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Allisions, Collisions and Groundings: Estimating the Impact of the Physical Oceanographic Real Time System (PORTS(R)) on Accident Reduction

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1. INTRODUCTION

One of the responsibilities of the National Oceanic and Atmospheric Administration's (NOAA) National Ocean Service (NOS) is to promote safe and efficient maritime navigation within the United States. NOS's Center for Operational Oceanographic Product and Services (CO-OPS) developed a public information acquisition and dissemination technology known as the Physical Oceanographic Real-Time System (PORTS®) with the Greater Tampa Bay Marine Advisory Council in 1990.

PORTS® are installed and managed in partnership between NOS and port management.[1] Edwing (2013) described PORTS® as a collection of meteorological, oceanographic, and geographic instruments that are integrated into a system that provides accurate, reliable, real-time, quality-controlled information about the environment (observations and predictions) in which commercial mariners and recreational personnel operate. The number of and type of instruments installed are based on the need of the individual port or system of ports. For example, the Chesapeake Bay that contains 97 separate instruments[2] provides shared data for 10 ports.[3] The smallest single port PORTS® installation consists of a single water-level gauge.

The purpose of this analysis was to investigate Allisions, Collisions and Groundings (ACGs) over a long period from several perspectives including number of occurrences, relative incidence rates, and costs associated with

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[1] NOS provides at no expense to participating ports: (1) personnel and technical expertise required to assure that the system design, enhancement, management, operation, maintenance and repair of the system are within NOS standards and guidelines; (2) 24/7 real-time quality control of all data through the Continuous Operational Real—time Monitoring System (CORMS); (3) software enhancements and upgrades; (4) communication costs with CORMS; and, (5) other associated administrative processes including proposals for future refinements.

[2] These include: water level; current; salinity; air gap; visibility; waves; and, meteorological parameters (e.g., wind speed, wind direction, air temperature, air pressure, air humidity, precipitation, etc.)

[3] Includes: (1) Alexandria, VA; (2) Annapolis, MD; (3) Baltimore; MD; (4) Cambridge, MD; (5) Crisfield, MD; (6) Hopewell, VA; (7) Newport News, VA; (8) Norfolk Harbor / Hampton Roads, VA; (9) Richmond/Petersburg, VA; and, (10) Washington, DC.

morbidity, mortality, and property damages. Concomitant with these calculations would be an estimate of monetary gross benefits derived from reductions in ACGs associated with PORTS® installations.[4]

2. IMPORTANCE OF INTERNATIONAL WATERBORNE COMMERCE

During 2016, about 1.4 billion tons of cargo was imported and exported via vessels at U.S. ports. Collectively this cargo was valued at almost $1.5 trillion (Figure 1).[5] Although aggregate cargo values have reflected the 2013 to 2016 downward trend of crude oil prices,[6] they have averaged in excess of $1.4 trillion ($2015) during the 2000 to 2016 period.

[4] Propriety damages includes losses from vessels, cargo, facilities, and other sources.

[5] Source: U.S. Department of Transportation, *Freight Facts and Figures 2017* for rail, truck, pipeline and other and the U.S. Department of Commerce, U.S. Census Bureau, USA Trade Online.

[6] Annual real costs of crude oil have declined since 2013 ($95.79 per barrel) to 2016 ($37.02 per barrel). Source: https://inflationdata.com/Inflation/Inflation_Rate/Historical_Oil_Prices_Table.asp

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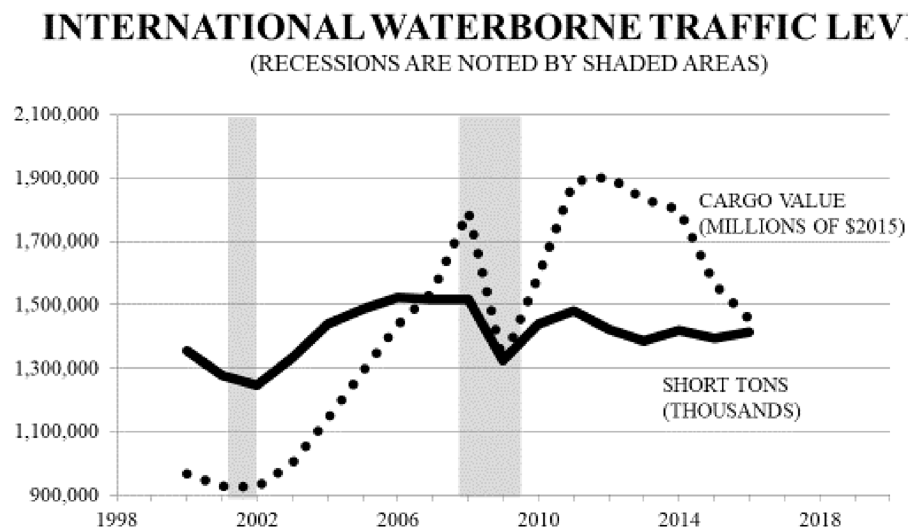

Figure 1

The Department of Commerce (DOC) reported in 2010 that over 69 percent of U.S. international trade (measured by tonnage) moves through the nation's ports and harbors and represents almost 41 percent of total international cargo value.[7] Although there are over 400 ports in the United States according to the DOC, only half reported handling imports and/or exports in 2016.[8] Highly concentrated, the top 60 locations handled over 98 percent of all cargo value and almost 96 percent of total cargo tonnage.

Between 2002 and 2015, total vessel calls at US ports increased from 50,877 to 82,044—a 48 percent increase.[9] At the same time, total deadweight tonnage increased from 2.6 billion to almost 4.2 billion—a 60 percent increase. Such larger vessels require deeper and wider channels that necessitate more frequent

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[7] United States Department of Commerce, Census Bureau, USA Trade Online Database. Refer to: https://usatrade.census.gov/ and U.S. Department of Transportation, *Freight Facts and Trends*, 2017.

[8] United States Department of Commerce, Census Bureau, USA Trade Online Database.

[9] Source: U.S. Department of Transportation, Maritime Administration, *2002 and 2015 Vessel Calls in U.S. Ports*, Selected Terminals and Lightering Areas. Refer to: https://www.marad.dot.gov/resources/data-statistics/

and larger volumes of maintenance dredging, as well as more cranes, berthing space, and associated landside port infrastructure to accommodate. As waterborne traffic continues to represent a large portion of total transportation, vessel increases in size contribute to the difficulty of improving the economic efficiency and competitiveness of U.S. maritime commerce while reducing accident risk.

3. VALUE OF PORTS®

The need for PORTS® was seen almost 30 years ago by the marine industry. In 1990, Captain Steve Day, President of the Tampa Bay Pilots, approached NOAA's CO-OPS with a strong requirement for reliable real-time water level, current, and meteorological information in the vicinity of the relatively newly-built Sunshine Skyway Bridge.[10] Subsequent quotes and additional anecdotal evidence revealed demonstrative benefits:

- John Yagacic, of the Delaware River Basin commission, wrote, "NOAA PORTS® stations in the upper Delaware Estuary were critical to monitoring the impact of Hurricane Irene, Tropical Storm Lee, and Super storm Sandy on tidal flooding in the Delaware Estuary".[11]

- "I can't imagine doing my job without PORTS®." Captain John Kemmerley, Delaware Bay and River Pilot at meeting of the Mariner's Advisory Committee for the Bay and River Delaware, June 13, 2013.

- "We use PORTS® data on the Bayonne Bridge and nearby Bergen Point to bring in vessels within 2' of the bridge and 2' under keel clearance at the same time. If PORTS® sensors were shut down, there are 3-4 classes of vessels we will not be able to bring to the Port." Comment from a NY Harbor Pilot.

[10] Frey, Henry R., *Physical Oceanographic Real-Time For Operational Purposes*, IEEE Oceans Proceedings, Vol. 2, October 1-3, 1991, p. 856.

[11] John Yagacic, Delaware River Basin Commission, Letter to Congressmen, March 21, 2013

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- The Final Report of the Delaware River and Bay Oil Spill Advisory Committee, published in December 16, 2010, highlighted the importance of PORTS® to preventing maritime accidents and associated pollution releases. Recommendation 14 of that report was to "fund the upgrade, continued operation, and maintenance of PORTS®". That report indicates that PORTS® has the potential to prevent shipping accidents and subsequent environmental damage and save millions of dollars in response, restoration, and damage claims.[12]

4. CURRENT STUDY

The current study investigated only gross benefits from accident reductions for several reasons. First, NOAA only sets standards for PORTS® sensors and related communication infrastructure. It does not sell such equipment to ports and consequently does not know their acquisition costs. Second, obtaining installation, operating, and maintenance costs would be extremely difficult from current users and speculative at best for potential users. This is due to the variety of vendors and the number and type of sensors employed at current locations and the unknown needs of future potential PORTS® users.[13] Finally, costs of subsequent modification of PORTS® systems would also be difficult to identify.

The study was conducted and presented in such a way as to be conservative in stating gross benefits, and transparent to enable the reader to evaluate the estimated gross benefits of PORTS® for themselves and develop alternative allocations of gross benefits should additional data become available.

At the end of 2016, PORTS® had been installed at 77 major port locations.[14] International vessel traffic at these locations represented almost 87 percent of total

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[12] Pages 37-38.

[13] Local port partners determine how many sensors and where those sensors will be located and is responsible for purchase, installation, and maintenance of its system.

[14] About 200 ports are identified each year as import and/or export locations by the U.S. Department of Commerce's, Bureau of the Census' USA Trade Online database. Of the 60 locations without PORTS®, only about one-third of these estimated to be large enough in terms of vessel transits and historical accident rates to potentially warrant PORTS® installations. (Refer to Table 10.)

waterborne cargo value and over 81 percent of total cargo weight. As PORTS® have been largely installed at the largest container handling facilities; it covers over 91 percent of cargo value handled in containers and almost 89 percent of total container weight handled at such locations. Among the remaining port locations with a PORTS® installation, the largest 60 locations (in terms of tonnage) were reviewed to estimate potential gross benefits that PORTS® might be capable of generating.[15]

During the study period, a number of technological and management and human factors have contributed to reductions in the number and severity of marine accidents (e.g., increased use of the Automated Identification System, electronic charting, safety management systems, bridge resource management and crew endurance/anti-fatigue programs, etc.) Reductions in accident rates attributed to installations of PORTS® were based on multiyear analysis of marine accident data amidst these other improvements.

5. PREVIOUS RESEARCH

A number of earlier studies by Kite-Powell (2005, 2007, 2010) estimated the gross economic impacts of PORTS® at specific locations including Tampa Bay, Houston/Galveston, and Portland. Later Wolfe (2016) estimated gross economic benefits from the then 58 existing PORTS® installations as well as estimated the potential value that might be realized from expanded implementation to an additional 117 ports. Both Kite-Powell and Wolfe detailed gross benefit estimates derived from a number of sources with associated varying degrees of confidence. Benefits were envisioned to result from: (1) increased vessel draft and cargo loadings; (2) reduced delays among commercial vessels; (3) improved (petroleum) spill pollution response; (4) avoiding ACGs; (5) reduced distress cases; (6) improved weather forecasts; (7) improved storm surge forecasts; (8) enhanced recreational boating, fishing, and beach recreation.

