July 2020

Gross Benefit Estimates From Reductions In Allisions, Collisions And Groundings Due To Electronic Navigational Charts

Eric Wolfe

Dept of Commerce/NOAA/NOS/AAMB

Percy Pacheco

Department of Commerce/NOAA/NOS/OCS

Follow this and additional works at: <https://cbe.miis.edu/joce>

Part of the [Business Commons](#), and the [Economics Commons](#)

Recommended Citation

Wolfe, Eric and Pacheco, Percy (2020) "Gross Benefit Estimates From Reductions In Allisions, Collisions And Groundings Due To Electronic Navigational Charts," *Journal of Ocean and Coastal Economics*: Vol. 7: Iss. 1, Article 3.

DOI: <https://doi.org/10.15351/2373-8456.1121>

This Research Article is brought to you for free and open access by Digital Commons @ Center for the Blue Economy. It has been accepted for inclusion in Journal of Ocean and Coastal Economics by an authorized editor of Digital Commons @ Center for the Blue Economy. For more information, please contact ccolgan@miis.edu.

1. INTRODUCTION

Beginning in 1807 when President Thomas Jefferson signed an “Act to provide for surveying the coasts of the United States”, the U.S. Coast Survey, later U.S. Coast and Geodetic Survey in 1878 that was subsequently incorporated into NOAA when it was formed in 1970 have created thousands of nautical charts. Today, the Office of Coast Survey (OCS) maintains more than 20 thousand historical nautical charts while maintaining its current collection of over one thousand charts.¹ OCS receives over 6,000 digital and hardcopy source documents each year from five main sources that account for over 70 percent of all input.² These include:

- Water depths and the identification of wrecks, rocks, and other obstructions (Source: NOAA’s Hydrographic Surveys Division);
- Depths within federally maintained channels (Source: U.S. Army Corps of Engineers);
- Delineation of shoreline (Source: NOAA’s National Geodetic Survey);
- Reports of “dangerous to navigation” - wrecks and obstructions (Source: U. S. Coast Guard Notice to Mariners); and,
- Positions, types, and characteristics of aids to navigation including buoys, beacons, and navigational lights (Source: U.S. Coast Guard).

The OCS has a large job to perform. Gonsalves et al. (2017) reports that the U.S. Exclusive Economic Zone is about 3.4 million square nautical miles (nm²). Of this area, about 44,000 nm² have been surveyed to “modern” standards. Each year, an average of about 3,000 nm² are surveyed. Compiling data for updating charts may take as little as six months but can take several years owing to the location, extent of the surveys required as well as competing requirements (e.g., routine or critical) from other charts.³

2. SCOPE OF ANALYSIS

This analysis involves the description and identification of marine accidents associated with vessel traffic. Accident measurements can help illustrate the effectiveness of navigational aids over time as well identify trends or potential problem areas that might benefit from additional investment.

¹ Source: NOAA celebrates 200 Years of Science, Service and Stewardship.
<https://celebrating200years.noaa.gov/foundations/welcome.html>

² <https://nauticalcharts.noaa.gov/learn/chart-source-data.html>. Remaining source material is provided by a variety of other federal, state and local government agencies, national and international regulatory organizations, private companies, professional organizations, and private citizens.

³ Source: https://oceanservice.noaa.gov/facts/chart_produce.html, “How Long Does It Take to Produce a Nautical Chart?”

Three types of commercial shipping accidents occurring between 2005 and 2017 were employed in this analysis.⁴ Allisions, Collisions, and Groundings (ACG) were defined as:

- Collisions – the striking of a (moving) vessel upon another (moving) vessel;
- Allisions⁵ – the striking of a moving vessel with a stationary object (another vessel, bridge, dock, etc.); and,
- Groundings – the impact of a vessel on the seabed or waterway side (within or outside of the channel).⁶

The goal of this analysis is to estimate gross benefits derived from two National Ocean Service (NOS) navigational aid systems: (1) Electronic Navigational Charts (ENCs) and (2) Physical Oceanographic Real-Time System (PORTS[®]) with respect to reductions in vessel accident rates. Employing a highly granular approach, estimates of accident reduction benefits (e.g., reductions in morbidity, mortality, vessel, cargo, facilities and other damages) are made for ENCs and PORTS[®] individually as well as estimates where both systems are believed to have had contributing influences.

A benefit-cost analysis was not undertaken owing to the inability to obtain complete historical costs from preexisting PORTS[®] installations and ENC data collection, processing and release. While some costs borne by NOAA might be historically reconstructed, they represent only a portion of total costs. For example, as NOAA only sets standards for PORTS[®] sensors and related communication infrastructure and does sell equipment, installation or maintenance service we do not know their costs. While ENCs may be updated, cost data from private retailers of such data is not known nor is the cost of vessel equipment to receive process and display such data. Hence, only gross benefits were estimated in an assessment ACGs and the impact of PORTS[®] and ENCs on their occurrence over time.

3. PREVIOUS VALUATION STUDIES

A number of studies in recent years have been undertaken to estimate benefits that have been obtained from NOS navigational aids. Approaches have varied as to both the level of confidence underpinning estimates and the manner in which estimates were made. In some cases, top-down assessments were made through parsing total benefits enjoyed by all while in others, bottom-up

⁴ This included all reported coastal accidents where nautical charts had been released. Anecdotal evidence from earlier 2003 to 2004 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 year-to-year increases in total ACGs.

⁵ The movement of objects involved in accidents is a critical decision factor in assignment of the type of accident. For example, if a bridge were stuck while in motion (e.g., a drawbridge in the process of opening for vessel passage), the accident would be classified as a collision rather than an allision.

⁶ Includes instances reported as “aground” in addition to “grounding”. Allisions, Collisions and Groundings are collectively referred to as ACGs.

estimates were made based on expansion of individual beneficiary groups to assess the benefits enjoyed by an entire population of users. In most cases, benefits were acknowledged to have come from several areas that encompassed: (1) ENCs; (2) PORTS®; and, (3) other navigational support systems and aids. Among these other supports were integrated bridge management systems, improved crew training, enhanced technology of vessel design, etc.

3.1 Integrated Bridge Management Systems

It is readily admitted that reductions in ACGs and resultant ACG accident rates are the result of a number of individual factors which when layered together and effectively utilized can significantly reduce marine accidents and resultant accident rates, pollutant releases as well as reduce transit times, vessel fuel, overall transportation costs, etc. In this discussion, these “other navigational aids” have been combined into the category of Integrated Bridge Management Systems (IBMS, alternatively IBS). Alexander (2003) states:

IBS is a combination of equipment and software which uses interconnected controls and displays to present a comprehensive suite of navigational information to the mariner. Rule from classification societies such as Det Norske Veritas (DNV) specify design criteria for bridgework stations. Their rules define tasks to be performed and specify how and where equipment should be cited to enable those tasks to be performed.⁷

Bhattacharjee (2017) reports that IBMS systems should support at least two or more of the following: (1) execution of passage, (2) communications; (3) machinery control; (4) cargo operations; and/or; (5) safety and security. He states that IBMS usually consists of an autopilot, dual radar with automatic radar plotting aid (ARPA), gyro, position fixing systems, Dual Electronic Chart Display and Information System (ECDIS)⁸, power distribution system, steering gear, conning display that summarizes navigational sensors and settings, and a global maritime distress and safety system.

Over time, improvements have been continually made in vessel design and management systems to enhance vessel handling and responsiveness. Montewka et al. (2017) reports that added to these technological enhancements have been expanded improvements in vessel design, crew training and process improvement based on human factor engineering. Continuous quality improvement also clearly plays a role in these evolutionary improvements. Additionally, concerns regarding crew fatigue and ergonomics have all contributed to more efficient and safer vessel design and operational procedures.

⁷ Integrated Bridge Systems, Chapter 14, Section 1414. Description.

⁸ ECDIS plus backup. ECDIS is a vector-based system that meets the federal chart carriage regulations and the highest level of the International Maritime Organization (IMO) standards and requirements.

