CATEGORY 1 and 2 COMMERCIAL MARINE VESSEL 2023 EMISSIONS INVENTORY

Prepared for:

U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
109 T.W. Alexander Drive
Research Triangle Park, NC 27711

Prepared by:

Eastern Research Group, Inc.
3800 Gateway Center Blvd, Suite 307
Morrisville, NC 27560

September 2025

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

List of Abbreviations

AIS	Automatic Identification Systems
BSFC	Brake-Specific Fuel Consumption
C1C2	Category 1 and 2
C3	Category 3
CMV	Commercial Marine Vessel
CO	Carbon Monoxide
CO2	Carbon Dioxide
ECA	Emissions Control Area
EF	Emission factor
GT	Gas turbine
GT-ED	Gas turbine-diesel-electric drive
IMO	International Maritime Organization
kn	Knot
kW	Kilowatt
kWh	Kilowatt-hour
LLAF	Low load adjustment factor
LNG	Liquified natural gas
MMSI	Maritime Mobile Service Identifier
MSD	Medium speed diesel
MSD-ED	Medium speed-diesel-electric drive
NOx	Nitrogen oxides
PM	Particulate matter
PM2.5	Particulate matter 2.5 microns or less in diameter
PM10	Particulate matter 10 microns or less in diameter
Reefer	Refrigerated vessels
RM	Residual marine
Ro Ro	Roll on/Roll off
RPM	Revolutions per minute
S-AIS	Satellite automatic identification systems
SO2	Sulfur dioxide

SOG Speed Over Ground

SOLAS Safety of Life at Sea

SSD Slow speed diesel

ST Steam turbine

T-AIS Terrestrial automatic identification systems

USCG United States Coast Guard

VOC Volatile organic compounds

1 Introduction

The National Emissions Inventory (NEI) and Emissions Modeling Platforms (EMP) are national compilations of air emission estimates of criteria air pollutants (CAPs), the precursors of CAPs, hazardous air pollutants (HAPs) and greenhouse gases for mobile, point, and nonpoint emissions sources. The hazardous air pollutants that are included in the EMP are based on Section 112(b) of the Clean Air Act. State, local and tribal air agencies submit emission estimates to EPA and the Agency adds information from EPA emissions programs, such as the emission trading program, Toxics Release Inventory (TRI), and data collected during rule development or compliance testing. The NEI and its derivative modeling platforms are used for various modeling and regulatory analyses performed by EPA, state and local air quality management agencies, and others.

This report documents the development of ERG's emissions inventory for Category 1 and 2 (C1C2) commercial marine vessels (CMV), including the conceptual framework, equations, data sources, and assumptions. A description of the development of the Category 3 (C3) CMV emissions inventory for vessels with engines having displacement greater than or equal to 30 liters per cylinder, including the conceptual framework, equations, data sources, and assumptions, is provided in a separate report by the EPA.

2 AIS Dataset

The EPA purchased Automated Identification System (AIS) data from Spire Global's database to quantify all ship activity which occurred between January 1 and December 31, 2023.[1] The International Maritime Organization's (IMO's) International Convention for the Safety of Life at Sea (SOLAS) requires AIS to be fitted aboard all international voyaging ships with gross tonnage of 300 or more, and all passenger ships regardless of size.[2] In addition, the United States Coast Guard (USCG) has mandated that all commercial marine vessels continuously transmit AIS signals while transiting U.S. navigable waters.[3] As the vast majority of C3 vessels meet these requirements, any omitted from the inventory due to lack of AIS adoption are deemed to have a negligible impact on national C3 emissions estimates.

The activity described by this inventory reflects ship operations within 200 nautical miles of the official U.S. coastline. This boundary is roughly equivalent to the border of the U.S Exclusive Economic Zone and the North American Emission Control Area (ECA), although some non-ECA activity is captured as well (Figure 1).