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[15] The smaller remaining locations with the least traffic handled less than two percent of total tonnage and were not believed to potentially obtain gross benefits of sufficient size to warrant PORTS® installation.

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In a series of multi-year analyses, Kite-Powell estimated that reductions in groundings resulting from PORTS® installations ranged from 20 to 60 percent depending on the type of vessel and location:

- "A plausible range for the decrease in grounding risk for Tampa-Bay self-propelled ship transits attributable to PORTS® data is from 20 to 50% from the long-term baseline level of about 1.5 groundings per 1,000 transits" (Kite-Powell, 2005).[16]
- "Grounding rates for self-propelled ships appear to have decreased from 0.5 groundings/1,000 transits during 1993-1997 to about 0.25 groundings during 2002-2005; grounding rates for tugs/tows decreased from 0.1 to 0.04 during the same intervals. This is a decrease in grounding rate of 50% for ships and 60% for tug/tows" (Kite-Powell, 2007).[17]
- "While it is not possible to assign a specific effect to a specific cause with certainty in this case, it is plausible that LOADMAX[18]/PORTS® may contribute 25 to 50% of this reduction in grounding risk" (Kite-Powell, 2010).[19]

In working with data from 2010, Wolfe (2016) observed the rate of allisions at locations with PORTS® was 67 percent lower compared with locations without PORTS®. Collisions and groundings at PORTS® installations were seen to be 45 and 80 percent lower, respectively, than at locations without PORTS® facilities.

6. DATA UTILIZED

6.1 USA Trade Online

[16] Page 10. Based on analysis of grounding incidents from 1981 to 1995.

[17] Page 11. Based on analysis of grounding incidents from 1990 to 2005.

[18] LOADMAX and PORTS® is a public acquisition and dissemination information system operated in partnership by NOAA and the Port of Portland. A river forecast system supported by six water level gauges are operated by the National Weather Service Northwest River Forecast Center. The system was begun as LOADMAX in 1984 and became a NOAA PORTS® system in 2006.

[19] Page 15. Based on analysis of grounding incidents from 1980 to 2004.

The DOC's, U.S. Census Bureau's Foreign Trade Division, USA Trade Online is the official source of import and export statistics carried by waterborne vessels and air. DOC also summarizes traffic from these 400 locations into 48 district totals. Beyond facilities alone, the database provides current and cumulative U.S. export and import data on up to 17,000 commodities by U.S. trading partner defined under the International Harmonized System Code (HS)[20] and the North American Industry Classification System NAICS)[21] codes, at the 10 and 6-digit levels of granularity, respectively.[22]

Data over the range of availability at the time of this report (2003 to 2016) was selected to identify dominant import and export port facilities. Selection of the period allowed for variations in transportation activity that occur during at least one complete business cycle to be observed.[23] While meant to identify major import and export locations as well as to estimate coverage of PORTS®, USA Trade Online must be viewed with some caveats as to the precise level of tonnage and/or cargo value attributed to a specific port may have been disguised or redacted in some manner to ensure confidentiality.

There are several ways, especially when employed with other publically available data, that a specific shipper or receiver might be identified owing to the unique nature of the goods being shipped and/or received. In those cases, traffic levels (e.g., tonnage and/or cargo value) may not be reported accurately in USA Trade Online for a given port.[24] To conceal data, traffic at the restricted location

[20] The U.S. International Trade Commission maintains the Harmonized Tariff Schedule of the U.S. covering international traffic.

[21] The NAICS was developed by the Office of Management and Budget in 1997 to classify business establishments for the purpose of collecting, analyzing and publishing statistical data on the U.S. economy.

[22] The statistics include both government and non-government shipments by vessel into and out of the U.S. foreign trade zones, the 50 states, District of Columbia, and Puerto Rico. The statistics exclude postal and military shipments.

[23] The last recession ran from December 2007 to June 2009. The National Bureau of Economic Research (NBER) is considered the authority that identifies a recession and which takes into account several measures in addition to GDP growth before making an assessment.

[24] There also may be ports of notable activity that are not referenced because they do not directly send or receive international traffic. Other ports showing no traffic may be listed but are unmanned, are of a vestigial nature or while decommissioned remain on the list.

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may be added to the traffic reported at the largest port within the port's district assignment.

Finally, this database does not record the number of total vessel transits that occur by port that is essential to investigate the relative rate of marine accidents over time. Even so, to identify major international ports USA Trade Online contains the best data on import and export traffic that is publically available and its restrictions do not significantly impede the overall goal of identifying major US ports.

6.2 United States Coast Guard

The Marine Information for Safety and Law Enforcement (MISLE) system contains data related to commercial marine casualty investigations reportable under 46 C.F.R. 4.03 and pollution investigations reportable under 33 C.F.R. 153.203.[25] The data reflect information collected by U.S. Coast Guard (USCG) personnel concerning vessel and waterfront facility accidents and marine pollution incidents throughout the United States and its territories. Collisions are defined as the striking of a (moving) object upon another (moving) vessel. Allisions describe the striking of a moving vessel with a stationary object (pier, docked or anchored vessel, bridge, etc.) and groundings represent instances where a vessel collides with the seabed or side of the channel.[26]

6.3 United States Army Corps of Engineers

The U.S. Army Corps of Engineers (USACE) is home to the Waterborne Commerce Statistics Center (WCSC), which collects, processes, and publishes marine vessel transit counts and cargo flow totals for ports, rivers, and navigable waterways throughout the country. This data is used by the Corps to inform decisions concerning new investments in port and waterway expansions as well as annual operations and maintenance of existing water resources infrastructure.

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[25] The marine casualty reporting requirements are in 46 CFR 4.03, but that rule exempts vessels covered by 33 CFR 1783.51, which are recreational vessels. The USCG office of Boating Safety works with the various state agencies that have jurisdiction over recreational boating to ensure accurate record keeping on recreational boating accidents.

[26] Collisions also include instances where a vessel and a temporarily moving object (e.g., moving span of a bridge) come into contact.

By using the proprietary, dock-level origin-destination cargo flow data maintained by WCSC within a routable network of georeferenced channel segments, the Channel Portfolio Tool (CPT; Mitchell 2009, 2012, Kress 2016) allows for the entire inventory of USACE-maintained federal navigation projects to be analyzed, sorted, and summarized per user-defined criteria.[27] CPT conducts nearest-neighbor matching of WCSC's Master Docks database with a spatial network representing USACE-maintained channels and waterways. The cumulative statistics for tons, dollar value, vessel draft, commodity types, and traffic types are then compiled for each individual reach (channel segment) in the network.[28]

CPT has been employed in several previous analyses, notably a recent gross benefit assessment of the CO-OPS' PORTS® (Wolfe 2016). The origin-destination cargo flow data that is readily available via CPT has been used as the objective function basis in several waterway and freight network optimization studies (Mitchell 2013, Khodakarami 2013, Kruse 2014), all of which consider the interdependencies that arise among portions of a transportation network with cargo flows that are shared across many segments. Other efforts (Rosati 2013, Dunkin 2015) have focused on quantifying the relative economic impacts to shipping interests as a result of channel shoaling and vessel draft restrictions. Internal to the USACE, CPT has been used within the annual maintenance dredging budget development cycle to generate channel throughput metrics that focus on just the cargo utilizing the five deepest feet of maintained depth (GAO 2017), since all else being equal, this is the cargo most vulnerable to year-to-year channel shoaling. Annualized throughput totals are shown in terms of cargo tonnage (short tons), cargo value (U.S. dollars), and vessel trip counts.[29] The data

[27] Special thanks is extended to Dr. Marin M. Kress (Research Physical Scientist, U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory) who was instrumental in provision of CPT data.

[28] CPT output can be selected from a large number of options to enable the researcher to focus on specific aspects of vessel and commodity movements Present channel conditions and historical shoaling rates are compared to the draft profile to determine the amount of cargo that is directly impacted by channel shoaling conditions.

[29] The Department of the Census supplies cargo value to the USACE. Under the January 2015 Memorandum of Understanding between the two agencies, cargo value cannot be made available to users outside of the USACE owing to data confidentiality concerns. Hence, cargo value in this study was obtained from the USA Trade Online database.

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is collated into a nested hierarchy that reflects the organizational structure of the Corps' Civil Works mission area: at the most granular level, navigation projects in CPT are divided into "reaches," which can represent individual berthing terminals within a port, or longer portions of channel that are maintained to consistent dimensions and for which the cargo throughput totals will be relatively stable (pending the distribution of any landside dock facilities). These channel reaches make up the spatial extent of federally authorized Navigation Projects, the next level within the CPT hierarchy and which the Corps of Engineers maintains to dimensions specified in Congressional legislation.

Commodity classifications are similarly organized within CPT, featuring a nested coding convention that ranges from 1-digit specificity (10 resulting cargo types) to a five-digit commodity code level with over 660 commodity types.[30] Per its Navigation mission in support of maritime commerce, the USACE actively maintains dredged channels in over 360 individual nationwide projects that are detailed across more than 970 areas or river segments.[31] While CPT does not provide origin or destination data involving specific vessel transits, that does not affect the value of the database as it is unique in its ability to identify the number of both international and domestic vessel transits at highly specific geographic levels.

7. MARINE ACCIDENT OVERVIEW

In order to place ACGs in perspective, it is prudent to establish the larger picture in which ACGs are reported. During the 2003 to 2016 period over 136,000 incidents were reported to the MISLE database across 122 categories.[32] During

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[30] The commodity code structure developed by WCSC is unique to the USACE and generally reflects the types of bulk commodities that are commonly encountered in waterborne transportation. Crosswalk tables are available to link the WCSC codes to other conventions such as the Harmonized System (HS) Commodity Code system. The USACE stores its commodity code data to five digits. While not as detailed as the Census Bureau's seven-digit commodity data, the CPT data is detailed enough for nearly all marine transportation research.

[31] Within CPT, a number of port locations are identified as "non-project," which refers to ports and waterways that are not federally authorized navigation projects. This does not mean that cargo cannot move there, just that the USACE has no authority or obligation to maintain those areas.

