a structure for discussions regarding seasonal and larger system patterns concerning water resources, especially if the model includes long waterway stretches. Furthermore, with any database, tying this information to mapping software could provide additional insights.

This structure of listing the events can also provide a basis for integrating various attributes within a maritime system. Any training programs for maritime/emergency response staff should rely on locally acquired knowledge, but the structure provides a starting point for discussing regional events. For example, while practical, the FEMA Risk Matrix did not contain the same information as the NOAA Storm Event database. While different, both provide a starting point for discussing the relative concerns for emergency responders and business continuity planning concerning the likelihood and duration/severity of an event. While it is not a traditional risk model, it provides a structured approach to identifying and categorizing potential risk factors by their impact on the three E's. It can link to broader discussions of climate change, specifically system resiliency. Using this matrix with more traditional risk assessment tools, port stakeholders can better understand their operations' potential risks and prioritize their response efforts accordingly.

Integrating more specific information that could be collected, but is currently not published at the monthly level, could provide additional insights and baselining/monitoring trends associated with weather-related activities or other cultural events. There is a need to understand better what information becomes public as more resources are released. However, no one can assume that users, beyond the specialists, understand, know, access, or process additional information.

The SEM Model itself may provide a structure for other modal users. For example, other modes are subject to changing weather conditions, such as aviation or transportation networks. (Kulesa; Stamos et al., 2015) In this regard, maritime transportation has the same elements of balancing equipment, networks and forecasting risks related to operations.

Finally, the SEM Matrix may be a precursor to developing a risk matrix that examines navigation activities across different time/geography/event frameworks while allowing for local inputs. The SEM matrix is not a risk model in the traditional sense because it does not attempt to quantify or measure risk. Instead, it provides a structured approach to identifying potential risk factors and categorizing them by their potential impact on the 3E's. Instead, it can be used with these tools to provide a more comprehensive understanding of the potential risks facing a port or waterway. For example, a formal risk assessment may identify a specific threat to navigation, such as a hazardous material spill. The SEM matrix can assess the potential impact of this event on the 3E's, and assist in planning how to prioritize response efforts based on this assessment. In another example, the matrix includes categories such as "Low Water Events" and "High Water Events," which are potential risk factors for navigation in a waterway that would benefit from local knowledge. However, the matrix does not attempt to quantify the likelihood or severity of these events, nor does it attempt to assign a risk score or ranking to them. Instead, the matrix provides a way to prioritize and assess potential risk factors based on their relationship to the 3E's. For example, a low water event may significantly affect a port's economic viability if it prevents ships from loading and unloading cargo. However, depending on the specific circumstances, it may place less burden on the environment or equity goals. By categorizing events, the matrix may help port stakeholders prioritize their response to potential risk factors based on their unique concerns/experiences and, by extension, understand, over time, the changes in seasonal patterns due to climate change.

The traditional risk matrix, focusing on estimating risks, may lead to underreporting the number of events, as the disruptions are assumed to be "normal" and are often addressed through ongoing training/operations. As such, they will not necessarily be included but these events are a part of the local system and need to be considered. The SEM Model could fill that gap by having these events as part of the seasonal pattern without quantifying the event's risk, especially for those events potentially tied to human factor elements and economic costs.

6. Conclusion

The paper aimed to develop a basic seasonal framework tied to sustainability elements but customized by predictable events within a waterway or port for emergency planners and operational/regulatory stakeholders Using the 3E's allows for linking these elements into the resiliency side of sustainability and the possibility underpinning previous studies between operations and climate change adoption. This paper did not quantify these different elements, but it provided a framework for integrating other work efforts to address seasonal patterns that are related to climate change and which may be underreported in the literature due to various factors, such as data availability or statistical robustness. For example, the information developed for emergency managers did not specifically outline when these events may occur by month, making them potentially less effective for local stakeholders interested in addressing/prioritizing different concerns over a year. The use of the HEROIC hierarchy can assist in refining those casual relationships that may occur from a seasonal event and identify priorities for improving communication or other regional needs.

There exists a place for baselining waterway performance not only to improve actual port operations but to identify the relationship of the maritime sector to broader regional activities that may influence waterway capacity/risk Nevertheless, there can be more practical reasons, such as understanding resource allocation for a manager or assisting inexperienced staff/managers in understanding the seasonality of a particular region. Such a framework could give outside stakeholders an understanding of why certain things occur during one time of the year and the implications for planning and operations.

Applying the Seasonal Event Matrix to Mobile indicates that publicly available information is inadequate alone in providing the detail to develop a monthly indicator of potential but predictable events. For Mobile, the published events do not necessarily include specific maritime-related items, such as fog events, that can lead to temporary disruptions in maritime system capacity. The authors acknowledge that part of this gap could be their inability to understand where to access the correct information or if these datasets were available for public release.

Developing a more integrated baseline, such as the SEM Matrix, which could be supplemented with additional information/studies on specialized elements related to trends in seasonal weather patterns/events, would be beneficial. The SEM Matrix can be a starting point for collaborative planning among the navigation community and other groups, especially recognizing diverse users and needs. Hopefully, this methodology is flexible for other waterways, which may be interested in baselining seasonal activities. Future research could link the SEM Matrix to risk matrices, or the framework could be extended to broader watersheds such as the Yangtze or Rhine instead of focusing on a single port region.

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