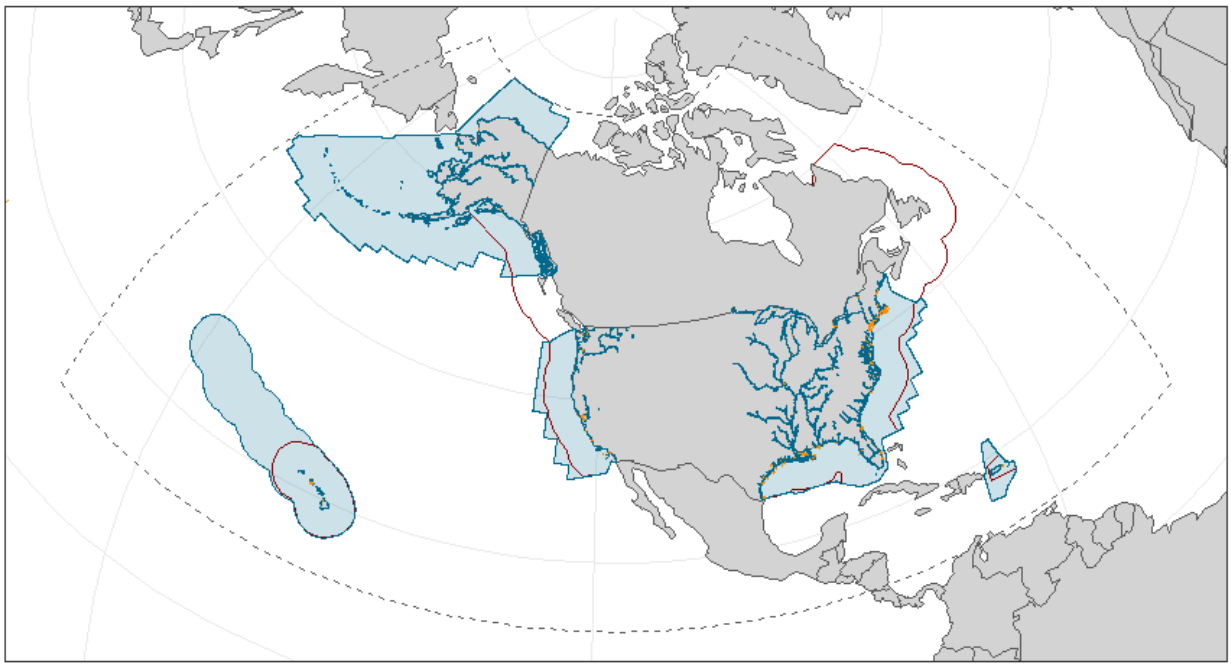


Figure 1 Geographic Regions used for the C1C2 Emissions Inventory NEI Geographic Extent (blue), North American and Caribbean ECAs (red outline), Ports and Anchorages (orange dots), AIS area of interest encompassing the air quality modeling domain (dashed outline)

2.1 AIS Pre-Processing

The data was delivered as comma separated value (csv) files that contain AIS records of global ship movements. The global AIS dataset for calendar year 2023 contained a total of 42,247 files totaling 10.6 TB of data. The as-received dataset includes all global vessel operations with a sampling frequency that depends on the geographic coverage of the AIS receiver network. The dataset also contains some anomalous data such as duplicate records, and records from non-vessels. The data fields retained for calculating emissions were: Maritime Mobile Service Identifier (MMSI), timestamp, IMO number, call sign, latitude (degrees), longitude (degrees), speed (knots), Course over ground (degrees), heading (degrees), navigation status, Draught (meters), ship and cargo type, length (meters), width (meters), and receiver. Many of these fields were not directly used for emissions calculations but were retained for QA purposes. Of these fields only MMSI, timestamp, latitude, longitude, speed, and receiver were reported in every row of the csv files. Therefore, MMSI was used as the primary identifier for distinguishing between unique vessels.

The first step in processing the AIS data was to filter the dataset for the records that fall within the geographic domain of the NEI and parse them into standardized data fields, with non-vessel and duplicated records removed. The geographic area of interest was defined as: latitudes between 11.32° and 75.10°, and longitudes between 166.38° and -40.61°. Note that the area of interest spans the anti-meridian (±180°). Non-vessel entities were identified using MMSI patterns, based on information obtained from the USCG Navigation center.[4] Records with MMSI numbers identified as: ship, auxiliary craft associated with a parent ship, or group of ships, were retained. The following MMSI types were dropped: divers' radios, coastal stations, aids to navigation, search and rescue aircraft and transmitters, man overboard devices, and emergency position indicating radio beacon.

Next the records were aggregated by MMSI to a standardized five-minute time interval to reduce the size of the dataset and to match the time interval used by EPA to develop previous marine emissions inventories. For this step, dynamic numerical fields (latitude, longitude, speed, course over ground, heading, draught) were averaged over the five-minute interval. For the other fields the most frequent observed value was selected when multiple values were present. The aggregated data was written to a database keyed by MMSI and timestamp for fast data retrieval.

2.2 Preparing Ship AIS Data for Emissions Calculations

EPA delivered the pre-processed AIS dataset to ERG who performed additional processing steps in preparation for C1C2 emissions calculations. Every record within the AIS dataset was assigned a unique vessel identification number that corresponds to a record within the ship characteristics dataset described in Section 3. C1C2 vessels identified within the ship characteristics dataset were extracted from the AIS dataset. Vessels that reported only a single AIS record throughout the year were removed, because at minimum two records are needed per ship to calculate activity durations. Consecutive hoteling activity of each ship was aggregated in the dataset to reduce the dataset size. Hoteling records were aggregated to no more than an hour to ensure that hourly rasterized emissions properly represented hoteling activity. Time and distances were calculated between each consecutive record of each vessel's annual transit and allocated to the record following the activity duration, with time calculated in hours and distance calculated in meters using the haversine method. Activity intervals exceeding 24 hours were omitted from emissions estimates as there was too much uncertainty in a vessel's movement.

Though AIS reports speed over ground (SOG), an additional speed was calculated using the calculated duration and distance intervals between consecutive records. Records associated with a calculated speed greater than 40 kn helped identify AIS messages that had erroneously reported their location and/or time, as the activity needed to transit to that location at that time for that vessel would have been impossible. These records were removed, and time and distance were recalculated across their gap. Erroneous vessels were identified if 30% or more of their daily records were associated with erroneous calculated speeds. These erroneous vessels were removed from that day's emissions estimates. Where time, distance, and calculated speed were considered within reason, SOG was greater than 40 kn, SOG was replaced by calculated speed, otherwise SOG was used for all emissions estimations calculations.