[32] Among the 122 MISLE categories were: abandoned/derelict, adrift (unmanned), alleged violation of law/regulation, anchored [unmanned], assist other agency, beset by weather, boating

the 2003 to 2004 period of time, anecdotal evidence suggests that "no consequence" incidents including "touch and go" groundings and "bump and go" allisions that did not result in any damages were not uniformly reported. Beginning in 2005 this changed as witnessed by the 80 percent (2003 to 2004) and 30 percent (2004 to 2005) increases in reported ACGs.[33] During the period 2005 to 2016, the 17,629 ACGs reported represented about 15 percent of all documented incidents (Figures 2 and 3). Consequently, research was focused on more complete data beginning in 2005. Overall, ACGs have been relatively rare events, occurring in little more than 0.05 percent of total vessel transits between 2008 and 2015.[34] Since 2011, there has been a general decline in reported ACGs (Figure 4). Overall, collisions result in much higher rates of mortality and vie with allisions as a major causal agent in morbidity (Table 1).

under the influence, breakaway, Bridge Closures, Capsize, Capsized Vessel, Cargo Transfer Monitor, Commercial Fishing Vessel Safety, Commercial Vessel Safety Enforcement, Disabled Vessel, Disoriented Vessel, Distress Alert - situation unknown, Diving Accident, Drug Trafficking, Enforcement of Security Zones and other Marine Events, Equipment Failure, Explosion, Facility Inspection, Fire, Flooding, Hazard to Navigation, Hazardous Vessel Operation, Heavy Weather Damage, Irregular Navigation Incident, Loss of Life/Injury, MAYDAY Broadcast, MEDEVAC, MEDICO, Near-miss Situation, Non-Maritime EMS, Transport, Outstanding Wants or Warrants, Overdue Person (Non-Maritime), Overdue Vessel, Person in Water, Personnel Casualty, Piracy, Pollution – Garbage, Pollution - Hazardous Material, Pollution - Medical/Infectious Waste, Pollution – Oil, Pollution – Sewage, PWCS Boarding, Recreational Boating Safety Enforcement, Security Assessment, Security Breach - Potential, Facility, Security Breach, Facility, Security Breach, Vessel, Sinking, Special Operation Suspicious Activity Report, Taking on Water, Towing Vessel Exam, Uncorrelated MAYDAY, Uninspected Towing Vessel Safety Enforcement, Unknown, Unreported Vessel, Vessel Inspection PSC, and Waterway Restriction/Closure, etc.

[33] In 2003, only 499 ACG events were recorded while 896 were reported in 2004. These represented only four and nine percent of all reported MISLE incidents, respectively, as compared with the 15 percent average for the 2005 to 2016 time period.

[34] From 33.5 million vessel transits.

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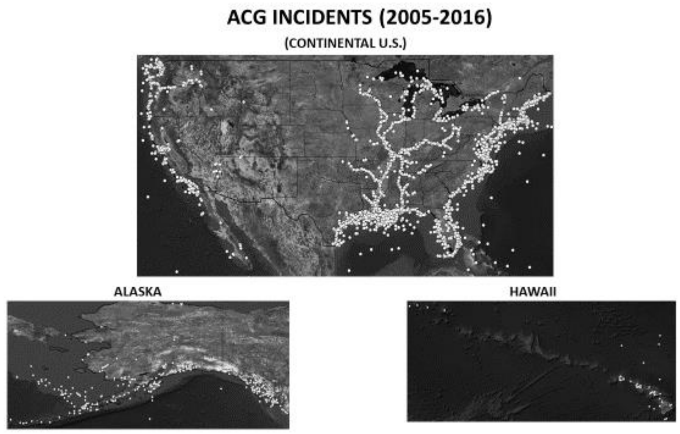

Figure 2.

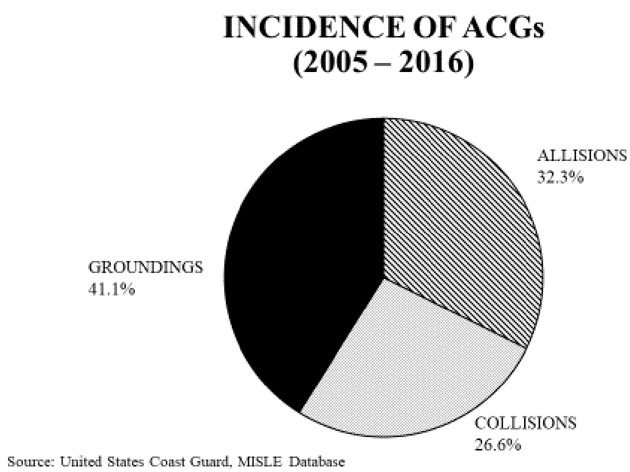

Figure 3.

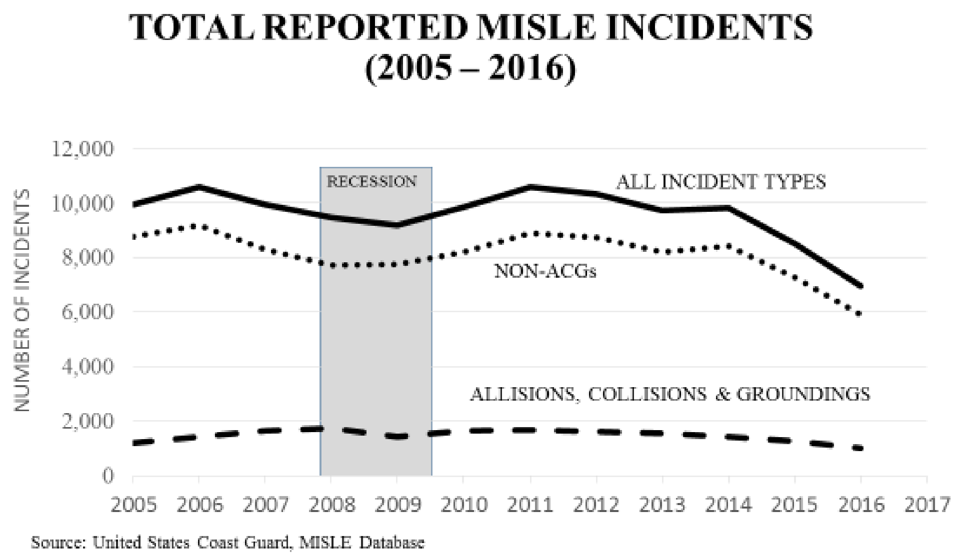

Figure 4.

INCIDENT TYPE	NUMBER OF INCIDENTS	NUMBER OF DEATHS	NUMBER OF INJURIES	DEATH RATE PER INCIDENT	INJURY RATE PER INCIDENT
Allision	5,702	6	421	0.11%	7.38%
Collision	4,685	58[35]	381	1.24%	8.13%
Grounding	7,242	3	161	0.04%	2.22%
Total	17,629	67	963	0.37%	5.46%

Table 1. Incidence of Mortality and Morbidity by Type of Incident

[35] Includes one missing person.

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8. PORT AND PORTS® IDENTIFICATION

During the 2003 to 2015 period, over 200 port locations imported and/or exported vessel traffic.[36] Of these, 77 locations, or about 31 percent of the total, had PORTS® installations in 2016 or before. A list of these locations is provided in Appendix A. Remaining locations without PORTS® are listed in Appendix B.

8.1 Matching ACGs with Locations with and without PORTS®

Where PORTS® had been installed, MISLE accidents were matched with an individual port location based on the area of surveillance or "influence" provided by PORTS® navigational aids. This was done through a "lassoing technique" based on the expertise of PORTS® managers.[37]

In cases where PORTS® had not been installed by the end of 2015, not knowing the locations or numbers of PORTS® sensory instruments which might be installed in the future, a series of three, five, and ten mile radii were drawn around these locations to estimate potential areas of influence if PORTS® were to be installed. During the assignment process, extreme care was exercised to prevent duplicative assignment of ACGs between existing areas with PORTS® and adjacent locations owing to overlapping radii with existing PORTS®' area of influence.

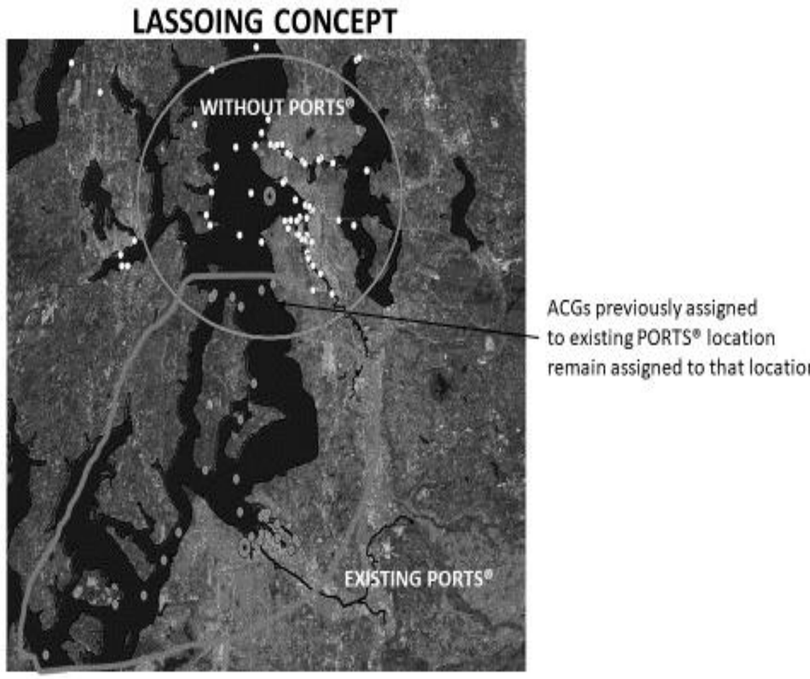
For example, accidents that had already been assigned to an existing PORTS® location (Tacoma, WA in the lower portion of Figure 5) were removed

[36] Note that import and export traffic was not transported through all 240 ports identified in USA Trade Online in each of the years from 2003 to 2015. The 13-year survey period was employed to assess long-term activity at these locations. For example, in 2016 the number of ports, which handled import and export goods, fell to 216. Some of this reduction in port count may have been due to mergers of one port's data with another owing to confidentiality concerns. The extent to which this may have occurred is not known.

[37] Special thanks to Darren Wright (Program Manager, Maritime Services, Center for Operational Oceanographic Products and Services, National Ocean Service, National Oceanic and Atmospheric Administration) for his assistance in identifying areas of PORTS® influence as well as Percy Pacheco (Environmental Engineer, Office of Coast Survey, National Ocean Service, National Oceanic and Atmospheric Administration) for his GIS support.

from the radii of a potential PORTS® location (Seattle, WA in the upper right portion of the figure).

Figure 5



As several of the locations without PORTS® were within three, five, or ten miles of one another, and it was impossible to know when and if these sites without PORTS® may receive them or the extent of those installations, overlaps of potential areas of influence among these potential sites were allowed to remain.[38] This resulted in a different manner in which the results of potential future benefits could be estimated. In this case, an initial ranking of locations without PORTS® was made employing the individual location's potential contribution to future benefits. It is fully understood that these estimates cannot be

[38] For example, in the port of Savanah, GA, a water level gauge with meteorological instrumentation (e.g., wind speed and direction, barometric pressure, air temperature, etc.) is located at Fort Pulaski while an air gap sensor is located more than 13 miles up-river at the Talmadge Memorial Bridge. Source: Conversation with Darren Wright, Manager, PORTS® CO-OPS, NOS, NOAA, March 3, 2017.

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summed to estimate a grand total – rather employed to provide an initial ordinal ranking of potential locations for future PORTS® installations.[39]

9. ANALTICAL APPROACH

Three approaches were employed to estimate the impact of PORTS® on ACG rates, which are estimated based on the maritime casualty event counts in the MISLE database and the vessel transit counts obtained from the Corps' Waterborne Commerce data via the CPT. The first was based on a direct comparison of ACG rates before and after PORTS® installation at the same location. The second was predicated on a brief span of time when a large number of PORTS® were installed. The final estimation compared beginning and ending years of the study (2008 with 2015) ACG rates at locations with and without PORTS®.