Clearly, both ENC^s and PORTS[®] contribute valuable information into IBMS and it would be highly difficult to exact the precise benefit of each as several researchers have noted. Several previous researchers (VOLPE 2009, Econometrica 2015), have comingled ENC and PORTS[®] benefits.⁹ In this analysis, IBMS, training and related capital improvement programs are assumed to be a given in supporting both ENC and PORTS[®] in that there is no empirical data to suggest that, once available, that newer technology was limited to any geographic region or port area. Stated another way, it is assumed in this analysis that IBMS improvements served as the base for all changes in ACG rates and contribute to benefits obtained from both ENC and PORTS[®]. What is unique about this study is its empirical investigation of ACG accident rates with respect to ENC releases and PORTS[®] installations collectively and individually.

3.2 Nautical Charting

Previous efforts at quantifying the value of hydrographic surveys and nautical charts have largely taken one of three approaches. In some cases, researchers have simply stated that “it is difficult to quantify cost-benefit ratios”. In other studies, due to interdependence of factors, only high levels of aggregation were employed to define beneficiary groups (e.g., combining the impacts of both ENC^s¹⁰ and PORTS[®]). Still others parsed estimated national total benefits to lower levels of granularity to estimate ENC benefits.

In an early example, Oudet (1972) recounts how the lack of real-time data coupled with inappropriate actions of the captain of the vessel led to the wreck of the Antilles in 1972. In his review, no quantitative data was provided. Vadus (1996) stated

It is difficult to determine a specific monetary value attributed to electronic charting based on its role in support of marine transport operations, just as it would be to assign a value to e.g. the ship's propulsion system. Yet, it is recognized that electronic charting and navigation systems are critical components in marine transport operations and contribute to the economic gains of such operations.

While he identified the magnitude of domestic waterborne traffic activities in regards to commerce, avoidance of pollution, support of fisheries, reduction in marine accidents, etc. no specific dollar valuations of charting benefits alone were provided.

Stating that no previous in-house audit had been performed on The Canadian Hydrographic Service (CHS), Brinkman et al. (1992) cited benefit-cost ratios ranging between 9.49 and 11.86 for Canadian mapping services. Their study addressed impacts on commercial shipping, accident rates, recreational boating and fishing vessels based on changes in consumer and producer surplus¹¹ as

⁹ Including Tides and Currents information

¹⁰ In this analysis, it is recognized that there are also a few open source sources of navigation data supplied by volunteers. The TeamSurv and Open Sea Maps are examples. However, TeamServ notes on its website for mariners not to rely only on these charts for “navigation or any other critical purposes”.

¹¹ Producer surplus is measured as the difference between what producers are willing and able to supply a good for and the price they actually receive. Consumer surplus is the difference between the total amount that consumers are willing to pay for a good or a service and the total amount that they actually pay (i.e., the market price).

well as elasticity of transportation demand. Overall, they estimated total benefits from all sources to exceed \$473 million (1989 Canadian Dollars) against costs of between \$40 to \$50 million (1989 Canadian Dollars). Also, in 1992, the Australian Department of Defense Report stated:

what is beyond reasonable doubt is that the existence of official up-to-date charts has a benefit to the national economy that greatly exceeds the cost of the Hydrographic Programme.

Kite-Powell et al. (1997) estimated that:

Electronic charts and integrated navigation systems at an intermediate level of effectiveness could help avoid 3,000 accidents involving commercial vessels in U.S. waters between 1996 and 2010, assuming no significant changes in underlying casualty rates. The expected overall cost of these accidents is estimate to be about \$2.1 billion (1995 dollars)¹²

Kite-Powell (2007) employed surveys of both commercial and recreational users of nautical charts.¹³ Based on respondents' indication of the "willingness to pay" for an "ideal" chart, the value of charts (as measured by consumer surplus) was \$15.3 million (2007 dollars) per year for recreational users and \$27.5 million for commercial users. He also estimated that the value of producer surplus derived from the activities of value-added resellers of charts and data was about \$2 million (2007 dollars) per year. He concluded that the lower bound of his total estimate as \$44.8 million (2007 dollars) per year.

VOLPE (2009) estimated the net benefits from seven areas that included: (1) voyage planning; (2) avoided delays due to PORTS[®]¹⁴; (3) PORTS[®] capacity optimization; (4) averted property damage from grounding; (5) averted spill costs; (6) averted fatalities; and, (7) averted injuries. In these calculations, individual benefits from PORTS[®] and ENC's were not always clearly delineated.

Overall, VOLPE estimated total gross benefits of \$1.98 billion while calculating costs at \$48.5 million (2006 dollars) for a benefit-cost ratio of 24 to 1. Problematic with their approach was that benefits were accumulated at the societal level while costs were estimated for only NOS production and maintenance of PORTS[®] and charts. This ignored all other costs that are incurred to obtain to societal benefits, such as the purchase of electronic charts and IBMS systems, training, and maintenance. Additionally, benefits were accrued as marginal benefits of NOS deliverables while costs included fixed costs. Specific monetary benefits associated with voyage planning for commercial vessels (\$26.8 million), recreational vessels (\$4.2 million) and search and rescue (SAR) officers (\$75.5 million). Collectively they account for a benefit of \$106.5 million. This would be equivalent to \$125.6 million in 2017 dollars.

¹² Page 161.

¹³ 1,975 surveys were sent to recreational users while 1,000 were sent to commercial users. 406 (20 percent) of recreational users and 138 (14 percent) of commercial users responded.

¹⁴ In these calculations, benefits from PORTS[®] and Tides and Current (TC) data were comingled.

Benefits from averted property damage resulting from groundings or storm-related accidents were estimated for only recreational vessels and SAR vessels. VOLPE found that ENC's and PORTS[®] were major factors at minimizing risk. Averted damages were placed at \$2.9 million (\$3.5 million in 2017 dollars) while increased efficiency of search and rescue (SAR) operations were valued at \$27.1 million (\$31.9 in 2017 dollars). Employing the then value of a human life (\$5.8 million), total averted fatalities were estimated to be \$449 million with \$197 million due to SAR activity (\$528.4 and \$231.8 million, respectively in 2017 dollars).

Leveson (2012) provided a focused report involving the value of coastal mapping. In his analysis he noted the wide-array of Coastal Mapping Program (CMP) mapping beneficiaries to include: (1) navigation safety; (2) shoreline modification; (3) environmental protection (including precise coordinated of sensitive and protected areas; (4) GIS applications in coastal zone management; (5) on-shore development; (6) recreation; (7) fish habitat mapping; (8) energy exploration and construction; (9) offshore aquaculture; (10) planning and response to natural disasters and environmental emergencies; (11) marine spatial planning; (12) legal and insurance applications; (13) homeland and port security; (14) monitoring sea level change; (15) scientific research; (16) national and international standards; (17) archeology and cultural heritage; and (18) military activities.¹⁵ Issues related to inter-state boundaries, resultant taxation issues and international boundaries are additional issues reported by Leveson impacted by the CMP. In his analysis, Leveson estimated total direct, indirect and induced benefits to range between \$217.4 and \$265.0 million with an overall estimate of \$241.4 million (2011 dollars).¹⁶ (See Table 1) This would equate to a range between \$247.7 and \$302.0 and an overall estimate of \$275.1 million in 2017 dollars. In his calculations, direct, indirect and induced benefits were identified.¹⁷

Table 1. Summary of Coastal Mapping Program Benefits, 2011

AREA	ESTIMATE	RANGE
Direct Economic Benefits	\$100.4	\$90.4 – \$110.4
Indirect and Induced Economic Benefits	\$100.4	\$90.4 - \$110.4
Total Economic Benefits	\$200.8	\$180.8 - \$220.8

¹⁵ Leveson (2012), Page 2.

¹⁶ Direct economic benefits were largely based on willingness to pay for products or outcomes.