Each remaining AIS record was assigned a state and county FIPS code for NEI aggregation purposes. FIPS codes were assigned using three shapefiles: the NEI Port Shapefile, the 2023 TIGER County Shapefile, and the NEI Shipping Lane Shapefiles.[5,6] If an AIS record reported from a location within an NEI Port Shapefile, it would receive the FIPS code associated with that port polygon. In addition, these records with port polygons were assigned port source classification codes (SCCs), and all others were assigned underway SCCs. Otherwise, if an AIS message did not report from a port but did report from within a TIGER County shapefile, it would receive the FIPS code associated with that county shape. Finally, an AIS message reported from within the shipping lane shapefiles, but not within the TIGER County or port shapefiles (i.e., federal waters), would be assigned the FIPS associated with that specific federal waters shipping lane shape. All records reported outside United States territorial waters were assigned a FIPS of 98001. Additional codes were used to differentiate Canadian and Mexican waters.

3 Ship Characteristics Dataset

To calculate a ship's emissions, additional information about the ship is needed beyond its position and speed. For that data ERG primarily used the Clarksons ship registry supplemented with and validated by

smaller datasets.[7-10] The vessel characteristics data must be matched with the AIS data using a combination of the vessel's IMO number and MMSI number. In addition, not all of the ship characteristics needed to calculate emissions are available for every vessel. This section describes how ERG assembled a ship characteristics dataset based on the observed vessel ID values in the AIS data set, and gap-filled missing fields where required.

3.1 Identifying Observed Ships

After the AIS dataset was cleaned, the MMSIs were compiled for vessel identification. Vessels must be identified to determine their vessel type, and thus their vessel group, power rating, and engine tier information which are required for emissions calculations. Ship characteristics information was compiled from Clarksons 2024 Ship Registry and Global Fishing Watch's (GFW) Version 2 Fishing Vessels dataset, with a preference for Clarksons reported data when the same vessels were reported across multiple datasets. GFW determines ship type information by analyzing processed 2012 to 2020 AIS data through machine learning classifiers, which identify activity patterns by ship and gear type.

Vessel-specific information was linked to AIS records by matching the AIS fleet MMSIs and IMOs with those in the compiled ship registry dataset. C3 vessels that could not be matched on both identifiers were matched on IMO and then MMSI, in that order. In contrast, C1C2 vessels were matched on MMSI before IMO if it could not match on both identifiers.

The received AIS data included ship and cargo type information, but because these data are entered by the user, there might be issues with regards to the accuracy of this field. The current version of the Marine Cadastre AIS data includes updated vessel type information that tries to address some of these quality issues.[11] The Marine Cadastre vessel types associated with the AIS ship and cargo type number were used for the remaining vessels unidentified by both the Clarksons and GFW datasets.

The vessel parameters required to calculate ship propulsive power, estimate operating modes, and assign emission factors are listed in Table 1. The following sections describe how missing values were filled for each of these fields.

Table 1 Ship Parameters

Vessel Identification	Vessel Category Determination	Vessel Power Parameters	Vessel Grouping/Emission Factor Parameters
• IMO number • MMSI	• Engine bore • Engine stroke	• Total installed propulsive power (kW) • Service Speed (kn)	• Keel-laid year • Propulsion type • Engine revolutions per minute (rpm) • Main engine stroke type

3.2 Ship Type

Each vessel in the 2023 fleet was assigned a unique vessel type based on the combination of vessel types designated from Clarksons, ERG's prior assignments, and Marine Cadastre. Priority was given to Clarksons when making vessel type assignments since it contains more up-to-date information than ERG's prior assignments and it does not contain the data quality issues of AIS. In total, 308 different vessel types were assigned to C1C2 vessels (Appendix A.1). Surrogate vessel attribute data is not available for all vessel types, so vessel types were aggregated into 16 different ship types for which surrogate data were

available. Table 2 lists each ship type with its vessel counts in the entire AIS dataset. Vessels were assigned to the Miscellaneous vessel group if their vessel type did not fit into any of the other groups. The Miscellaneous vessel group represents 2.8% of the 2023 fleet. All pleasure craft, barges, and non-self-propelled vessels were removed from inventory calculations as they are not commercial vessels or do not produce emissions (Table 3).

Table 2 C1C2 Inventory Ship Counts in Entire AIS Data

Ship Type	2023 Entire Area Ship Count
Bulk Carrier	107
Commercial Fishing	16,414
Container Ship	68
Ferry Excursion	2,702
General Cargo	6,415
Government	1,524
Miscellaneous	1,088
Offshore support	2,254
Pilot	24
Reefer	33
Ro Ro	350
Tanker	1,061
Tug	6,970
Work Boat	255

Table 3 C1C2 Vessels Removed

Ship Type	2023 Entire Area Ship Count
Pleasure Craft (Removed)	50,293
Non-Propelled (Removed)	64

Figure 2 below shows the fraction of AIS messages associated with each of the ship types.