9.1 Direct Location Comparison

Ideally, ACG rates would be compared for several years before and after a PORTS® installation to estimate the impact of such changes. The use of several years of data could help overcome experiences in an atypical year. Absent documentation of major changes among all other types of navigational aids, it was assumed that the documented installation of PORTS® represented the most significant documentable change among ACG reduction agents.

Seven port locations had been installed which provided a sufficient number of "before" and "after" ACG events (Table 2). If PORTS® had been installed in November 2010, all ACGs and vessel counts for 2010 would be assigned to the "without (PORTS®)" period. ACGs and vessel counts for 2011 and later would be assigned to the "with (PORTS®)" group. As this approach reduces some of the benefits of PORTS® through assignment of ACG events that occurred within the partial year of PORT® installations (e.g., transfers to the "without" group), it is likely that this methodology will result in a conservative estimate of gross PORTS® benefits.

[39] In the partnership between a port authority and NOAA, the determinations for future PORTS® locations can be based on the goals improving personal safety, preservation of property, and enhanced environmental protection. PORTS® investments can result in different levels of improvement at varying locations based on the types of ACGs that are prone to occur there and the types of cargo handled.

PORTS® NAME	MONTH / YEAR INSTALLED	FIRST FULL YEAR OF PORTS® OPERATION	PERIOD BEFORE PORTS® INSTALLATION	PERIOD AFTER PORTS® INSTALLATION
Beaumont, TX	5 / 2010	2011	2008 - 2010	2011 - 2015
Orange, TX	5 / 2010	2011		
Port Arthur, TX	5 / 2010	2011		
Sabine Pass, TX	5 / 2010	2011		
Anacortes, WA	11 / 2010	2011		
Humboldt / Eureka, CA	12 / 2012	2013	2008 – 2012	2013 - 2015
New London / Groton, CT	12 / 2012	2013 [40]		

Table 2. Before and After PORTS® Location ACG Comparisons.

Ultimately, only seven of all PORTS® locations could be compared on a full year's basis at least three years before and after installation (Table 2). Among these seven locations reviewed in this manner, evidence suggests reductions among all types of ACGs occurred once PORTS® had been installed (Table 3).

TYPE OF INCIDENT	ACG RATE BEFORE PORTS®	ACG RATE AFTER PORTS®	PERCENT CHANGE
Allisions	0.0147%	0.0089%	-39.4%
Collisions	0.0130%	0.0049%	-62.6%
Groundings	0.0123%	0.0087%	-20.3%
All ACGs	0.0401%	0.0225%	-43.9%

Table 3. ACG Rates Before and After PORTS® Installations at Seven Identical Locations.

[40] Matching the precise day of PORTS® installation with the date of the ACG was not performed for several reasons. First, while the month of PORTS® installation was known, the exact day was not recorded. Second, to provide users with a chance to become acclimated to PORTS® information, time was added to the installation date. No PORTS® were installed during 2011 that could have made use of before data from 2008-2011 and after data from 2012-2015.

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In these instances, PORTS® appeared to have differential impacts on ACG reductions -- most effective in collisions and allisions and to a lesser rate with groundings.

Although at the low end of the range of Kite-Powell's (2010) earlier estimates, direct before and after comparison at these seven locations suggest at least a 20 percent reduction in groundings was due to PORTS®. The drawback to this approach is the number of locations and the level of traffic these seven port locations serve as these places represent less than ten percent of all locations with PORTS® and little more than two percent of all vessel transits during the 2008 to 2015 study period.

9.2 Major PORTS® Installation Period

A second approach to estimate the portion of ACG reductions due to PORTS® installations was made involving changes in ACG rates which occurred during a time of rapid expansion in the number of PORTS® installations. During the 2008 to 2010 period, 17 new PORTS® facilities were installed in Mississippi, Louisiana, Texas, and California. [41] These additions increased the portion of total vessel transits covered by PORTS® from 38 to 67 percent (Figure 6). During this timeframe allision rates declined over 53 percent, while collision rates dropped by almost 39 percent (Figure 7). The nearly 53 percent reduction in the rate of groundings was also in line with the earlier estimates from Kite-Powell (2010). Overall, the 17-site expansion of PORTS® increased vessel transit coverage by 76 percent, while a 51 percent decline in total ACG rates occurred.[42]

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[41] The 17 ports included: (1) Gulfport, MS; (2) Pascagoula/Moss Point, MS; (3) Avondale, LA; (4) Baton Rouge, LA; (5) Empire/Venice, LA; (6) Good Hope, LA; (7) Gramercy, LA; (8) Lake Charles/Cameron, LA; (9)New Orleans, LA; (10) Port of Plaquemines, LA; (11) South Louisiana, LA; (12) Port of Stockton/St. Rose; (13) Anacortes, WA; (14) Beaumont, TX; (15) Orange, TX; (16) Port Arthur, TX; and, (17) Sabine Pass, TX.

[42] Vessel transits within the influence of PORTS® increased from 1.69 to 2.73 million from 2008 to 2010. Source: CPT/WCSC.

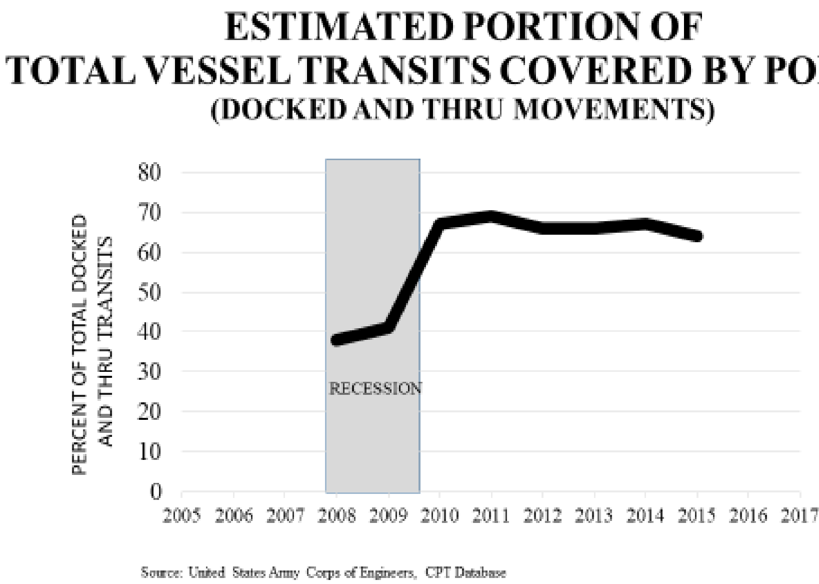

Figure 6

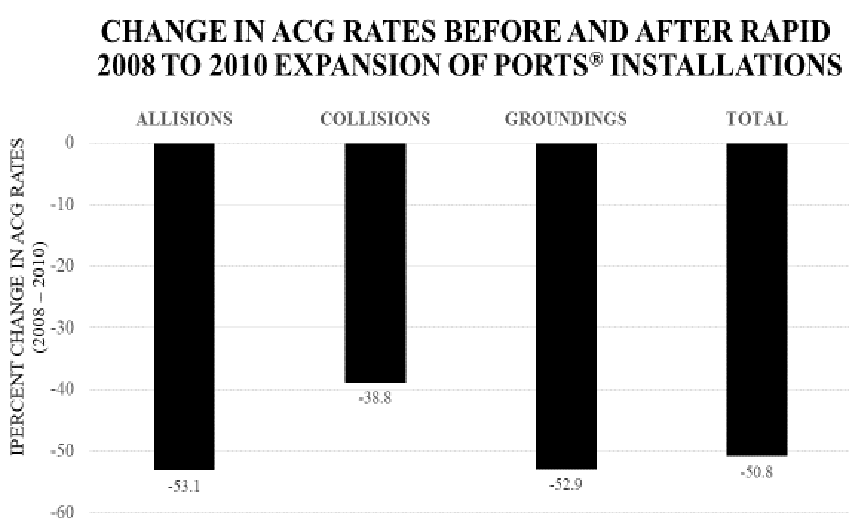

Figure 7

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The extent to which other navigational aids were enhanced or more efficiently utilized at these locations is the underlying question in attributing ACG reductions to PORTS® versus all other navigational aids. During the 2008 to 2010 timeframe, enhancements in all navigation aids (e.g., AIS data, electronic navigational charts) as well as improved knowledge and use of such technological supports undoubtedly took place alongside the expansion of the 17 additional PORTS® installations. Enriched management and human factor training, including boosted safety management systems, greater bridge resource management, boosted crew endurance, and anti-fatigue programs, were certainly further refined and expanded.[43] However, without documentation to identify significant advances or increased utilization of other navigational aids and technological and managerial systems at these locations during the timeframes and where reductions in ACG rates occurred following PORTS® installations, advances among these other navigational aids was deemed to be more evolutionary than revolutionary as compared with expanded use of PORTS®. In other word, the addition of PORTS® was seen as a dominate factor in ACG reductions.

9.3 Long Term Evaluation of ACG Changes

A third method to assess the impact of PORTS® installations is a comparison between the first year (2008) and last year (2015) of the analysis. Employing the same ACG assignment methodology to “with” and “without” PORTS®, a comparison between the first and last year vessel transit data was made to calculate changes in ACG rates (Table 4). Comparison of the base year (2008) with the last year transit count data was available (2015) suggested that the number of vessel transits that occurred at locations with PORTS® per ACG event increased by almost 163 percent. At the same time, the number of vessel transits per ACG event that occurred at locations without PORTS® declined by almost 31 percent. As this analysis did not measure the distance from shore of any of the ACGs which occurred outside the area of influence from a PORTS® installation, the without PORTS® figures cannot be directly interpreted as a potential measure

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[43] Critical skills include enhanced communication, teamwork, decision-making, and situational awareness. Refer to: https://www.marineinsight.com/guidelines/understanding-bridge-resource-management-and-its-key-elements-on-board-ships/

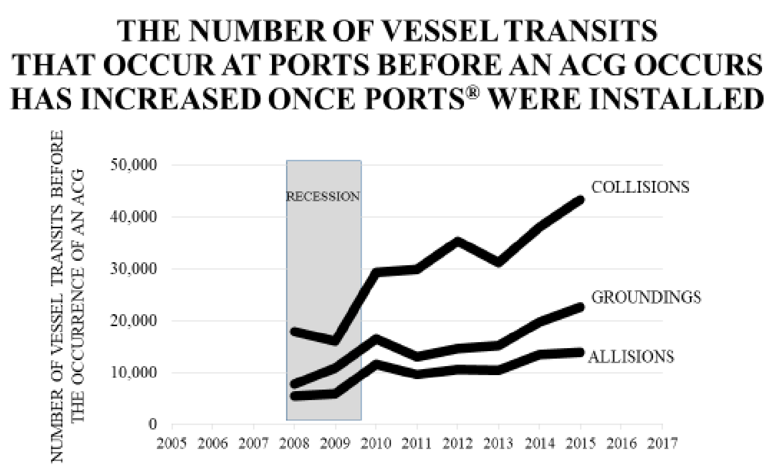
of future ACG reductions should PORTS® be universally installed. In some cases, the ACGs occurred at more than 10 miles from shore.