¹⁷ Direct benefits include faster transit times, reduced accidents, etc. Indirect benefits are those based on demand generated in supplier and using industries. For example, faster transit times might increase demand for marine transport and suppliers of materials and services to support such activity. Induced benefits are those produced by supporting industries and their employees in other sectors of the economy.

Non-Economic Benefits (not included in Economic Benefits, with 8% adjustment and 10% range)	\$40.6	\$36.5 - \$44.7
Total Benefits	\$241.4	\$217.4 - \$265.0

Source: Leveson, Table ES3, Page 7.

Reductions in morbidity and mortality are addressed with respect to natural hazards (e.g., tornados, coastal storms, hurricanes, etc.), as well as commercial and recreational vessels. Levenson assumed that averted morbidity and mortality would have been five to ten percent higher without CMP products. Illustrating the difficulty of such estimations he pointed out that as some of the benefits captured were the result of interdependence among products that “emphasis should be placed on the benefit estimates of CMP as a whole rather than individual products”, it is difficult to specifically estimate the precise dollar amount these reductions represent.¹⁸

Econometrica performed the most recent analysis on the value of charting in 2015. They stated that such estimations were difficult as no empirical data or base case where charting products did not exist could be found. In their study, they estimated that total incidence costs from all sources (e.g., morbidity, mortality, property loss, etc.) across all vessel types investigated averaged \$106,807.19. Also noted were reductions in travel and delay times that were estimated at \$18 per passenger (in terms of passenger travel) and recreational boating user and \$46 per hour for commercial vessel crewmember. While they estimated the impact of a one-hour, reduction in all waterborne freight travel time at \$0.6 million per year.

Rather than estimating willingness-to-pay, the purpose of this analysis was to compare and contrast long-term historical ACG rates and resultant costs at locations where both ENC's had been released and PORTS® instrumentalities had been installed as opposed to locations where only ENC's had been released and PORTS® never installed.

4. DATA EMPLOYED

Begun in 1862, paper lithographic nautical charts have been printed by the U.S. government and sold to the public by commercial vendors. Beginning in April of 2014, paper charts were no longer to be published by the Government owing to declining demand for lithographic charts, the increasing use of digital and electronic charts, and federal budget realities.²⁰ NOAA continues to develop and maintain Print on Demand (POD) charts which are available from NOAA-certified vendors.

¹⁸ Ibid, Pages 5 and 65.

¹⁹ This included fishing, freight, offshore drilling, passenger recreational and other vessel types. Table 1, Page 3.

²⁰ Announced October 22, 2013.

In essence, raster charts are pictures of paper nautical charts. In raster charts data is a series of pixels (tiny dot of color) that are positionally referenced to that picture only. The raster data is often referred to as "dumb" data because of limited useful information. An ENC (or vector chart) is made of information rich or "smart" data.²¹ That is, data each bit of which has positional information (latitude and longitude), as well as, information on what it is (dangerous rock, depth, or navigational light) and its relationship to other data in that feature (depth area, shoreline) in addition to other important meta data.

ENCs with an easier updating method and GPS linkage can be used to assist mariners in plotting courses to avoid dangerous areas relative to that vessels unique draft and will sound warnings if the vessel is at risk of entering into a dangerous area.²² While it is recognized that the United States Coast Guard through the its local districts publishes a weekly Notice to Mariners, their coverage is by definition concerned with local issues and was not considered in this analysis as ACGs have occurred across a wide variety of geographic areas.

New data for updating charts is prioritized as either "critical" or "routine". Critical change examples are those that potentially pose dangers to navigation (e.g., changes in position of lights, bacons, buoys, rocks, newly discovered wrecks, shoals or other obstructions). Routine changes involve less critical data such as ordinary shoreline and hydrographic surveys. If electronic charts are employed, data is updated weekly commensurate with its release. While existing paper charts must be manually updated, newly issued paper charts will contain updates. From 1834 to 2017, OCS and its predecessors completed over 13,831 studies across eight different types of hydrographic surveys. (See Table 2) Of these, the hydrographic surveys (Type H) have accounted for almost 87 percent of all surveys undertaken.

Table 2. Types of Surveys Conducted

TYPE OF SURVEY	SURVEY CODE	YEARS CONDUCTED (Through the End of 2017)	NUMBER OF SURVEYS PERFORMED
Hydrographic Exclusive Economic Zone (EEZ) Surveys Lower-resolution early multi-beam echo sounder surveys.	B	1984 - 1995	290

²¹ Electronic Chart Display Information Service (ECDIS) is a vector-based system that meets the Federal Chart carriage regulations and the highest level of the International Maritime Organization (IMO) standards and requirements.

²² Weintrit (2010) notes that raster data is only available in one layer and one format while ENC charts while ENCs contain layered information that allows users to "deselect" certain categories of data that are not required at the time.

Discovery Surveys Substandard Survey (Special reconnaissance, or evaluation/test surveys). These reconnaissance surveys, often do not meet IHO Order 1 because they may be deep; have inadequate vertical control, inadequate sound velocity control or substandard sounding density. These requirements are intentionally relaxed so that data may be obtained over a larger area either to inform future surveys or to supplement areas of the chart with little to no data.	D	1977 - 2017	112
Field Examination Surveys They are item investigations or surveys that cover small areas of specific interest frequently called a smaller scoped version of surveys type H. They may be assigned to prove or disprove dangers or obstructions, to provide data for harbor development, or supplement prior hydrographic surveys.	F	1934 - 2017	614
Hydrographic Surveys (Basic) These are the systematic hydrographic surveys, typically meeting IHO Order 1 and adhering to the Coast Survey's Hydrographic Surveys Specifications and Deliverables Manual (HSSD). These are the most common commissioned surveys from Coast Survey's Hydrographic Survey Division (HSD) and Coast Survey's Navigation Services Division (NSD).	H	1834 - 2017	11,968
Chart Letter They cover all types of information (it may or may not pertain to a survey). In the past when OCS did not receive digital data, the source documents were recorded as either letters or blueprints.	L	1900 - 1975	450
Homeland Security Survey These surveys are Homeland Security (HLS) and are conducted by NOAA ships. They have not been done for a while but the nomenclature are retained in the event there is need to perform HLS surveys again. Typically, HLS surveys were IHO Special Order.	S	2002 - 2016	29
Triangulation Positioning Technique Surveys In the past, positioning by this method from baseline points onshore was used to position vessels on near-shore projects using generally the azimuth/azimuth method.	T	1859 - 1860	3
Non-NOS Hydrographic Surveys These are hydrographic surveys not commissioned by HSD.NSD and are received as externally sourced data, generally by other government agencies (CHS, BA) which are Canada and British Admiralty. They obtain	W	2000 - 2017	365

a “W” registry number once a requirement has been identified to process the data.			
---	--	--	--

During production, ENC's are assigned a compilation scale based on the nature of the source data they are derived from and are allocated to a navigational purpose band related to this assignment. Such scales could be reported in inches, yards, centimeters, etc. Compiling data for updating charts may take as little as six months but can take several years owing to the location, the extent of the surveys required as well as competing requirements (e.g., routine or critical) from other charts.²³ Since 1998, the average number of days from the time information is initially gathered until the time an ENC is produced has substantially fallen. In 2017, the average days to from data to chart was 614. (See Figure 1)

Figure 1

4.1 Physical Oceanographic Real-Time Systems (PORTS®)

Edwing (2013) and Wolfe et al. (2016) detail PORTS® as a management system that “measures and disseminates observations and predictions of water levels, currents, salinity, and meteorological parameters (e.g., winds, atmospheric pressure, air and water temperatures) that mariners need to navigate safely”.²⁴ The system is designed to provide users with high quality information to support decision making (e.g., is there sufficient water for a ship to safely operate, can a ship safely transit under a bridge, are sea and weather conditions favorable to undertake a recreational boating

²³ Source: https://oceanservice.noaa.gov/facts/chart_produce.html, “How Long Does It Take to Produce A Nautical Chart?”