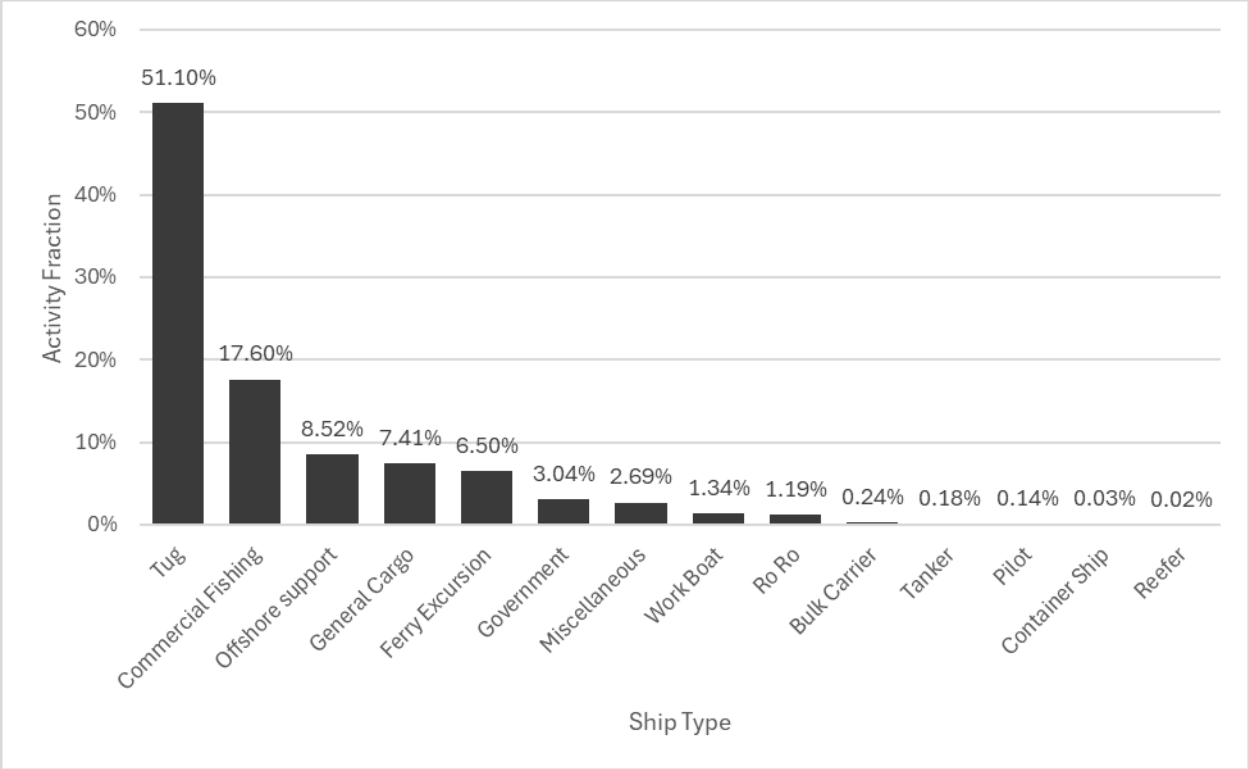


Figure 2 Breakdown of Category 1 and 2 AIS Activity by Ship Type

The aggregated vessel counts were evaluated to ensure they were reasonable using publicly available data sources. For example, the US Army Corps of Engineers (USACE) reported that there are 6,501 US flagged tugs operating in the US in 2023, which is close to the 2023 AIS value of 6,970 tugs.[12]

The USACE reported 1,842 support vessels that provide services to oil and gas platforms in federal waters.[12] The 2023 AIS C1C2 fleet included 2,254 offshore support vessels. Both the USACE and the 2023 AIS estimates would include vessels that support offshore platforms located in federal and state waters in the Gulf of Mexico, California, and Alaska.

The USACE documented that there were 80 domestic flagged tankers.[12] This stands in comparison to the 2023 AIS estimate of 1,061 tankers which includes non-US flagged vessels operating in the US, Canadian, or Mexican waters.

The 2023 AIS estimate of 2,702 ferry-excursion vessels exceeds the USACE's 2023 estimate of 1,238 passenger-ferry vessels.[12] AIS participation is not mandated for vessels with less than 150 passengers with fixed, limited, slow speed transits, suggesting that AIS may not be including the smaller vessels; conversely, some of the vessels included in the USACE may be Category 3 vessels; further study may be needed to better understand these vessel counts.

Other comparisons are more problematic. For example, the USACE estimates that there are 857 U.S flagged dry cargo vessels operating in the U.S.[12] However, 6,415 general cargo ships were identified in the 2023 AIS fleet is much larger than the USACE number as it includes foreign flagged vessels. It should be noted that the general cargo vessel type is vaguely defined, such that some of these vessels may be

mapped to other vessel groups if more detailed data were available. Even accounting for foreign registered vessels, AIS indicates that the dry cargo fleet may be larger than what is reported by the USACE.

16,414 commercial fishing vessels were identified in the 2023 AIS dataset. The national fisherman trade association estimated that nearly 2,900 commercial fishing vessels are required to comply with the AIS reporting standard.[13] In addition, the estimated size of the U.S. commercial fishing vessel fleet is approximately 27,000 vessels, suggesting that 2023 inventory is still underreporting commercial fishing vessels.[14]**Error! Bookmark not defined.** This underreporting may indicate that most of the fleet is composed of smaller vessels that do not trigger reporting requirements. The cost of AIS transmitter installation and the desire to keep fishing sites and activities secret may contribute to this underreporting of AIS data for commercial fishing vessels.

3.3 Engine Type

Vessel engine type is required for ship parameter gap-filling described in Section 3.4. The majority of the C1C2 fleet operated with medium-speed diesel (MSD) engines, which are identified as two-stroke engines. Slow-speed diesel (SSD) vessels were identified as those having four-stroke engines. While rpm classifications vary, 500 revolutions per minute (rpm) was deemed to be the most appropriate cutoff between SSD and MSD engines, given the broad band of rpms separating the two groups.[15] ERG used rpm classifications to determine engine type only when engine stroke type information was unavailable. Gas turbine (GT) and steam turbine (ST) engines were determined by a descriptive propulsive type vessel characteristic field. This propulsive type field also allowed for the identification of electric-drive vessels (MSD-ED or GT-ED). Currently, no standardized identification methods are available for liquified natural gas (LNG) engines. All auxiliary engines were assumed to be MSD.