TYPE OF INCIDENT	2008 ACCIDENT RATE	2015 ACCIDENT RATE	2008 VESSEL TRANSITS PER INCIDENT	2015 VESSEL TRANSITS PER INCIDENT	PERCENT CHANGE
ALLISION	0.0184%	0.0072%	5,446	13,461	154.7%
COLLISION	0.0056%	0.0023%	17,960	38,112	141.4%
GROUNDING	0.0129%	0.0044%	7,744	22,556	191.3%
TOTAL	0.0368%	0.0139%	2,714	6,624	164.1%

Table 4. Number of Vessel Transits Before An ACG Incident Occurs (2008 Compared With 2015 for PORTS® Locations).

Another way to present before and after results is calculation of the number of vessel transits that took place for each reported ACG (Figure 8). The number of vessel transits that occurred per grounding at a location with PORTS® increased over 190 percent. Vessel transits per allision increased by almost 155 percent and transits per collision increased 141 percent at PORTS® locations.

Figure 8.



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10. MORBIDITY AND MORTALITY COST ESTIMATION

10.1 Value of Mortality Risk Reduction

In assessing the potential benefits associated with reductions in injuries and deaths resulting from AGGs, dollar values associated with these events must be calculated. In performing analysis of their programs, most Federal agencies have sought to identify these values through estimations of a Value of Statistical Life Year (VSLY). VSLY represents an approach to view the risks that people are voluntarily willing to take and how much they must be paid for taking them Mankiw (2012). The Willingness To Pay (WTP) to avoid the risk of a fatal injury increases proportionally with growing risk.[44]

Given the conservative nature of this analysis and the transportation-related nature of the injuries and deaths that could be reduced through timely accurate and complete use of more rigorous navigational data, the U.S. Department of Transportation's (DOT) figure of $9.4 million ($2015) was selected.[45]

10.2 Value of Injury Reduction

The National Highway Transportation Safety Administration (NHTSA) has calculated comprehensive transportation-related accident costs through the "Maximum Abbreviated Injury Scale" (MAIS).[46] The Office of the Secretary of

[44] Refer to US Department of Transportation. 2015. "Revised Departmental Guidance 2014: Treatment of the Value of Preventing Fatalities and Injuries in Preparing Economic Analyses", June 17. Downloaded October 7, 2016. https://www.transportation.gov/sites/dot.gov /files/docs/VSL2015_0.pdf

[45] In this analysis, a constant $9.4 million was universally employed regardless of the victim's age. As it represented a 2015 value and was applied to all deaths and prorated for injuries, it did not have to be converted to 2015 dollars. Other researchers (e.g., Muller et al. 2011) have suggested varying VSL based on age and have employed up to 19 age groups in their analysis of the population at risk due to pollution.

[46] National Highway Transportation Safety Administration, *The Economic Impact of Motor Vehicle Crashes 2000*, May 2002; FHWA, "Treatment of Value of Life and Injuries in Preparing Economic Evaluation", January 8. 1993.

Transportation (OST) calculated relationships between the MAIS indicating injury severity and the portion of WTP value (Table 5).[47]

DOT AIS LEVEL OF SEVERITY	INJURY SEVERITY	FRACTION OF THE VSL OF AN AVERTED FATALITY[48]	VSL FOR AN AVERTED INJURY OR DEATH[49] (2015 Dollars)
AIS 1	Minor	0.003	$28,200
AIS 2	Moderate	0.047	$441,800
AIS 3	Serious	0.105	$987,000
AIS 4	Severe	0.266	$2,500,400
AIS 5	Critical	0.593	$5,574,200
AIS 6	Unsurvivable	1.000	$9,400,000[50]

Table 5. Willingness to Pay to Avert Injuries.[51]

Beginning in 2011, the USCG reported not only the number of injuries but also the level of injury severity for each accident.[52] Of the 824 reported injuries during 2011 to 2015, over 59 percent were classified as "minor".[53] From this

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[47] The Department of Transportation refers to this scale as the "Abbreviated Injury Scale (AIS)".

[48] Refer to Table 2, Relative Disutility Factors by Injury Severity Level, Page 10, U.S. Department of Transportation, 2015. *Guidance on treatment of the Economic Value of a Statistical Life (VSL) in the U.S. Department of Transportation Analysis – 2015 Adjustment*, June 17. Downloaded March 22, 2017 from https*://www.transportation.gov/office-policy/transportation-policy/revised-departmental-guidance-on-valuation-of-a-statistical-life-in-economic-analysis.*

[49] Employing 2015 Department of Transportation's value of $9.4 million.

[50] Note: the total WTP values do not add up to $9.4 million due to the rounding of the AIS fractions in DOT Table 2.

[51] Source: U.S. Department of Transportation, 2015. *Guidance on Treatment of the Economic Value of a Statistical Life (VSL) in the U.S. Department of Transportation Analysis – 2015 Adjustment,* June 17. Table 2.

[52] The USCG does not claim that its injury scale is the AIS scale. The descriptions of the levels in the CG and AIS are similar, such that the match-up in Table 3 provides a way to monetize injuries. This approach was used in the Inspection of Towing Vessel and other rulemakings.

[53] While an additional 36 injuries were reported, upon closer examination, the USCG determined that their severity was less than "minor" and subsequently excluded from the analysis.

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distribution, the expected average cost of injuries, where severity had not been reported in earlier years, could be calculated (Table 6). Following this procedure, the average cost of an injury where severity was not delineated was estimated to be approximately $336,000 ($2015) (Table 7).

DOT AIS SCALE LEVEL OF SEVERITY	USCG SCALE OF INJURIES	INJURY SEVERITY	NUMBER OF REPORTED INJURIES (2011-2015)	PERCENT OF TOTAL INJURY REPORTS
AIS 1	1	Minor	487	59.1%
AIS 2	2	Moderate	228	27.7%
AIS 3	3	Serious	83	10.1%
AIS 4	4	Severe	21	2.5%
AIS 5	5	Critical	5	0.6%
AIS 6		Unsurvivable		

Table 6. USCG Distribution of ACG Injury Severity.

Source: United States Coast Guard MISLE database (2011 – 2015)

USCG SCALE OF INJURIES	INJURY SEVERITY	PERCENT OF TOTAL USCG INJURY REPORTS	VSL FOR AN AVERTED INJURY (2015 Dollars)	PERCENT TIMES VSL (Column 3 * Column 4) 2015 Dollars
1	Minor	59.1%	$28,200	$16,667
2	Moderate	27.7%	$441,800	$122,246
3	Serious	10.1%	$987,000	$99,419
4	Severe	2.5%	$2,500,400	$63,724
5	Critical	0.6%	$5,574,200	$33,824
		EXPECTED COST:		**$335,879**

Table 7. Estimation of Expected Average Injury Cost.

Source: United States Coast Guard MISLE database (2011 – 2015) and U.S. Department of Transportation, 2015.

To estimate gross benefits of reduction in morbidity and mortality, overall accident rates were estimated predicated on average vessel transit counts during the 2008 to 2015 period. To ensure a conservative approach, vessel transits for locations with PORTS® were compared with locations without PORTS®. Adjustments were necessary to help ensure that vessel transit counts were not overstated for PORTS® locations (Table 8).[54]

MEASUREMENT	DEATHS & MISSING	INJURIES
2008-2015 ACCIDENT RATES AT LOCATIONS WITH PORTS®	0.00005%	0.00161%
2008–2015 ACCIDENT RATES AT LOCATIONS WITHOUT PORTS®	0.00023%	0.00269%
NUMBER OF INCIDENTS AT LOCATIONS WITHOUT PORTS®	3.9	45.9
NUMBER OF INCIDENTS AT LOCATIONS WITH PORTS®	1.2	39.9
ANNUAL DIFFERENCE IN FREQUENCY	2.8	6.1
ANNUAL LOSS SAVINGS (@ $9.4 million per death, $335,879 per injury)	$26.3M	$2.0M

Table 8. Morbidity and Mortality at PORTS® and NON-PORTS® Locations (2008 to 2015).

Based on the expected number of deaths and injuries that occurred during the study period, almost three fewer deaths and six fewer injuries occurred in areas with PORTS® than would have been expected had PORTS® not been installed. Employing a value of a life of $9.4 million and cost of an average accident of $0.34 million, annual reductions resulting from human-based losses were estimated at approximately $28.4 million. Over ten years, this would equate

[54] About 148 thousand vessel transit counts were subtracted from locations with PORTS® to reflect the time during an installation year when PORTS® were yet to be installed. For example, if PORTS® was installed in July of a given year that location vessel transits were not assigned to the "after" group (locations with PORTS®) until the following year. While this ultimately assigned some PORTS® and other navigational aid benefits to the "before installation" group, it helped ensure a conservative approach where the number of transits with PORTS® would be otherwise overstated.

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to a present value in excess of $244 million from 28 fewer deaths and 61 fewer injuries.[55]

10.3 Property Loss Reductions

Property losses for the "average" ACG was estimated to exceed $71 thousand ($2015) (Table 9).

LOSS TYPE	AVERAGE LOSS PER ALLISION, COLLISION OR GROUNDING (Thousands of $2015)	PROPERTY LOSS TOTAL (Thousands of $2015)
Vessel	$30.7	$71.4
Cargo	$0.9	
Facility	$18.5	
Other	$21.5	

Table 9. Average Property Losses Per ACG (2005 to 2016).

Examination of the ACGs that occurred between 2008 and 2015 revealed the rate of ACGs where property loss occurred was 0.00019 per vessel transit at locations with PORTS® and 0.00054 at locations without PORTS®. Employing the differential in property loss rates suggests about 176 fewer incidents occur at locations with PORTS®. This equates to over $13.5 million per year from an additional 189 property loss incidents that would have occurred. Over ten years this could exceed $116 million in savings.

11. POTENTIAL PORTS® INSTALLATION VALUE

According to the USCG's MISLE database, during the 2005 to 2016 study period, 116 of the 163 port locations without PORTS® experienced one or more ACG incidents. Almost 2,300 ACGs occurred within a ten-mile radius of port locations that did not have PORTS® installed. Within a five-mile radius of locations without PORTS®, 1,514 ACGs were reported. Closer to each of these locations, 944 occurred within a three-mile radius of the ports without PORTS®.

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[55] Employing the 2.8 percent discount rate reflecting the expected ten-year life of PORTS® instruments. Source: Office of Management and Budget, Circular Number A-94, January 21, 2015.