²⁴ Including commercial cargo and fishing vessels as well as recreational boaters.

trip, are conditions favorable for fishing near a port, etc.) PORTS® come in a variety of sizes and configurations, each specifically designed to meet local user requirements. The largest of NOS's existing PORTS® installations is comprised of over 50 separate instruments; the smallest consists of a single water-level gauge and associated meteorological instruments (e.g., water level, winds, barometric pressure, etc.)

4.2 United States Coast Guard (USCG) Accident Data

The Marine Casualty and Pollution Database 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 An incident must be filed if: (1) a person dies; (2) a person disappears from the vessel under circumstances that indicate death or injury; (3) a person is injured and requires medical treatment beyond first aid; (4) damage to vessels and other property totals \$2,000²⁶ or more; and, or (5) the vessel is destroyed.

While data is available for 2003 and 2004 the number of reported ACGs incidents are significantly lower than the long-term average of over 1,424 events per year during the latter 2005 to 2017 period.²⁷ During the earlier period of time in reporting it appears 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.²⁸ A comparison of 2005-2017 ACG reports with earlier 2003-2004 ACG reports showed reported events doubling in later years. Consequently, examination of ACGs was based on more complete and representative data from 2005 to 2017.

4.3. Channel Portfolio Tool (CPT)

CPT, developed by Dr. Ken Mitchell of the United States Army Corps of Engineers (USACE), has been employed in several previous analyses most notably several benefit assessments of PORTS®. Refer to Wolfe et al. (2016, 2018) CPT represents a method to transform raw data involving water transportation into tabular and graphic representations of activity. Central to the value of CPT is its ability to uniquely assess traffic by river or channel segment and provide summary origin or destination data without double counting ship passing, tonnages or values of cargo. CPT was employed to obtain the level of vessel traffic measured by docked and through movements at over 200 locations in the U.S. Containing data on channel depth, commodity transported, vessel depth, cargo value, cargo weight, cargo type (container versus non-container), ship type (dry cargo barge,

²⁵ Any person in charge of a vessel or of an onshore or offshore facility shall, as soon as they have knowledge of any discharge of oil or a hazardous substance from such vessel or facility in violation of section 311(b)(3) of the Act, immediately notify the Commandant (CG-MER-3).

²⁶ Losses include the vessel itself, its cargo, damage to facilities (e.g., docks) and other.

²⁷ In 2003 and 2004 an average of 724 ACG events reported each year. During the 2005 to 2017 period, an annual average of 1,424 ACG events were reported.

²⁸ The U.S. Coast Guard transitioned from the Marine Safety Information System (MSIS) to the Marine Information for Safety and Law Enforcement (MISLE) information system in December 2001.

liquid barge, tanker, towboat, rafted logs, etc.) and ship direction, it is possible to review actual movements and how those movements might be at risk owing to channel constraints.

5. MORBIDITY AND MORTALITY COST ESTIMATION

5.1 Value of Mortality Risk Reduction

In assessing the potential benefits associated with reductions in injuries and deaths resulting from groundings, allisions and collisions, dollar values resulting from these events must be assigned.

The value per statistical life year (VSLY) is an approach for adjusting the value of statistical life (VSL) estimates to reflect differences in remaining life expectancy and involves calculating the value of each year of life extension. Because the degree of life extension is usually closely related to the age of the affected individuals²⁹, VSLY is often interpreted as an approach for adjusting VSL to reflect age differences.³⁰ It is generally derived by applying simple assumptions to VSL estimates based on Moore and Viscusi (1988).

Several Federal agencies delineated their methodologies to value lives at an interagency workshop.³¹ From their discussions and presentations, it was learned that some agencies employed the VSLY approach while one utilized the Quality-Adjusted Life Year (QALY) approach. When responses from that 2012 conference were adjusted to constant 2017 dollars³², the VSL across agencies ranged from \$4.8 at the Nuclear Regulatory Commission's Headquarters and National Nuclear Security Agency to \$10.2 million at the Environmental Protection Agency.³³ In the wake of the sinking of the Duck Boat in Branson, MO and bridge collapse in Genoa, Italy, Viscusi (2018) suggests that \$10 million may be the appropriate value in 2018.

²⁹ 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.

³⁰ The relationship between VSL and VSLY may be clarified by recognizing that any change in an individual's mortality risk can be described by a corresponding shift in her survival curve, which can be summarized by the expected number of lives saved (as a function of time or within a specified time period) or by the expected number of life-years saved. An individual's willingness to pay (WTP) for a shift in her survival curve can be summarized by her average VSL or VSLY for that change. Economic theory suggests that both VSL and VSLY may depend on the individual's initial survival curve, characteristics of the shift, and individual characteristics such as health and income. Neither VSL nor VSLY is likely to be constant across changes in mortality risk. Therefore, accurate valuation requires the use of scenario-specific values. The choice between VSL and VSLY summary measures is largely one of convenience. Refer to: Hammitt (2007) and <http://reep.oxfordjournals.org/content/1/2/228.abstract>

³¹ Interagency Regulatory Analysis Workshop: Cost-Benefit Analysis, Value of a Statistical Life, Hyatt Regency, Bethesda, March 19-20, 2012.

³² The Gross Domestic Product was employed as the basis for conversion to constant (2017) dollars.

³³ VSL estimates by Muller et al. (2011) ranged from \$6.0 million in 2011 (\$6.6 million in \$2015) to \$8.1 million by Holland et al. in 2016 (\$8.0 in \$2015). Both studies also included sensitivity analyses that ranged from \$2 to \$10 (nominal) million and \$8.1 to \$10.8 (nominal) million, respectively.

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 recent U.S. Department of Transportation's (DOT) figure of \$9.6 million (\$2016) was adjusted \$9.8 million (\$2017 dollars).³⁴ In this analysis, \$9.8 million was employed regardless of the victim's age.³⁵

5.2 Value of Injury Reduction

The measurement of the society's Willingness To Pay (WTP) to avoid catastrophic transportation accidents is based on a combination of the economic losses from the accidents and the broader societal values held in support of social justice and equity. In this context, the value of a life to a society cannot be fully represented by direct costs and lost earnings alone. This approach to assessing the value of life – also referred to as the “comprehensive” model – represents the values citizens themselves would assign to a reduced risk of death if they were purchasing the protection directly. This approach estimates accident costs in reference to the values attached to a broad array of costs – property damages, delays, fatalities involved in each reported accident, plus an estimated measure of QALY for the injuries resulting from each accident.

Using the QALY as an additional measure of the comprehensive cost of transportation-related accidents, the National Highway Transportation Safety Administration (NHTSA) has calculated the comprehensive accident costs through the “Maximum Abbreviated Injury Scale” (MAIS).³⁶

For estimating the WTP to avoid a severe transportation-related injury, the Office of the Secretary of Transportation (OST) calculated relationships between the MAIS indicating injury severity and the WTP value.³⁷ Table 3 presents the estimated dollar cost of accidents by the degree of injury severity.

³⁴ U.S. Department of Transportation Office of the Secretary Of Transportation MEMORANDUM TO: From: Subject: August 8, 2016 SECRETARIAL OFFICERS MODAL ADMINISTRATORS 1200 New Jersey Ave., S.E. Washington, DC 20590 Molly J. Moran, Acting General Counsel Thomson, Carlos Monje, Assistant Secretary for Policy, Guidance on Treatment of the Economic Value of a Statistical Life (VSL) in U.S. Department of Transportation Analyses - 2016 Adjustment

³⁵ 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.

³⁶ 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.

³⁷ The Department of Transportation refers to this scale as the “Abbreviated Injury Scale (AIS)”.