3.4 Ship Parameter Gap Filling

The ship characteristics dataset contains data gaps within many of its fields. These gaps are filed for service speed and mechanical propulsion power as they are used in the C1C2 emissions calculations. Initially, the activity time-weighted average (Eq. 1) for service speed and mechanical propulsion power is calculated for each unique ship category, ship type, tier, and engine type. These values are used to gap-fill vessels with the same ship category, ship type, tier, and engine type that do not have service speed and/or mechanical propulsion power values within the ship characteristics dataset. Remaining gaps are filled using the same calculation but with iterative steps through a broader series of characteristic groups (Appendix B.1). This iteration occurs until each vessel has a service speed and mechanical propulsion power value within the ship characteristics dataset. Appendix B.2 shows the distribution of original and gap-filling parameter values for each ship type.

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i \cdot t_i}{\sum_{i=1}^{n} t_i} \qquad \text{Eq. 1}$$

where:

- $\bar{x}$ = time weighted average of parameter values
- n = count of vessels with existing parameter values
- x_i = parameter value of vessel *i*

t_i = activity time value of vessel *i*

4 Calculating Emissions

This inventory compiles emissions using the methods described in EPA's 2022 Ports Emissions Inventory Guidance and implemented in EPA's Marine Emissions Tools.[16,17] Emissions are calculated for each marine vessel represented in the AIS datasets, for each time interval between consecutive AIS messages and assigned to the location of the message before the interval. Emissions are calculated according to the equation below (Eq. 2).

$$Emissions_{interval} = Time_{interval} \times Power \times EF \times LLAF \quad \text{Eq. 1}$$

where:

Emissions = mass of emissions estimated for each time interval between AIS messages for each vessel, typically calculated in grams and then converted to tons when emissions are aggregated

Time = length of time between AIS messages, measured in hours

Power = calculated in kWh for each AIS message, for each vessel, for each of the three engine groups on a vessel: propulsive (main), auxiliary, and auxiliary boiler engines

EF = assigned emission factors for each engine group on the vessel

LLAF = low load adjustment factor, a unitless factor that reflects increasing propulsive emissions during low load operations and varies according to the calculated propulsive power

Emissions were calculated for each unique C1C2 ship identified in the gap-filled ship characteristics dataset. The emissions for ships were calculated in parallel and combined afterwards to create a final overall inventory. In total emissions were calculated for 23,207 ships.

4.1 Calculating Main Engine Power

Propulsive power was calculated using the Propeller Law, which requires each vessel's total installed propulsive power in addition to their optimal service speed, as documented in Equation 3.

$$Power\ (kW) = \mathrm{LF} \times P_{ref} = \left(\frac{V}{V_{ref}}\right)^3 \times P_{ref} \quad \text{Eq. 2}$$

where:

LF = load factor

P_{ref} = total installed propulsive power (kW)

V = AIS-reported speed (kn)

V_{ref} = service speed (kn)

Equation 3 is used to estimate the likely propulsive power applied for each vessel between consecutive AIS messages. The cubic ratio of the AIS reported speed following the message interval and the vessel's optimal service speed is calculated to estimate a load factor (LF). The load factor represents the percentage of the vessel's total installed propulsive power assumed to be used during that activity interval.

4.2 Assigning Operating Mode

Operating mode was determined using geospatial, speed, and propulsive load data. For anchorage and port activity shapefiles from NOAA and EPA were used.[18,5] The operating modes were assigned using the following rules in order of preference:

1. If a vessel was in an anchorage zone and had a speed less than or equal to 3 knots, it was assigned the anchorage operating mode.
2. If a vessel was in a port area and had a speed less than or equal to one knot, it was assigned the berth operating mode.
3. If a vessel's speed was more than 1 knot with a propulsion engine load factor less than or equal to 20%, it was assigned the maneuvering mode.
4. If a vessel's propulsion engine load factor was more than 20%, it was assigned the transit operating mode.

These rules are consistent with the general considerations presented in EPA's Ports Emissions Inventory Guidance.[Error! Bookmark not defined.] If a vessel's operation was not covered by the above rules (e.g., traveling less than 1 knot outside of an anchorage zone or port area), it was assigned to the anchorage operating mode. Figure 3 shows an example of the shape files used for operating mode assignment.