Collectively, within 10 mile radii, allisions accounted for 34 percent of events while collisions and groundings represented 27 and 39 percent, respectively. These accidents represented approximately $241 million ($2015) in total losses. The majority of these losses (67 percent) was from vessel, facility, cargo and other damages. Mortality and morbidity losses exceeded $28 million (12 percent) and $51 million (21 percent), respectively.[56] While average total losses from all ACG types averaged $106 thousand, one allision in 2013 represented orders of magnitude higher than historical levels and illustrates the potential high degree of variability over time.[57]

Due to the overlap of area of influence should PORTS® be installed in adjacent locations, along with lack of knowledge of the scope of such installations, it is not possible to develop a precise value of potentially averted losses. It is possible to identify the top 20 percent of non-PORTS® locations where the largest number of ACGs occurred and estimate ACG rates through application of CPT transit counts (Table 10).[58] While not precise, it is also possible to project a less than perfect estimate of the maximum gross benefit that would occur if no overlap occurred.

PORT NAME	STATE	TOTAL NUMBER OF ACGs	ACG RATES	VESSEL TRANSITS PER ACG
Beaufort	NC	38	0.01260	3,017
Panama City	FL	33	0.00247	13,362
Brownsville	TX	29	0.00137	21,229
Chicago	IL	31	0.00132	23,457
Miami	FL	60	0.00112	53,429
Boston	MA	52	0.00105	49,760
Perth Amboy	NJ	35	0.00099	35,220
Honolulu	HI	42	0.00072	58,146
Vicksburg	MS	26	0.00045	57,452

[56] Three deaths (one in 2009, 2010 and 2014) resulted from collisions during the study period.

[57] The allision between the merchant vessel *Herbert C. Jackson* and the West Jefferson Avenue bridge in Detroit, Michigan resulted in losses exceeding $50 million or almost 87 percent of total allision losses for 2013.

[58] These 23 locations accounted for about 74 percent of ACGs are named port locations.

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PORT NAME	STATE	TOTAL NUMBER OF ACGs	ACG RATES	VESSEL TRANSITS PER ACG
Detroit	MI	24	0.00043	55,421
Port Everglades	FL	29	0.00031	93,138
Wilmington	NC	57	0.00028	204,921
San Diego	CA	34	0.00027	127,411
Peoria	IL	50	0.00026	192,329
Freeport	TX	65	0.00025	256,437
Matagorda	TX	36	0.00019	191,267
St. Louis	MO	115	0.00018	635,988
Louisville	KY	61	0.00012	515,268
Seattle	WA	43	0.00007	594,173
Corpus Christi	TX	89	0.00006	1,418,235
Greenville	MS	47	0.00004	1,155,656
Charlotte Amalie	VI	37	-	Not Available

Table 10. Largest ACG Rates at Locations Without PORTS® (2008 to 2015).

Costs resulting from morbidity, mortality and property damages at all locations without PORTS® totaled in excess of $241 million (2,271 ACG events). Based on an average loss of about $106 thousand per ACG, if PORTS® were to be installed at all remaining major inland and coastal ports with significant histories of ACGs, maximum added benefits would be less than $58 million based on attributing 51 percent of total reductions in losses to PORTS®.[59]

12. CONCLUSIONS

Precise estimation of reductions in ACG rates and resultant benefits among the myriad of individual navigational aids (e.g., PORTS®, navigational maps, crew performance, pilot expertise, vessel design, etc.) is not practical, due to unknown utilization rates of the respective technologies as well as uncertainty concerning the degree to which these advances contribute to ACG rates reductions.

[59] Refer to "Total" impact in Figure 7.

However, it is more than coincidental that significant reductions in ACG rates occurred immediately following the installation of PORTS® at 17 additional locations between 2008 and 2010, before and after installation at an identical group of seven ports, and in the longer term of 2008 to 2015 when PORTS® coverage of vessel transits more than doubled (Figure 9). Installation of PORTS® resulted in estimated reduction of annual losses approaching $42 million. Over ten years this equates to a present value savings of approximately $360 million.

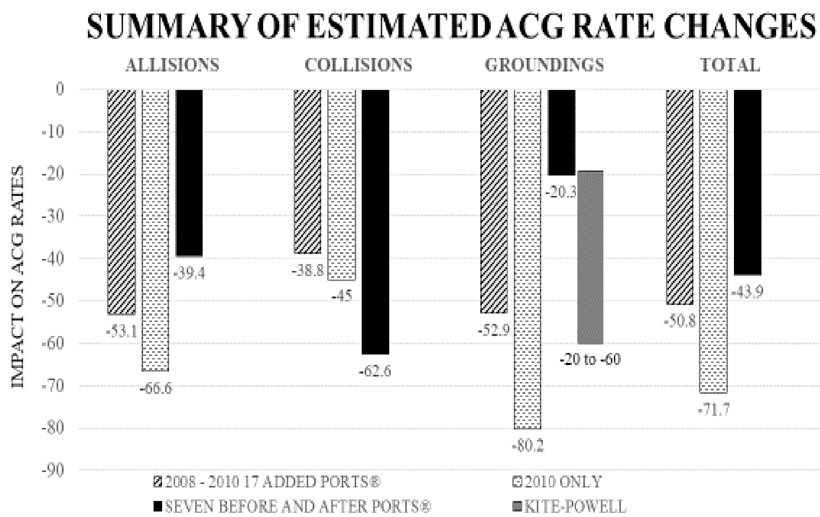

Figure 9

While historical estimates approach 72 percent, previous estimates (Wolfe 2016) of ACG rates employing only 2010 data may not have been representative of the longer term. From the current analysis, it would appear that installation of PORTS® reduced overall ACG rates between 44 and 51 percent. Both approaches employed in the current estimation agreed with the earlier 20 to 60 percent range of reductions in grounding provided by Kite-Powell (2010). Interesting to note is the change in ACG rates that occurred at all other locations without PORTS®. Between 2008 and 2015, ACG rates at these locations increased 28 percent (Table 11).[60] Future updating of this analysis when additional data becomes available can

[60] These incidents occurred at all distances from shore.

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assist in more precise estimation of the long-term impact of PORTS® on ACG rate reduction.

TYPE OF INCIDENT	2008 RATE	2015 RATE	PERCENT CHANGE
Allision	0.0138%	0.0169%	18.1%
Collision	0.0046%	0.0064%	27.6%
Grounding	0.0199%	0.0301%	33.7%
Total	0.0384%	0.0533%	28.1%

Table 11. ACG Rate Changes at Locations Without PORTS®.

REFERENCES

Dunkin, L., Mitchell, K. 2015. *"Quantitative Approach to Navigation Channels Asset Management."* Proceedings of Western Dredging Association and Texas A&M University Center for Dredging Studies' Dredging Summit and Expo *2015*. June.

Edwing, Richard, 2013. *"Improving Safety and Efficiency Through PORTS®"*, AAPA Seaports Magazine, Summer, accessed October 1, 2013, http://www.nxtbook.com/naylor/AAPQ/AAPQ0213/index.php?startid=29

Government Accountability Office, 2017. Report to Congressional Committees. *"Inland Harbors: The Corps of Engineers Should Assess Existing Capabilities to Better Inform Dredging Decisions."* GAO-17-635. July.

Khodakarami, A., Mitchell, K., Wang, B. 2014. *"Modeling Maintenance Project Selection on a Multimodal Transportation Network."* Transportation Research Record: Journal of the Transportation Research Board, No. 2409, Transportation Research Board of the National Academies, Washington, D.C.

Kite-Powell, Hauke, 2005. "*Estimating Economic Benefits from NOAA PORTS® Information: A Case Study of Tampa Bay",* report for the Tampa Bay Harbor Safety and Security Committee, July.

Kite-Powell, Hauke, 2007. *"Estimating Economic Benefits from NOAA PORTS® Information: A Case Study of Houston / Galveston",* report for the Houston Ship Channel users and Ports of Houston and Galveston, March.

Kite-Powell, Hauke, 2010. *"Estimating Economic Benefits from NOAA PORTS® Information: A Case Study of the Columbia River"*, report for the National Oceanic and Atmospheric Administration's Center for Operational Oceanographic Products and Services, June.

Kress, M., Mitchell, K. N., DiJoseph, P., 2016. *Marine Transportation System Performance Measures*. ERDC/CHL- TR-16-8. Vicksburg, MS: U.S. Army Engineer Research and Development Center. http://erdc.summon.serialssolutions.com/2.0.0/link?t=1481240527698

Kruse, J., et al., 2014. "*Integrating MTS Commerce Data with Multimodal Freight Transportation Performance Measures to Support MTS Maintenance*

https://cbe.miis.edu/joce/vol5/iss1/4
DOI: 10.15351/2373-8456.1091

Investment Decision Making". National Cooperative Freight Research Program, Report #42. Transportation Research Board. Washington, D.C., September.

Mankiw, Gregory, 2012. *"Principles of Economics"* Sixth Edition, South Western Cengage Learning, Mason, OH.

Mitchell, K. N. 2009. *"Depth-Utilization Analysis for Estimating Economic Activity Supported by Dredging." Terra et Aqua*. International Association of Dredging Companies. Number 116. September.

Mitchell, K. N. 2012. "*A Review of Coastal Navigation Asset Management Efforts Within the Coastal Inlets Research Program (CIRP): Part 2: The Channel Portfolio Tool."p* ERDC/CHL CHETN-IV-29. Vicksburg, MS: U.S. Army Engineer Research and Development Center. http://chl.erdc.usace.army.mil/chetn

Mitchell, K. N., Wang, B., Khodakarami, A. 2013. *"Selection of Dredging Projects for Maximizing Waterway System Performance"* Transportation Research Record: Journal of the Transportation Research Board, No. 2330, Transportation Research Board of the National Academies, Washington, D.C., pp. 39–46. DOI: 10.3141/2330-06

Muller, N., R. Mendelsohn and W. Nordhaus. 2011. *"Environmental Accounting for Pollution in the United States Economy"*, American Economic Review 101: pp 1649-1675.

Office of Management and Budget, *Circular Number A-94*, January 21, 2015.

Rosati, J.D., Beck, T., Lillycrop, J., Mitchell, K.N., Sanchez, A., and Li, H. 2013. *"Coastal inlet navigation research in the U.S. Army Corps of Engineers,"* Proceedings, Coastal Dynamics 2013, Arachon, France, pp.15-24.

Wolfe, K. Eric and MacFarland, David, 2016. *"A Valuation Analysis of the Physical Oceanographic Real Time System (PORTS®),"* Journal of Ocean and Coastal Economics: Vol. 3, Issue 1, Article 12.