Table 3. Values For Societal Willingness to Pay To Avert Injuries

DOT AIS SCALE FOR LEVEL OF SEVERITY	INJURY SEVERITY	FRACTION OF THE VSL OF AN AVERTED FATALITY³⁸	VSL FOR AN AVERTED INJURY OR DEATH (2017 Dollars)
AIS 1	Minor	0.003	\$29,400
AIS 2	Moderate	0.047	\$460,600
AIS 3	Serious	0.105	\$1,029,000
AIS 4	Severe	0.266	\$2,606,800
AIS 5	Critical	0.593	\$5,811,400
AIS 6	Unsurvivable	1.000	\$9,800,000 ³⁹

Source: U.S. Department of Transportation, 2016. *Guidance on Treatment of the Economic Value of a Statistical Life (VSL) in the U.S. Department of Transportation Analysis – 2016 Adjustment*, August 8,

Prior to 2011, only the total number of injuries was reported in the MISLE database.⁴⁰ Of the 1,475 events where the degree of injury was reported during 2011 to 2017, 12.9 percent were classified as “minor”.⁴¹ (See Table 4) From this distribution, the overall expected average cost of injuries were calculated. (See Table 5) Following this procedure, the average cost of an injury was estimated to be approximately \$789,000 (\$2017).

³⁸ Refer to Table 2, Relative Disutility Factors by Injury Severity Level (MAIS) for Use With 3% or 7% Discount Rate, Page 10, U.S. Department of Transportation, 2016. *Guidance on treatment of the Economic Value of a Statistical Life (VSL) in the U.S. Department of Transportation Analysis – 2016 Adjustment*, August 8.

³⁹ Note: the total WTP values do not add up to \$9.8 million due to the rounding of AIS fractions.

⁴⁰ The USCG does not claim that its injury scale is identical to the AIS scale. The descriptions of the categorization levels in the CG and AIS are similar, such that the match-up in Table 4 provides a way to monetize injuries

⁴¹ During this time, a total of 191 deaths were reported.

Table 4. Distribution of Injury Severity

DOT AIS SCALE FOR LEVEL OF SEVERITY	USCG SCALE OF INJURIES	INJURY SEVERITY	NUMBER OF REPORTED INJURIES (2011 – 2015) Source: USCG	PERCENT OF TOTAL INJURY REPORTS
AIS 1	1	Minor	190	12.9%
AIS 2	2	Moderate	789	53.5%
AIS 3	3	Serious	363	24.6%
AIS 4	4	Severe	109	7.4%
AIS 5	5	Critical	24	1.6%
		Total	1,475	100.0%

Source: USCG MISLE Database

Table 5. Estimation of Expected Average Injury Cost

USCG SCALE OF INJURIES	INJURY SEVERITY	PERCENT OF TOTAL INJURY REPORTS	VSL FOR AN AVERTED INJURY (2017 Dollars)	PERCENT TIMES VSL (Column 3 * Column 4) (2017 Dollars)
1	Minor	12.9%	\$29,400	\$3,793
2	Moderate	53.5%	\$460,600	\$246,421
3	Serious	24.6%	\$1,029,000	\$253,134
4	Severe	7.4%	\$2,606,800	\$192,903
5	Critical	1.6%	\$5,811,400	\$92,982
			EXPECTED COST:	\$789,233

Source: United States Coast Guard MISLE database (2011 – 2017) and U.S. Department of Transportation, 2016. *Guidance on Treatment of the Economic Value of a Statistical Life (VSL) in the U.S. Department of Transportation Analysis – 2016 Adjustment*, August 8, Table 3.

6. MARINE ACCIDENT OVERVIEW

ACGs account for 18,518 (15 percent) of just over 122 thousand MISLE incidents with groundings, allisions and groundings representing 6.3, 4.8 and 3.9 percent of events, respectively.⁴² (See Figure 2) From 2005 to 2017 real ACGs losses resulted less than eight percent of total losses from all types of reported incidents.⁴³ Over the study period, total losses associated with ACGs were

⁴² Of the MISLE incidents that were classified as ACGs; 41.5 percent were groundings (7,685 events), 32.6 percent were allisions (6,037 events) and collisions represented the remaining 25.9 percent (4,796 events).

⁴³ In 2017, two catastrophic collisions occurred between US Navy warships and merchant ships that accounted for a disproportionate portion of total ACG losses. These were excluded from this analysis as they occurred significantly outside US waters. In one event, an Arleigh Burke-class guided missile destroyer (USS McCain) collided with a tank vessel while approaching Singapore. In this event, ten sailors were killed, five were injured and \$500 million in vessel damage occurred. In the other event the USS Fitzgerald collided with the ACX Crystal, a Philippine-flagged container ship, about 80 nautical miles southwest of Tokyo. In this event, seven sailors were killed, three were injured and vessel damage was \$350 million. Overall, these two events represented almost 87 percent of all vessel damage in 2017 (\$850 million out of \$980 million)

estimated to approximate (\$2017) with costs from all incident types projected to exceed \$41 billion (\$2017). See Table 6

Compared with an estimated total 4.0 million vessel transits in 2016 only 1,060 MISLE incidents were classified as ACGs – about 0.024 percent of total transits.⁴⁴ As roll-on roll-off vessel, commercial fishing and recreational boating transits are not captured in the CPT database, the overall rate of ACGs is no doubt lower.⁴⁵

Figure 2

Table 6. Summary of Estimated Marine Accident Losses
(Millions of \$2017 during 2005 to 2017)
Percent of ACG, NON-ACG and Total in Parenthesis

TYPE OF ACCIDENT	TOTAL LOSSES (\$2017)	VESSEL DAMAGES (\$2017)	CARGO DAMAGES (\$2017)	FACILITY DAMAGES (\$2017)	OTHER DAMAGES (\$2017)	MORBIDITY COSTS (\$2017)	MORTALITY COSTS ⁴⁶ (\$2017)
ACG ⁴⁷	\$2,859.5 (100.0%)	\$584.8	\$16.2	\$375.2	\$397.0	\$800.3	\$686.0

⁴⁴ Source: CPT, Dr. Ned Mitchell, Vessel transits included: internal, local, coastwise, lakewise, overseas-exports, overseas- imports, intra-territory, Canadian – Exports, Canadian – Imports. While the percent of ACGs cannot be calculated for 2017 owing to lack of transit counts at this time, the number of ACGs fell from 1,029 in 2016 to 891 in 2017 – a drop of 13.4 percent.

⁴⁵ At the same time, minor ACGs instances where boats may “bump” into one another, a floating or “fixed” object (e.g., sunken drum, tree, etc.) that do not require USCG or other intervention probably go unreported.

⁴⁶ Includes one missing crew person in 2008.

⁴⁷ Excludes two Navy collisions in 2017.

		(20.5%)	(0.6%)	(13.1%)	(13.9%)	(28.0)	(24.0%)
NON-ACG	\$37,556.0 (100.0%)	\$2,183.7 (5.8%)	\$157.2 (0.4%)	\$236.0 (0.6%)	\$776.2 (2.1%)	\$7,635.0 (20.3%)	\$26,567.8 (70.7%)
TOTAL ⁴⁸	\$40,415.5 (100.0%)	\$2,768.5 (6.9%)	\$173.3 (0.4%)	\$611.3 (1.5%)	\$1,173.2 (2.9%)	\$8,435.3 (20.9%)	\$27,253.8 (67.4%)

However, a small number of catastrophic events can significantly alter year-to-year total property losses.⁴⁹ Two exceptional years (2005 and 2010) for non-ACG incidents and one (2011) year for ACGs, are examples of such catastrophic events.⁵⁰ Non-ACG events in 2005 such as heavy weather damage from Hurricane Katrina in 2005 (*HK Mars, Ocean Warwick*) and the *Deepwater Horizon* and the sinking of the *J.R. Nichols* in the Houston Ship Channel in 2010 were the major contributors of vessel, facility, cargo, and other losses. The 2011 allision of the *Zhen Hua* with the terminal in Portsmouth VA resulted over \$273 million in damages – about 91 percent of total damages that year.