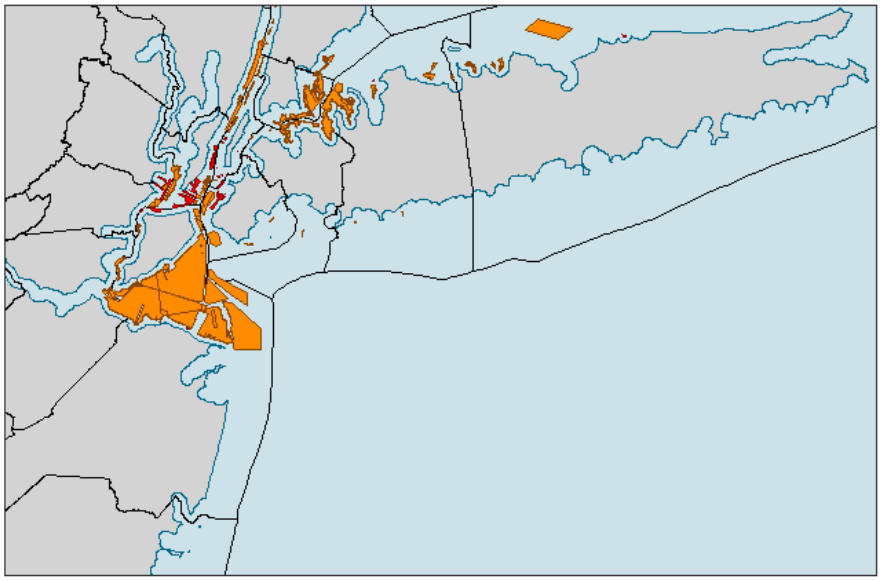


Figure 3 Example map illustrating the shape files used for assigning operating mode. The map covers the area surrounding the ports of New York and New Jersey. Red polygons indicate port shapes, and orange polygons indicate anchorage areas. The blue region is a buffered coastline shape used to filter out data over land but still capture small deviations near shore. County lines in black are from the US Census 2023 TIGER shape files.[Error! Bookmark not defined.,Error! Bookmark not defined.,Error! Bookmark not defined.]

4.3 Calculating Auxiliary and Boiler Power

Auxiliary engine power ratings are rarely documented in ship registry datasets, and auxiliary boiler power is not included at all. Therefore, to calculate auxiliary engine and boiler emissions, power surrogates are required, as shown in Table 4. Auxiliary power ratings were developed from analysis of C1C2 vessels with auxiliary data available in the Clarksons ship registry dataset. Similar to propulsive engines, auxiliary power is applied to each AIS observation by multiplying the auxiliary LF with the auxiliary total installed power rating. Surrogate auxiliary kWs were developed by adjusting the average auxiliary power rating by the load factors presented in Table 4. Additional auxiliary LFs were compiled from EPA's (2009) Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories in addition to EPA-provided values.[19]

Table 4 C1C2 Auxiliary and Boiler Power Surrogates

Ship Type	Aux Operating Load Factor	Auxiliary Power Rated at Load (kW)	Boiler Power Rating at Load (kW)
Bulk Carrier	0.1	100.9	109
Commercial Fishing	0.43	243.7	0
Container Ship	0.19	112.9	506
Ferry Excursion	0.43	595.5	0
General Cargo	0.22	246.3	106
Government	0.43	994.4	0
Miscellaneous	0.43	459.8	0
Offshore support	0.56	605.2	0
Pilot	0.43	8.7	0
Reefer	0.32	913.3	464
Ro Ro	0.26	180.8	109
Tanker	0.26	623.7	346
Tug	0.43	69.5	0
Work Boat	0.43	641.6	0

Boilers are used on commercial marine vessels to provide hot water and steam for multiple applications. Previously, heat from boilers was used to elevate the temperature of storage tanks and fuel system to allow residual fuels to flow, but with a requirement to use low sulfur residual blends that do not have the viscosity of residual fuels, this need for heat may be reduced. Boiler emissions were estimated for vessels that typically are equipped with boilers (e.g., bulk carriers, containerships, general cargo ships, Roll on/Roll off (Ro Ros), refrigerated vessels (Reefers), and tankers). The boiler power ratings reported in Table 4 were adopted from EPA's (2009) Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories and reflect boiler usages at common boiler engine loads.[19] Therefore, a load factor is not needed for boiler power assignments and the values reported in Table 4 are used as-is.

4.4 Emission Factors

The emission factors used in this inventory take into consideration the EPA's marine vessel fuel regulations as well as exhaust standards based on the year that the vessel was manufactured appropriate regulatory tier. These values are reported as g/kWh in Table 5 and were developed using engine tier factors reported in Appendix H of the EPA's (2020) Port Emissions Inventory Guidance.[16] To compile these emissions

factors, population-weighted average emission factors were calculated by engine tier based on C1C2 population distributions grouped by engine displacement. Table 6 shows boiler emission factors that were obtained from an earlier Entec study.[20]

If the year of manufacture was unknown then it was assumed that the vessel was Tier 0, such that actual emissions may be less than those estimated in this inventory. Without more specific data, the magnitude of this emissions difference cannot be estimated.

Table 5 C1C2 Propulsive and Auxiliary Emission Factors

Tier	CO (g/kWhr)	CO2 (g/kWhr)	NOx (g/kWhr)	PM2.5 (g/kWhr)	PM10 (g/kWhr)	SO2 (g/kWhr)	VOC (g/kWhr)
Tier 0	1.612632	679.47	10.28152	0.251135	0.258902	0.006246	0.295615
Tier 1	1.61	679.47	9.624039	0.251135	0.258902	0.006246	0.295615
Tier 2	0.918732	679.47	5.642273	0.143608	0.148049	0.006246	0.295615
Tier 3	0.918732	679.47	4.749214	0.080486	0.082975	0.006246	0.124798
Tier 4	0.918732	679.47	1.3	0.0291	0.03	0.006246	0.124798

Table 6 C1C2 Auxiliary Boiler Emission Factors

CO (g/kWhr)	CO_2 (g/kWhr)	NOx (g/kWhr)	$PM_{2.5}$ (g/kWhr)	PM_{10} (g/kWhr)	SO_2 (g/kWhr)	VOC (g/kWhr)
0.2	961.8	2	0.19	0.2	0.0088	0.11