APPENDIX A

INTERNATIONAL TRAFFIC AT LOCATIONS WITH PORTS® INSTALLED AS OF 2016

COUNT	PORT LOCATION	MONTH / (July if not known) YEAR PORTS® INSTALLED	TOTAL TONNAGE VESSELS (SHORT TONS)	TOTAL TONNAGE-CONTAINERS (SHORT TONS)	TOTAL CARGO VALUE VESSELS ($2015 DOLLARS)	TOTAL CARGO VALUE CONTAINERS ($2015 DOLLARS)
1	Alameda, CA	7/1995	36,394	5,439	$20,307,776	$15,545,241
2	Alexandria, VA	2/7003	310,668	2,482	$176,879,756	$3,421,695
3	Anacortes, WA	11/2010	40,216,439	2,768,236	$20,520,968,584	$42,094,271
4	Anchorage, AK	7/2002	66,822,648	8,114,259	$50,341,585,373	$9,057,172,841
5	Annapolis, MD	7/2003	285,233	35,632	$291,813,827	$135,666,205
6	Astoria. OR	7/2005	1,676,468	289,717	$317,390,794	$39,036,801
7	Avondale, LA	10/2009	2,950,596	341,808	$909,870,533	$709,244
8	Baltimore, MD	7/2003	404,459,462	91,118,556	$602,108,708,286	$251,723,707,575
9	Baton Rouge, LA	10/2009	331,805,519	34,634,133	$144,077,104,634	$3,446,014,161
10	Beaumont, TX	5/2010	362,491,286	26,093,677	$182,798,391,743	$3,640,289,365
11	Cambridge, MD	7/2003	55,841	1,743	$17,464,347	$8,100,118
12	Camden/Gloucester, NJ	7/2002	4,556,670	2,382,639	$3,931,614,677	$1,292,714,979
13	Cape Cod (Provincetown), MA	7/2016	4,304	3,319	$4,303,374	$3,053.842
14	Charleston, SC	5/2013	247,884,152	155,949,810	$819,781,963,023	$612,285,291,904
15	Chester, PA	7/2002	109,050,768	18,219,804	$109,720,781,570	$54,807,099,631
16	Cleveland, OH	7/2016	31,128,182	2,268,219	$6,925,788,699	$853,387,854

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17	Crisfield, MD	7/2003	731,672	409		
18	Empire/Venice, LA	10/2009				
19	Fall River, MA	7/2000	18,431,713	834,172	$1,090,990,893	$40,106,555
20	Galveston/Bolivar, TX	7/1996	174,212,823	9,184,008	$93,117,439,756	$8,468,659,119
21	Gloucester City, NJ	7/2002	328,690	113,320	$407,441,789	$156,985,457
22	Good Hope' LA	10/2009	31,347,356	126,182	$8,192,428,516	$3,740,636
23	Gramercy, LA	10/2009	768,981,912	67,230,394	$247,955,626,613	$2,979,711,624
24	Gulfport, MS	6/2008	26,226,031	19,030,683	$40,171,167,437	$32,647,613,650
25	Hopewell, VA	7/2003	4,139,675	430,098	$842,686,024	$5,677,253
26	Houston, TX	7/1996	1,991,819,508	376,015,682	$1,767,721,577,089	$581,471,266,371
27	Humboldt/Eureka, CA	12/2012	2,105,019	256,832	$384,129,155	$28,398,129
28	Jacksonville/Mayport, FL	6/2014	151,119,776	32,381,978	$277,935,912,909	$72,340,201,220
29	Kalama, WA	7/2005	126,644,256	12,795,118	$40,653,242,468	$145,251,679
30	Lake Charles/Cameron, LA	5/2009	427,335,432	32,867,597	$181,720,429,959	$968,823,869
31	Long Beach, CA	7/2001	560,985,478	294,098,850	$1,215,066,867,563	$1,012,424,611,763
32	Longview, WA	7/2005	82,263,001	11,890,478	$22,863,677,994	$449,170,357
33	Los Angeles, CA	7/2001	970,296,573	657,421,397	$3,371,916,779,168	$2,863,443,393,077
34	Marcus Hook, PA	7/2002				
35	Martinez, CA	7/1995	62,539,913	8,360,338	$36,090,255,229	$6,955,159
36	Mobile, AL	12/2007	414,469,988	55,589,442	$134,881,157,841	$33,478,626,853
37	Morgan City, LA	5/2015	640,998,080	26,834,733	$329,413,650,664	$537,839,455
38	New Castle, DE	7/2002				
39	New Haven, CT	7/2004	39,690,339	2,661,980	$22,428,422,850	$97,738,843
40	New London/Groton, CT	12/2012	2,253,967	251,589	$2,655,152,004	$62,119,809
41	New Orleans, LA	10/2009	1,296,346,356	170,114,843	$598,042,235,517	$114,520,245,059

35

42	New York, NY	7/1994	274,123,748	144,083,803	$652,248,766,595	$485,862,668,583
43	Newark, NJ	7/1994	780,289,143	321,992,070	$1,703,799,398,799	$1,197,488,278,306
44	Newport, RI	7/2000	3,464,975	262,258	$1,081,477,166	$80,558,006
45	Newport News, VA	7/2003	154,171,181	5,915,152	$31,491,676,748	$10,374,878,745
46	Nikishka/Kenai, AK	7/2002				
47	Norfolk-Newport News/ Hampton Roads, VA	7/2003	515,943,514	193,194,604	$724,984,614,320	$610,859,056,912
48	Oakland, CA	7/1995	236,751,726	160,805,006	$551,039,115,531	$478,893,922,248
49	Orange, TX	5/2010	74,894	7,220	$351,454,850	$41,398,400
50	Pascagoula, Moss Point, MS	8/2008	307,012,756	17,018,948	$137,257,814,476	$913,106,226
51	Paulsboro, NJ	7/2002	41,483,376	7,434,271	$26,111,383,185	$9,952,938
52	Pennsbury Manor, PA	7/2002				
53	Philadelphia, PA	7/2002	562,511,156	47,061,959	$378,931,743,074	$91,014,180,700
54	Plaquemines, Port of, LA	10/2009				
55	Port Arthur, TX	5/2010	605,180,556	49,829,063	$463,462,068,438	$5,365,790,690
56	Port Fourchon, LA	7/2015				
57	Port Manatee, FL	8/1991	28,790,677	6,674,881	$10,139,730,603	$2,437,707,364
58	Portland, OR	7/2005	213,933,351	39,348,455	$183,479,616,270	$44,157,869,590
59	Providence, RI	7/2000	66,178,415	6,701,160	$80,107,287,746	$3,255,694,131
60	Redwood City, CA	7/1995	14,254,694	1,021,445	$300,632,143	$5,322,679
61	Richmond, CA	7/1995	159,464,020	19,381,633	$103,441,101,502	$4,573,317,646
62	Richmond/Petersburg, VA	7/2003	3,915,065	3,191,292	$12,260,597,980	$11,101,434,292
63	Sabine Pass, TX	5/2010	1,581,272	164,756	$568,901,277	$36,460,787
64	San Francisco, CA	7/1995	69,518,188	7,081,942	$51,554,958,621	$7,793,509,517
65	Sault Ste Marie, MI	6/2001	13,257,102	1,328,900	$1,186,344,142	$152,555,024

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66	Savannah, GA	8/2016	419,488,328	253,359,155	$781,609,045,626	$624,767,144,834
67	Soo Locks, MI	6/2001				
68	South Louisiana, Port of, LA	10/2009				
69	St. Petersburg/Weedon Island, FL	8/1991	38,843	934	$108,612,508	$5,422,617
70	St. Rose, LA	10/2009	17,485,694	452,496	$7,347,807,929	$259,410
71	Tacoma, WA	7/2004	240,612,007	124,705,557	$510,824,472,483	$414,580,152,880
72	Tampa, FL	7/1991	155,789,161	16,600,685	$62,635,300,493	$6,086,279,639
73	Texas City, TX	7/1996	376,739,068	23,679,902	$211,326,122,478	$2,451,262,422
74	Trenton, NJ	7/2002				
75	Vancouver, WA	7/2005	70,227,974	10,987,031	$42,732,266,743	$2,004,629,808
76	Washington, DC	7/2003	171,959	46,795	$259,848,594	$140,168,487
77	Wilmington, DE	7/2002	170,993,871	37,340,735	$104,701,023,222	$10,936,768,361

Source: U.S. Census Bureau, USA Trade Online.

APPENDIX B

INTERNATIONAL TRAFFIC AT LOCATIONS WITHOUT PORTS® AT THE END OF 2016

COUNTER	PORT NAME(S)	STATE LOCATION	TOTAL TONNAGE VESSELS (SHORT TONS)	TOTAL TONNAGE CONTAINERS (SHORT TONS)	TOTAL CARGO VALUE-VESSELS ($2015 DOLLARS)	TOTAL CARGO VALUE CONTAINERS ($2015 DOLLARS)
1	Aberdeen-Hoquiam	WA	17,263,289	2,202,285	$6,327,899,732	$206,996,393
2	Aguadilla	PR	110,419	66,521	$1,252,345,222	$951,093,550
3	Albany	NY	19,725,243	2,020,930	$9,992,590,674	$203,793,820
4	Alexandria Bay	NY	342,016	53,252	$412,861,194	$235,011,767
5	Algonac	MI	28,546	462	$6,795,502	$679,553
6	Alpena	MI	3,528,893	95,302	$163,839,657	$200,842
7	Ashland	WI	15,895	550		
8	Ashtabula-Conneaut	OH	14,347,280	1,843,716	$2,688,819	$1,008,590
9	Bangor	ME	184,453	37,801	$134,566,454	$20,289,018
10	Bar Harbor	ME	5,540	288	$86,498,763	$2,346,672
11	Bath	ME	608	247	$11,083,822	$87,333
12	Battle Creek	MI	2,087,146	330,143	$126,029,150	$15,067,602
13	Baudette	MN	8,944	418	$6,108,922	$4,556,038
14	Beaufort-Morehead City	NC	16,450,268	2,976,415	$11,616,324,073	$3,002,266,813
15	Belfast	ME	5,803,591	308,805	$1,286,443,706	$165,037,818
16	Bellingham	WA	62,283,847	3,540,818	$33,269,525,602	$82,041,187
17	Blaine	WA	10,450,723	2,516,158	$7,771,151,980	$1,375,854,237

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18	Boca Grande	FL	595	195	$24,184,466	$465,593
19	Boston	MA	195,589,282	28,897,037	$137,196,594,587	$54,708,075,917
20	Bridgeport	CT	17,319,892	225,004	$1,359,395,177	$39,198,719
21	Brownsville	TX	18,554,353	2,190,527	$10,115,106,466	$442,694,338
22	Brunswick	GA	32,252,999	4,117,874	$159,326,525,564	$14,269,160,756
23	Buffalo-Niagara Falls	NY	70,036,128	4,745,453	$10,242,214,952	$1,427,632,774
24	Calais	ME	2,126,785	315,968	$983,458,441	$34,695,894
25	Cape Vincent	NY	511	6,456	$8,328,766	$54,746
26	Capitan	CA	189	46,419	$834,071	$323,941
27	Carquinez Strait	CA	34,246,349	2,884,266	$21,578,455,816	$67,670,618
28	Champlain-Rouses Point	NY	23,932,968	1,634,980	$9,552,102,861	$764,084,562
29	Charlotte Amalie	VI	804,992	174,772	$694,407,014	$299,339,712
30	Chicago	IL	56,009,279	6,621,763	$21,949,737,465	$7,727,279,693
31	Christiansted	VI	236,245,153	1,784,302	$116,438,013,139	$193,572,829
32	Clayton	NY	13,085	1,927	$18,889,011	$12,386,420
33	Conneaut	OH	2,220,828	168	$102,621,301	$233,138
34	Coos Bay	OR	22,031,290	1,995,980	$1,834,930,129	$16,649,695
35	Coral Bay	VI	241,972	5,137	$111,737,181	$12,056,502
36	Corpus Christi	TX	662,123,568	54,574,243	$304,270,353,992	$5,861,994,773
37	Crockett	CA	9,757,096	428,939	$4,052,258,290	$29,505,596
38	Cruz Bay	VI	489,556	6,696	$396,812,027	$8,304,274
39	Dalton Cache	AK	533,330	43	$501,511,198	$112,390
40	Destrehan	LA	141,472	113,847	$16,222,174	$5,715,431
41	Detour City	MI	23,768	25,889	$97,295,739	$45,049,235
42	Detroit	MI	61,149,738	9,583,460	$43,694,235,719	$25,948,971,033
43	Duluth	MN	6,499,994	7,955	$ 779,933,444	$9,376,036