Compared with all types of accidents reported, morbidity and mortality costs from ACGs represented about 9.5 percent of all morbidity costs and 2.5 percent of all costs associated with mortality. Vessel losses accounted for 20.5 percent of all ACG losses. Cargo, facility and other losses represented 0.6, 13.1 and 13.9 percent, respectively of all ACG losses.⁵¹

Table 7. Estimated Dollar Losses by ACG During 2005 to 2017

(Millions of \$2017 Dollars Unless Otherwise Noted)

LOSS DESCRIPTION	ALLISIONS (\$ 2017)	COLLISIONS (\$ 2017)	GROUNDINGS (\$ 2017)	TOTAL ACGs (\$ 2017)
Deaths & Missing	\$68.6 ⁵²	\$588.0	\$29.4	\$686.0

⁴⁸ Includes two Navy collisions in 2017.

⁴⁹ These loss figures do not contain estimates for pollution remediation. USCG estimates place oil remediation costs at over \$10,700 per 42-gallon barrel. This equates to \$12,176 in 2017 dollars. Refer to: USCG, Inspection of Towing Vessels, Notice of Proposed Rulemaking, *Preliminary Regulatory Analysis and Initial Regulatory Flexibility Analysis*, USCG-2006-24412, July 2011.

⁵⁰ The two collision incidents in the Far East involving US warships would have dramatically increased mortality (deaths & missing), morbidity (injuries) and vessel costs if included in the study.

⁵¹ Resulting from 1,022 injuries, 69 deaths and one missing (which was classified as a death).

⁵² Calculated by multiplying the number of dead from allisions (7) times cost of a death (\$9.8 million).

Injuries	\$339.4 ⁵³	\$332.3	\$128.6	\$800.3
Total Deaths & Missing Injuries Loss	\$408.0	\$920.3	\$158.0	\$1,486.4
Vessel Losses	\$170.0	\$165.6	\$249.2	\$584.8
Cargo Losses	\$9.7	\$3.5	\$3.0	\$16.2
Facility Losses	\$352.1	\$20.3	\$2.8	\$375.2
Other Losses	\$364.1	\$27.9	\$5.0	\$397.0
Total Property Loss	\$895.9	\$217.3	\$260.0	\$1,373.2
Number of ACG Incidents	6,045	4,786	7,687	18,518
TOTAL ACGs DOLLAR LOSS	\$1,303.9	\$1,137.6	\$418.0	\$2,859.5
Average Loss Per Event	\$215,694	\$237,689	\$54,383	\$154,417

Among ACG losses morbidity and mortality accounted for 52 percent of total losses with property losses accounting for the remaining 48 percent. Non-ACG events were more heavily weighted toward mortality and morbidity (91.1 percent of the total). Overall, mortality and morbidity losses accounted for 88.3 percent of total losses across all incident types.

Regardless of ACG type, cargo losses remained a de minimis portion of total losses. Closer examination of ACG losses illustrate the type of incident each represents. For example, in the case of allisions (where a moving vessel strikes a stationary object such as a bridge) the largest areas of loss occurred among “other” and “facilities”. Overall allision losses were concentrated among property losses (68.7 percent of total allision losses) rather than morbidity and mortality.

Collision costs were dominated by morbidity and mortality costs – 80.9 percent of total costs. Considering a grounding event represents the striking of a vessel’s hull (side or bottom) with the soil, rocks or other riverbed materials it is not unexpected that the majority of costs involve the

⁵³ Calculated by multiplying the number of injuries from allisions (430) times average injury cost (\$789,233).

vessel itself. Here 59.6 percent of all losses are associated with vessel damages while all other property-related losses are miniscule in nature (2.6 percent of the total). Given the change in the speed of the vessel in the case of groundings, the portion of losses resulting from injuries (30.8 percent) is the second largest area of loss.⁵⁴

An overall graphic comparison of allision, collision and grounding costs by type of damage is shown in Figure 3. Overall collisions result in greater combined morbidity and mortality losses while allisions result in greater overall property losses.

Figure 3

7 PORT IDENTIFICATION

Recognizing the differences in methods of data collection, content and confidentiality, comparison of the two is essential to identify major both international domestic port locations. In 2017, 203 port locations imported and/or exported vessel traffic.⁵⁵ Of these 80 locations (or about 40 percent of the total) had PORTS® information systems installed in 2017 or before.

8 ANALYSIS STRUCTURE

As mentioned in several earlier ENC valuation studies, granular empirical data and resultant analysis is difficult for several reasons. First, unlike PORTS® which have a definitive implementation date, CMPs have been conducted, often repeatedly, over large periods of time such that immediacy of “before” and “after” is not always straight forward. Second, given ongoing

⁵⁴ Deaths resulting from groundings represent only 7 percent of total grounding losses.

⁵⁵ Source: USA Trade OnLine

benefits from both systems (PORTS[®] and CMP) it is not physically or morally possible to remove this information from potential users to assess the resultant impact of such revocation.

In brief, this analysis seeks to understand historical ACG instances with respect to implementation of PORTS[®] and release of ENC navigational charting data. Sensitivity analyses based on areas charted and influenced by PORTS[®] were run to assess changes in ACGs and ACG rates from three perspectives. These include situations where: (1) ENCs had been released and PORTS[®] had been installed; (2) only ENC updates had been released no PORTS[®] had ever been installed; and, (3) a combination of the first two groups.

It is readily recognized that integrated bridge management systems include both ENC and PORTS[®] data and have, along with, improved vessel design, crew training, etc. produced synergistic improvements in vessel operational safety and efficiency. However as the actual and potential implementation and use of such systems are universal and not limited to specific harbors or coast lines, their impact was not individually considered but assumed to be virtually inseparable from underlying ENC and PORTS[®] data. Consequently, in this analysis, only attempts at assessing relative impacts of ENC, PORTS[®] were considered.

9. ASSOCIATING ACCIDENTS WITH ENC AND PORTS[®] LOCATIONS

Employing tonnage, cargo value and international vessel transit activity a list of over 200 U.S. ports were identified. Locations with PORTS[®] and ENC charts were linked to accidents reported in the USCG's MISLE database from the 2003 to 2017 period based on the latitude and longitude of the accident event. Working with CO-OPS and OCS, respectively, locations of PORTS[®] installations and releases of ENCs as of December 2017 were identified.

Figure 4

In the case of ENCs, accidents that occurred within the geographic area surveyed were assigned to that ENC based on the year the chart was released to the public. (See Figure 4) Overall, over 97 percent of 1,226 ENC updates during the 2008 to 2016 period had identified release dates. From this, individual ACG rates were calculated based on the number of vessel transits what had occurred in the surveyed area.

10. VESSEL TRANSIT COUNTS

While accident counts derived from MISLE data provide an overview of accident frequency and trends over time, the relative rate of accidents (calculated by the number of ACGs divided by vessel exposure) can provide an important perspective of navigational aid effectiveness over time.

In a perfect world, locations of accidents would be compared with the number of total vessel transits that had occurred within those identical locations during identical times. Resultant calculations would reveal the precise number of ACGs (or other reportable events) that occurred per vessel transit. Two issues prevent exact calculation of accident rates. First, there is not a perfect match between reported CPT data and the multi-sided polygons developed to estimate the extent of PORTS[®] influence. CPT utilizes objective measures of ports and river segments (e.g., recognized harbor definitions and mileposts⁵⁶) which cover areas the USACE has been granted the

⁵⁶ To levels of one decimal point precision.

responsibility to maintain by the Congress. On the other hand, assignment of the scope of PORTS® influence through use of the Environmental Systems Research Institute (ESRI) GIS mapping software ArcMap lassoing technique was (albeit performed by industry experts) was more subjective in nature.

The second reason why precise (multi decimal precision) estimates of accident rates in any one year cannot be made is the fact that CPT does not collect transit counts on commercial fishing vessels or recreational boaters. However, relative change in accident rates before and after PORTS® installation or updates of navigational charts may be approximated, as the denominator in such calculations would have been presented in a consistent manner across all years of study.⁵⁷ Use of CPT docked plus through data is the best measure available to make such determinations employed in this investigation.