4.5 Low Load Adjustment Factor

EFs are treated as constant when a vessel's modeled propulsive engine load represents more than 20% of its total installed propulsive power. Below that threshold, EFs tend to increase as the engine load decreases. This trend results because diesel engines are less efficient at low loads and the BSFC tends to increase. To account for this, low load adjustment factors (LLAFs) are applied in Equation 2. Table 7 below shows the emission factor adjustments by load and pollutant, based on the data compiled for the Port Everglades 2015 Emission Inventory.[21]

Table 7 Low Load Adjustment Factors

Load	CO	CO_2	NO_X	$PM_{2.5}$	PM_{10}	SO_2	VOC
0.01	1	1	4.63	7.29	7.29	1	21.18
0.02	1	1	4.63	7.29	7.29	1	21.18
0.03	1	1	2.92	4.33	4.33	1	11.68
0.04	1	1	2.21	3.09	3.09	1	7.71
0.05	1	1	1.83	2.44	2.44	1	5.61
0.06	1	1	1.6	2.04	2.04	1	4.35
0.07	1	1	1.45	1.79	1.79	1	3.52

0.08	1	1	1.35	1.61	1.61	1	2.95
0.09	1	1	1.27	1.48	1.48	1	2.52
0.1	1	1	1.22	1.38	1.38	1	2.18
0.11	1	1	1.17	1.3	1.3	1	1.96
0.12	1	1	1.14	1.24	1.24	1	1.76
0.13	1	1	1.11	1.19	1.19	1	1.6
0.14	1	1	1.08	1.15	1.15	1	1.47
0.15	1	1	1.06	1.11	1.11	1	1.36
0.16	1	1	1.05	1.08	1.08	1	1.26
0.17	1	1	1.03	1.06	1.06	1	1.18
0.18	1	1	1.02	1.04	1.04	1	1.11
0.19	1	1	1.01	1.02	1.02	1	1.05
0.2	1	1	1	1	1	1	1

4.6 HAP Specific Profiles

The hazardous air pollutants (HAP) are calculated from the criteria pollutants using speciation profiles based on VOC or PM emissions. The HAP speciation profiles are from EPA's Ports Emissions Inventory Guidance, Appendix D.[16] The fractions reported in D.1 were multiplied by the emissions of their assigned basis pollutant to complete this calculation.

5 Gridding Emissions

In order to include the results of the inventory in the national air quality modeling platform which requires hourly emissions by modeling grid cell, scripts were written to grid the estimated C3 emissions into hourly flat files needed to support emissions modeling using the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system. The scripts use the following process to take emissions attributed to the latitude and longitude coordinates of AIS messages and output them as aggregated gridded emissions for a given grid definition. The grid origin, grid dimensions, and map projection used for the grid are provided as an input to the scripts.

First the spatial coordinates of the emissions are transformed to the Lambert Conformal Conic projection of the desired grid with the origin at the lower left corner of the grid. Next the grid cell location was calculated from the X and Y coordinates using Equations 4 and 5 below:

$$Grid\ Column = \frac{floor\left(X_{Projected}(m) - X_{Origin}(m)\right)}{Cellwidth(m)} \quad \text{Eq. 3}$$

And

$$Grid\ Row = \frac{floor\left(Y_{Projected}(m) - Y_{Origin}(m)\right)}{Cellwidth(m)} \quad \text{Eq. 4}$$

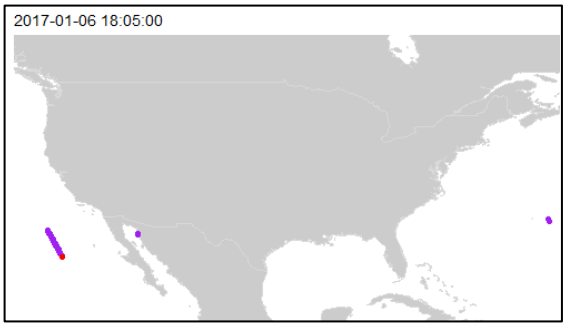
The emissions estimates are then aggregated by grid cell row, and column, date, hour, SCC, port ID, and FIPS code. Finally, the gridded emissions are output following the format of an hourly Flat File 2010 (FF10) file.

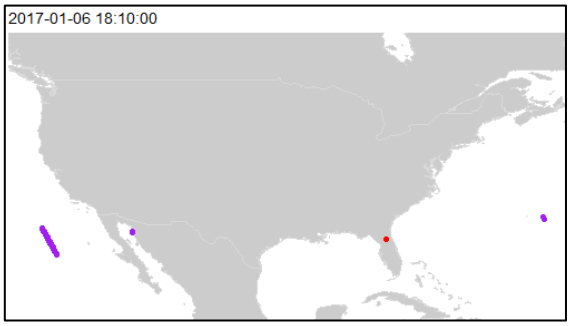
5.1 Masking Raster

The MET includes interpolated data points between all AIS messages associated with non-hoteling activity intervals greater than five minutes. This was done with the intention that each underway emissions estimation should represent the same activity duration. However, some messages were interpolated to locations that cannot contain C1C2 activity, like narrow inland waterways and shallow water bodies. Therefore, because interpolated messages were included in the rasterization process described above, a masking raster was required to define likely and unlikely C1C2 locations. This masking raster was then used to remove all emissions from grid cells in unlikely C1C2 locations.