44	Duluth - Superior	MN / WI	34,041,483	2,376,430	$7,301,284,914	$547,880,173
45	East Chicago	IN	196,546	280	$10,620,283	$487,191
46	Eastport	ME	5,252,655	335,636	$2,975,769,834	$210,337,177
47	El Segundo	CA	142,536,234	11,443,805	$71,666,856,786	$58,303,497
48	Erie	PA	1,060,810	57,251	$328,631,261	$38,624,082
49	Escanaba	MI	1,301,875	135,696	$38,372,583	$12,993,642
50	Everett	WA	4,295,732	542,070	$17,881,655,371	$16,105,683,151
51	Fairbanks	AK	3,110	126	$20,680,033	$355,789
52	Fairport	OH	543,024	39	$13,641,718	$191,576
53	Fajardo	PR	7,824,899	2,962,122	$2,378,117,091	$35,760,213
54	Fernandina	FL	4,467,574	1,702,800	$4,665,795,692	$2,288,823,132
55	Ferrysburg	MI	274,158	4,520	$3,731,997	$149,808
56	Fort Pierce	FL	891,558	116,198	$1,009,320,932	$159,662,617
57	Frederiksted	VI	482,887	27,032	$297,060,553	$123,893
58	Freeport	TX	279,392,229	24,081,821	$134,688,750,665	$7,506,534,220
59	Friday Harbor	WA	78,017	1,052	$142,006,182	$4,220,390
60	Gary	IN	2,130,276	63,515	$287,403,598	$2,683,839
61	Georgetown	SC	4,022,578	523,952	$679,503,619	$95,125,508
62	Gloucester	MA	23,877	1,979	$39,631,827	$7,347,377
63	Grand Haven	MI	488,626	1,835	$12,259,877	$2,149,186
64	Grand Portage	MN	39,076	201	$12,058,588	$645,114
65	Green Bay	WI	5,490,899	739,995	$1,547,144,776	$135,676,630
66	Greenville	MS	41,416	23,583	$19,448,256	$8,861,010
67	Guanica	PR	90,880	16,372	$28,529,823	$7,560,626
68	Guayanilla	PR	53,047,987	2,347,816	$25,564,734,338	$395,285,132
69	Hartford	CT	90,947	1,141	$63,606,797	$13,355,093
70	Hilo	HI	427,876	92,901	$152,479,625	$26,365,483

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71	Honolulu	HI	112,874,075	12,240,811	$62,499,302,590	$6,664,826,684
72	Humacao	PR	27,408,131	161,426	$15,556,640,316	$753,106
73	Huntsville	AL	234,986	4,443	$79,479,340	$3,338,653
74	Huron	OH	134,103	11,576	$109,992,397	$32,857,043
75	International Falls-Ranier	MN	3,191,880	2,572,194	$7,981,869,024	$6,498,974,145
76	Jobos	PR	22,307,141	19,611,170	$1,881,429,456	$1,279,576,963
77	Jonesport	ME	4,178	4,032	$2,333,598	$2,081,541
78	Juneau	AK	2,335,877	70,162	$2,569,266,039	$6,505,077
79	Kahului	HI	727,339	74,329		
80	Ketchikan	AK	6,581,360	393,737	$2,120,912,822	$28,833,201
81	Key West	FL	77,343	17,030	$246,646,118	$84,924,398
82	Kodiak	AK	3,554	1,306	$6,192,797	$1,079,193
83	Kona	HI	86,465	22,172	$46,101,063	$24,067,638
84	Lorain	OH	284,383	1,043	$44,389,142	$999,223
85	Louisville	KY	117,706	7,360	$84,015,976	$36,382,514
86	Mackinac Island	MI	89,885	508	$23,085,646	$221,058
87	Manitowoc	WI	804	1,002		
88	Marinette	WI	2,470,719	88,995	$11,208,258	$379,607
89	Marquette	MI	27,606,298	872,036	$2,626,914,005	$1,765,122
90	Massena	NY	159,595	6,245	$62,976,845	$17,523,708
91	Matagorda	TX				
92	Mayaguez	PR	2,070,005	1,535,113	$6,685,849,195	$5,915,913,319
93	Mellville	RI	60,599	1,055	$66,102,402	$12,727,021
94	Memphis	TN	411,098	91,201	$623,315,357	$218,859,490
95	Miami	FL	86,684,810	67,368,062	$311,169,775,044	$247,582,442,386
96	Milwaukee	WI	16,492,381	1,566,628	$3,175,170,153	$356,497,726

97	Monterey	CA	4,321	3,415	$50,774,310	$42,058,420
98	Morro Bay	CA	14,232	1,914	$24,480,153	$6,212,844
99	Muskegon	MI	2,473,441	560,441	$76,536,724	$23,390,728
100	Nawiliwili-Port Allen	HI	45,376	23,097	$19,937,248	$9,064,420
101	Neah Bay	WA	3,431	172	$2,612,720	$599,237
102	New Bedford	MA	249,227	46,120	$350,602,766	$123,945,505
103	Newport	OR	176,941	19,202	$100,327,199	$44,382,629
104	Ogdensburg	NY	2,088,098	164,955	$725,767,164	$193,875,345
105	Olympia	WA	5,356,527	929,431	$1,420,843,453	$190,445,497
106	Oswego	NY	6,118,594	593,796	$2,453,792,624	$249,624,191
107	Panama City	FL	18,046,287	4,509,854	$38,942,724,842	$13,363,395,263
108	Pelican	AK	654	43	$1,756,294	$558,435
109	Pensacola	FL	3,325,677	257,884	$2,448,026,434	$368,085,325
110	Peoria	IL	25,267	1,951	$47,769,206	$18,950,346
111	Perth Amboy	NJ	86,592,186	6,872,885	$51,949,002,569	$1,662,099,905
112	Petersburg	AK	9,225	4,628	$20,687,361	$13,251,277
113	Plymouth	MA	2,825,228	93,997	$666,166,366	$19,705,005
114	Point Roberts	WA	7,558	369	$78,157,097	$468,981
115	Ponce	PR	12,204,461	7,052,086	$4,884,404,632	$809,151,659
116	Port Angeles	WA	4,039,760	468,191	$1,628,511,345	$10,840,801
117	Port Canaveral	FL	34,233,650	3,284,337	$12,994,170,083	$251,198,567
118	Port Everglades	FL	146,126,913	55,676,866	$281,841,524,095	$175,391,154,998
119	Port Hueneme	CA	18,423,054	6,608,250	$95,632,421,433	$10,085,596,762
120	Port Huron	MI	110,513,377	3,785,644	$22,404,803,698	$4,733,842,559
121	Port Lavaca	TX	89,692,707	6,117,267	$15,193,129,051	$2,715,120,773
122	Port San Luis	CA	40,374	27,374	$145,393,225	$107,763,259
123	Port Sulphur	LA	1,588,462	157,062	$488,240,103	$47,970,126

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124	Port Townsend	WA	297,156	25,701	$2,375,847,882	$2,153,379,440
125	Portland	ME	49,147,272	3,765,498	$28,300,244,417	$1,465,673,124
126	Portsmouth	NH	41,630,133	2,446,372	$13,472,145,304	$1,026,200,050
127	Presque Isle	MI	340,817	23,149	$17,005,145	$227,765
128	Provincetown	MA	536	343	$2,086,146	$1,048,471
129	Racine	WI	14,507	6,356	$63,652,912	$42,412,985
130	Rochester	NY	1,497,443	123,852	$342,056,574	$224,441,070
131	Rockland	ME	840	55	$4,134,914	$219,742
132	Rogers City	MI	1,971,982	299	$134,018,417	$13,500
133	Sacramento	CA	5,084,374	800,112	$2,213,889,617	$512,882,493
134	Saginaw-Bay City	MI	7,306,720	437,082	$331,385,767	$9,124,471
135	Salem	MA	7,012,018	19,908	$523,637,534	$88,691,025
136	San Diego	CA	22,302,430	8,932,941	$87,815,512,618	$19,258,980,329
137	San Joaquin River	CA	14,544,232	1,357,885	$5,048,086,823	$9,282,539
138	San Juan	PR	73,579,583	31,966,994	$116,461,215,386	$64,714,705,007
139	San Pablo Bay	CA	6,192,298	1,556,177	$2,840,439,751	$1,036,361,392
140	Searsport	ME	15,614,172	1,209,644	$8,566,558,322	$89,813,587
141	Seattle	WA	260,078,650	137,140,517	$490,216,008,288	$429,672,697,079
142	Selby	CA	2,524,077	179,868	$1,684,590,025	$15,294,309
143	Sheboygan	WI	157	91	$2,218,697	$691,557
144	Silver Bay	MN	1,567,324	355	$177,552,267	$339,856
145	Sitka	AK	140,060	10,048	$24,068,720	$4,418,295
146	Skagway	AK	657,696	34,941	$931,367,456	$69,090
147	Sodus Point	NY	9,451	406	$10,462,577	$1,648,446
148	Springfield	MA	165	135	$38,665	$28,277
149	St. Louis	MO	114,148	16,562	$161,809,425	$46,939,965

150	Stockton	CA	36,739,418	5,726,194	$8,802,035,835	$1,207,666,021
151	Suisun Bay	CA	122,692	2,515	$36,498,969	$12,821,755
152	Superior	WI	21,818,466		$1,222,580,403	
153	Syracuse	NY	426,518	8,358	$235,444,314	$1,249,736
154	Toledo-Sandusky	OH	110,267,631	7,151,894	$14,997,568,614	$305,036,206
155	Utica	NY	30,907	263	$5,677,515	$653,201
156	Valdez	AK	461,055	503,146	$346,142,180	$16,786,129
157	Ventura	CA	2,513	767	$5,625,524	$1,616,518
158	Vicksburg	MS	2,262	438		
159	Warroad	MN	13,373	6,588	$54,918,584	$31,321,582
160	West Palm Beach	FL	14,391,765	7,957,002	$27,222,591,672	$20,943,902,569
161	Wilmington	NC	74,734,730	24,424,218	$86,911,919,610	$58,916,329,676
162	Worcester	MA	963	907	$2,940,322	$226,544
163	Wrangell	AK	99,511	51,610	$118,954,640	$102,614,992

Source: U.S. Census Bureau, USA Trade Online.

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