11 ENC BENEFITS

Previous investigators have well documented the difficulties of assessing the value of ENCs. Different approaches have been taken (e.g., consumer surplus, willingness to pay, engineered cost reductions, etc.) with varying levels of analysis scope (e.g., delay minimization, vessel and port capacity optimization, identification of coastal zones, response to natural disasters and environmental emergencies, accident mitigation etc.). The center of this analysis was the impact of ENCs on ACGs.

In an ideal situation, comparisons of ACG events and related rates could be undertaken through simple elimination of the other two major factors affecting accident events (e.g., IBMS and PORTS®). While it might be possible to assess partial impact of IBMS through an extensive analysis of individual vessel capabilities and changes in those capabilities over time, such an undertaking would require herculean efforts and, in all likelihood, would not be possible to obtain for a variety of reasons. Complicating this approach further would be the inability to judge the performance level of human performance in using IBMS. Consequently, while it is recognized that IBMS contributes to ACG reductions, their availability and potential impact was assumed to be the same across all locations. In other words, there is no evidence that updated IBMS systems were not available in certain geographic areas or limited to only certain commercial vessels.

Calculating a willingness to pay for ENCs was not employed as it can be biased by the requirement that mandates carriage of ENCs by U.S. flag vessels and well as foreign ones destined or departing from a port or location subject to U.S. jurisdiction.⁵⁸ Instead of attempting to assess direct, indirect or induced gross economic benefits resulting from ENCs, a more narrow alternative

⁵⁷ The number of accidents divided by the number of total vessel transits can be compared before and after the installation of PORTS® to estimate the impact of those installations.

⁵⁸ Refer to Code of Federal Regulations Title 33: Navigation and Navigable Waters, Part 164 – Navigation Safety Regulations §164.30 Charts, publications, and equipment: General.

approach was followed to attempt to assess the change in the number of ACGs that might have occurred had updated ENC's alone and in conjunction with PORTS[®] not been present.

11.1 Test Statistic

This analysis involves examining the relationship between two variables (i.e., the number of ACGs and number of ENC's released) through correlation analysis. As updated ENC's are released for a variety of reasons, it was hypothesized that the number of ENC's released would be inversely related to ACG accident rates. This was tested across all chart types with three groups of data: (1) locations with both PORTS[®] installations and ENC releases; (2) locations where no PORTS[®] had ever been installed and only ENC's had been released; and (3) all locations where PORTS[®] may or may not have been installed and ENC's released.

Correlation was estimated through the value for Pearson's *r* statistic. The value of correlation coefficients can range from 0.00 to 1.00, with values of 1.00 suggesting either a perfect positive correlation (+1.00) or negative one (-1.00). The strength of correlation is assessed as follows:

- Greater than 0.00 to 0.20, the correlation is slight, almost negligible relationship
- 0.20 to 0.40, the correlation is low, definite but small relationship
- 0.41 to 0.70, the correlation is moderate, substantial relationship
- 0.71 to 0.90, the correlation is high, marked relationship
- 0.91 to 1.00, the correlation is very high, very dependable relationship

If, hypothetically, the correlation between marine accident rates and the number of charts released over a period of time was -0.5, the variance of accident rates explained by updated charts would be 25 percent ($-0.5 * -0.5 * 100$). In this example, 25 percent of the variation in the overall rate could be attributed to updated chart releases. Results were accepted if the correlation statistic was both negative showing the expected inverse relationship and had at least a 0.05 level of significance.

11.2 Results and Suggested Benefits

Analysis was run comparing individual allision, collision and groundings accident rates with the number of ENC's released for locations where: (1) PORTS[®] had been installed; (2) PORTS[®] had not been installed; and, (3) all locations.

Table 8. Accident Rate – ENC Release Correlation Results

(Significance Level in Parenthesis)

TYPE OF EVENT	TOTAL ENC	OVERVIEW ENC	GENERAL ENC	COASTAL ENC	APPROACH ENC	HARBOR ENC
ALLISIONS						
All Locations	NS ⁵⁹	NS	NS	NS	NS	NS

⁵⁹ Not Significant at 0.05 level

With PORTS®	-0.8092 (0.01)					-0.7915 (0.01)
Without PORTS®	NS	NS	NS	NS	NS	
COLLISIONS						
All Locations	NS	NS	NS	NS	NS	NS
With PORTS®	-0.7986 (0.01)	NS	NS	NS	NS	-0.7985 (0.01)
Without PORTS®	NS	NS	NS	NS	NS	NS
GROUNDINGS						
All Locations	NS	NS	NS	NS	NS	NS
With PORTS®	-0.8081 (0.01)	NS	NS	NS	NS	-0.7850 (0.01)
Without PORTS®	-0.5037 (0.03)	-0.5371 (0.02)	NS	NS	NS	NS

Overall, locations where all types of ENC releases had been released as well as having PORTS® installations showed significant results. Refer to Table 8. Inverse correlations between allision

Table 9. Estimated Impact of Total ENC Releases where PORTS® Had Been Installed

(All correlations significant at the 0.05 level or higher)

TYPE OF EVENT	NUMBER OF ANNUAL TRANSITS	ACG RATES WITH PORTS®	NUMBER OF EXPECTED EVENTS	VARIABILITY ATTRIBUTED TO ENCS	NUMBER OF EVENTS DUE TO ENC	AVERAGE COST PER EVENT	POTENTIAL ANNUAL BENEFIT	LEVEL OF SIGNIFICANCE
Allision	2,794,119	0.0046%	129	65%	84	\$215,694	\$18,153,173	0.01
Collision	2,794,119	0.0015%	42	64%	27	\$237,689	\$6,353,366	0.01
Grounding	2,794,119	0.0031%	87	65%	57	\$54,383	\$3,076,097	0.01
						Total	\$27,582,635	

Table 10. Estimated Impact of Total ENC releases at Locations Without PORT (Allisions and Collisions were not significant at the 0.05 level)

TYPE OF EVENT	NUMBER OF ANNUAL TRANSACTIONS	ACG RATES WITHOUT PORTS®	NUMBER OF EXPECTED EVENTS	VARIABILITY ATTRIBUTED TO ENCS	NUMBER OF EVENTS DUE TO ENC	AVERAGE COST PER EVENT	POTENTIAL ANNUAL BENEFIT	LEVEL OF SIGNIFICANCE
Grounding (All chart types updated)	1,381,360	0.0084%	116	25%	29	\$54,383	\$1,601,007	0.03
Grounding (Overview Charts only)	1,381,360	0.0084%	116	29%	33	\$54,383	\$1,820,370	0.02

accident rates and the total number of ENC releases where all five types of charts had been released at least once during the study period was -0.8092 suggesting that about 65 percent of the variation could be attributed to ENCs. As allisions represent the meeting of moving vessels with stationary objects (e.g., pier, bridge abutment, etc.) it is not surprising that individual harbor ENCs showed large significant correlation with allision events. In cases where PORTS® had been installed, cases where all chart types had been released as well as cases where harbor charts had been issued (either alone or in association with one or more other ENC type) appeared to be significant at the 0.05 level. Collisions, which occur when two moving vessels strike one another, as well as groundings both appeared to be significantly explained at the 0.05 level in the presence of PORTS® in cases where all types of ENCs had been released. It was also noted that harbor ENC releases were also significant at the 0.05 level where PORTS® had been installed.

At locations where PORTS® had been installed and all types of ENCs had been released during the 2008 to 2016 study period, employing the average cost of an allision against the portion of total allisions that are explained by the total number of all ENC chart updates suggests an annual benefit of about \$18.1 million (\$2017). Refer to Table 9. The same procedure for collisions and groundings suggests annual benefits in excess of \$6.3 and \$3.1 million dollars, respectively.

Collectively for all three ACG types, total annual benefit approximated \$27.6 million (\$2017). Over ten years this would approach \$248 million.⁶⁰

At locations where no PORTS® had ever been installed, cases where updates of all chart types had occurred as well as releases of overview charts were both seen to have a significant reductive influence on groundings with annual benefits of \$1.6 million and \$1.8 million for all chart and overview chart updates, respectively. (Refer to Table 10) While allisions and collisions suggested annual benefits of about \$2.0 and \$0.3 million (\$2017) respectively, neither was statistically significant at the 0.05 level, and, were not included in final benefit estimations.

Collectively, where found to be statistically significant, annual benefits from all locations (with and without PORTS® (\$27.6 plus \$1.6 to \$1.8 million)) were estimated to range between almost \$29.2 and \$29.3 million (\$2017). Over ten years this would be valued at about \$262 million.

12 CONCLUSIONS

It has been well documented that navigational effectiveness and safety is due to a number of factors including IBMS, PORTS® and ENC's in addition to factors such as weather, etc. It is difficult, as several previous studies have pointed out, to tease precise estimates of the value of each navigation aid, let alone the synergies that can be produced when all are working together.

Overall, it appears as a greater amount of navigational information (through PORTS® and ENC releases of all types of charts) is available to mariners, rates of allisions, collisions and groundings are lowered. Unlike previous analyses often based on willingness to pay, this study was predicated on evaluation of ACG rates that occurred over time with and without PORTS® installations and releases of ENC's.

Over 1,200 ENC's across five types of charts (overview, general, coastal, approach and harbor) were released during the study period. At locations where PORTS® had been installed, a significant portion of ACG's variation was explained in cases where at least one of each type of ENC had been released during the study period. As the number of ENC releases increased, the accident rates for allisions, collisions and groundings declined. Overview charts were also seen to be significant in reducing collisions at locations where PORTS® had not been installed.

Collectively, an annual benefit in excess of \$29 million (\$2017) due to the presence of updated ENC's and PORTS® was suggested. Reductions in allision, collision and grounding rates were also found to be significant in cases where both PORTS® had been installed and only harbor charts had been released.

At locations where PORTS® had not been installed, ENC updates of all types as well as harbor only ENC's were found to be significant in explanations of reductions in groundings. Annual ENC benefits at locations without PORTS® from reduced groundings were estimated to range from \$1.6

⁶⁰ Employing a 2.1 percent discount rate for a ten-year project. Source: Office of Management and Budget, Circular Number A-94, November 2018.

to \$1.8 million (\$2017) in cases where all charts and only overview chart releases were considered, respectively. Over ten years this would approach a savings of about \$15 million. Total annual benefits were estimated to exceed \$29 million – equal to about \$262 million over a ten year period. Overall, these estimates for ACGs represented about 26 percent of the direct benefit estimates from all 18 beneficiary groups estimated by Leveson.⁶¹ While several weighting schemes involving different types of ENC's were investigated, none proved to increase explanatory power over the direct relationship between the total by the number of ENC's released and rates of ACGs.

REFERENCES:

- Alexander, Lee. 2003. "Electronic Charts, In: The American Practical Navigator", *National Imaging and Mapping Agency*, Chapter 14: 199-215.
- Australian Department of Defense Report. 1992. "An Economic Analysis of the benefits of the Royal Australian Navy's Hydrographic Program", *Annual Report*, 1992-1993.
- Bhattacharjee, Shilavadra. 2017. "What is Integrated Bridge System (IBS) on Ships", *Marine Insight*, October 23. Available://www.marineinsight.com/marine-navigation. Accessed 23 October, 2019.
- Brinkman, George L. and Susan L. Calverley. 1992. "Benefit Cost Assessment of the Canadian Hydrographic Service, *Canadian Hydrographic Service*, Report by INTERCAMBIO Ltd., February 29.
- Econometrica, Inc. 2015. "Socio-Economic Study: Office of Coast Survey's Nautical Charting Program", Contract No: GS-10F-0269K, Order Number: EA-133C-14-NC-1361, Submitted to the NOAA Office of Coast Survey, July 10.
- Edwing, Richard. 2013 "Improving Safety and Efficiency Through PORTS[®]", *AAPA Seaports Magazine*, Summer, p. 29.
- Gonsalves, Fandel, C., Patrick Keown, Lucy Hick and Barry Gallagher. 2017. "Hydrographic Health: A National Overview", Presentation, NOAA, U.S. Hydro 2017 Conference, Galveston, TX, March 20-23: 3.
- Hammit, James K. 2007. "Valuing Changes in Mortality Risk: Lives Saved Versus Life Years Saved", *Review of Environmental Policy*, Volume 1, Number 2: 228-240.
- Holland, S., E Mansur, N. Muller and A. Yates. 2016. "Are There Environmental Benefits from Driving electric Vehicles: The Importance of Local Factors", *American Economic Review*, 106(12): 3700-3729.
- Kite-Powell, Hauke, Di Jin and Scott Farrow. 1997. "Expected Safety Benefits of Electronic Charts", *Journal of Transport Economics and Policy*, May: 147-162.
- Kite-Powell, Hauke. 2007. "Use and Value of Nautical Charts and Nautical Chart Data in the United States", Report produced for the Office of Coast Survey, NOAA, August.
- Leveson, Irv. 2012. "Socio-Economic Study: Scoping the Value of NOAA's Coastal Mapping Program", Final Report, Leveson Consulting, Prepared for the Remote Sensing Division of the

⁶¹ Leveson's total direct benefit of \$100.3 million reported for 2011 increased to \$114.5 million in 2017.

- National Geodetic Survey, National Ocean Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce under contract DG133C11SE1521, March 8.
- Montewka, Jakub, Floris Goerlandt, Gemma Innes-Jones, Douglas Owen, Yasmine Hifi, and Romanas Puisa. 2017. "Enhancing Human Performance in Ship Operations by Modifying Global Design Factors at the Design Stage", *Reliability Engineering & System*, Volume 159, March: 283-300.
- Moore, Michael J., and W. K. Viscusi. 1988. "Doubling the Estimated Value of Life: Results Using New Occupational Fatality Data", *Journal of Policy Analysis and Management*, Volume 7, Issue 3: 476–90.
- Muller, N., R. Mendelsohn and W. Nordhaus. 2011. "Environmental Accounting for Pollution in the United States Economy", *American Economic Review* 101: 1649-1675.
- Oudet, L. 1972. "The Value of a Nautical Chart", *The Journal of Navigation*, Royal Institute of Navigation, Volume 25, Number 3, July.
- Vadus, Joseph R. 1996. "Electronic Nautical Charting: Economic value and Role in Sustainable Development of Marine Transport Operation", *International Hydrographic Review*, Monaco, Volume LXXIII, Number 1, March.
- Viscusi, W. Kip. 2018, *Pricing Lives, Guideposts for a Safer Society*, Princeton University Press.
- Volpe National Transportation Systems Center (The Volpe Center). 2009. "Valuation of the NOS Navigational Products, Final Report, Task 4 – Benefit-Cost Analysis (BCA) Model Estimates", Prepared for the National Ocean Service (NOS), National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce, March 23.
- Weintrit, Adam. 2010. "Six in One or One in Six Variants. Electronic Navigational Charts for Open Sea, Coastal, Off-Shore, Harbour, Sea-River and Inland Navigation", *International Journal of Marine Navigation and Safety of Sea Transportation*, Volume 4, Number 2, January.
- Wolfe, K. Eric and MacFarland, David. 2016. "A Valuation Analysis of the Physical Oceanographic Real Time System (PORTS®)", *Journal of Ocean and Coastal Economics*: Volume 3, Issue 1, Article 12.
- Wolfe, Eric and Mitchell, Kenneth N. 2018. "Allisions, Collisions and Groundings: Estimating the Impact of the Physical Oceanographic Real Time System (PORTS®) on Accident Reduction", *Journal of Ocean and Coastal Economics*: Volume 5, Issue 1, Article 4.