An R function was developed to create the initial masking raster. This function creates a single, annual raster of non-interpolated C1C2 activity with the intention to remove all emissions from the daily rasters that were in unlikely C1C2 locations. Unlikely C1C2 locations were grid cells in which exclusively interpolated messages existed.

However, an analysis of the 12km CONUS masking raster brought to light certain anomalies in non-interpolated data which may also result in unlikely emissions locations. The non-interpolated masking raster reported odd inland activity such as that near Assateague, MD and Clear Lake, CA. This is like activity found in the 2017 data around Gainesville, FL and up the Mississippi River where C1C2 activity is not likely. These emissions were determined to be the result of “rogue” messages within the raw AIS dataset initially received from the US Coast Guard. Rogue messages can easily be identified by analyzing a single vessel’s path. Figure 4 shows an example of a single vessel transiting along the west coast of Mexico, with red dots signifying the message associated with the timestamp reported above the image and the purple dots signifying past messages. Within the span of 45 minutes, AIS reports activity messages for this vessel inland near Gainesville, FL, in the Atlantic Ocean, and back in its likely true position along the west coast of Mexico.





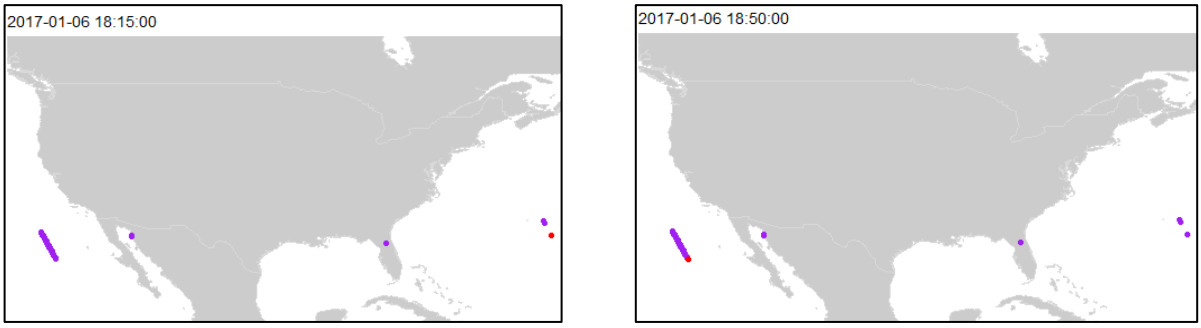


Figure 4 Example of Rogue AIS Messages (Current Activity Message in Red and Past Messages in Purple)

Given that a single vessel reported a non-interpolated message near Gainesville, FL, and given the rogue nature of this message, it is evident that C3 activity is not likely near Gainesville, FL. Similar analysis was done to determine the unlikelihood of C3 activity up the Mississippi River and near Cape Coral, FL.

Thus, the non-interpolated masking raster was altered to account for the findings in this analysis. ERG developed an R function for this purpose, which reads in the annual, non-interpolated raster described above and converts all raster values to either NA, to represent unlikely C3 activity areas, or 1, to represent likely C3 activity locations. It also reads in a table, such as Table 8 which was created for altering the 12km CONUS raster according to the above findings. This function creates a box for each row of Table 8, using the longitude and latitude minimum and maximum, and assigns all grid cell values within that box the value in the "Assign Grid Values" field. This allows for manual adjustments of likely and unlikely activity areas. The function then outputs a single raster, with only values of 1 or NA, to show likely and unlikely C3 activity areas. All emissions in the daily rasters which were in unlikely grid cells in the masking raster were set to 0.

Table 8 12km CONUS Masking Raster Adjustments

lngMin	lngMax	latMin	latMax	Description	Assign Grid Values
-75.7	-75.1	37.7	38.0	Assateague	NA
-123.0	-122.3	38.5	39.2	Clear Lake	NA

However, while the resulting submissions to the air quality modeling platform did use this masking raster, the NEI county-level submissions did not. Instead, counties which exclusively reported interpolated messages were assumed to be unlikely C3 areas and all C3 emissions were set to zero for those counties. Thus, because masks were applied at the grid cell-level for the air quality modeling platform, but the county-level for the NEI platform, certain differences will exist between them.

6 Emissions Summary

Table 9 presents the total estimated emissions from Category 1 and 2 marine vessels in the NEI area throughout 2023, Table 10 presents emissions by vessel type and Figure 5 shows the geographic distribution of NOx emissions in U.S. waters. Note that the totals shown in this section do not reflect adjustments that resulted from application of the masking raster described in 5.1.

Table 9 Total 2023 Category 1 and 2 Emissions in Tons for U.S. Waters including Federal Waters

Region	CO	CO_2	NO_X	$PM_{2.5}$	PM_{10}	SO_2	VOC
Alaska	1,681	10,33,495	17,238	299	325	776	765
Hawaii	220	148,519	2,268	37	40	91	94
Puerto Rico + Virgin Islands	490	314,624	4,429	81	88	198	230
CONUS	10,321	6,687,643	95,680	1,688	1,835	4,127	4,803
Federal Waters	48,649	22,393,262	463,896	12,551	13,643	33,521	23,456
TOTAL	**61,361**	**30,577,543**	**583,511**	**14,656**	**15,931**	**38,713**	**29,348**

Figure 5 2022 Annual C3 NO_X Emissions

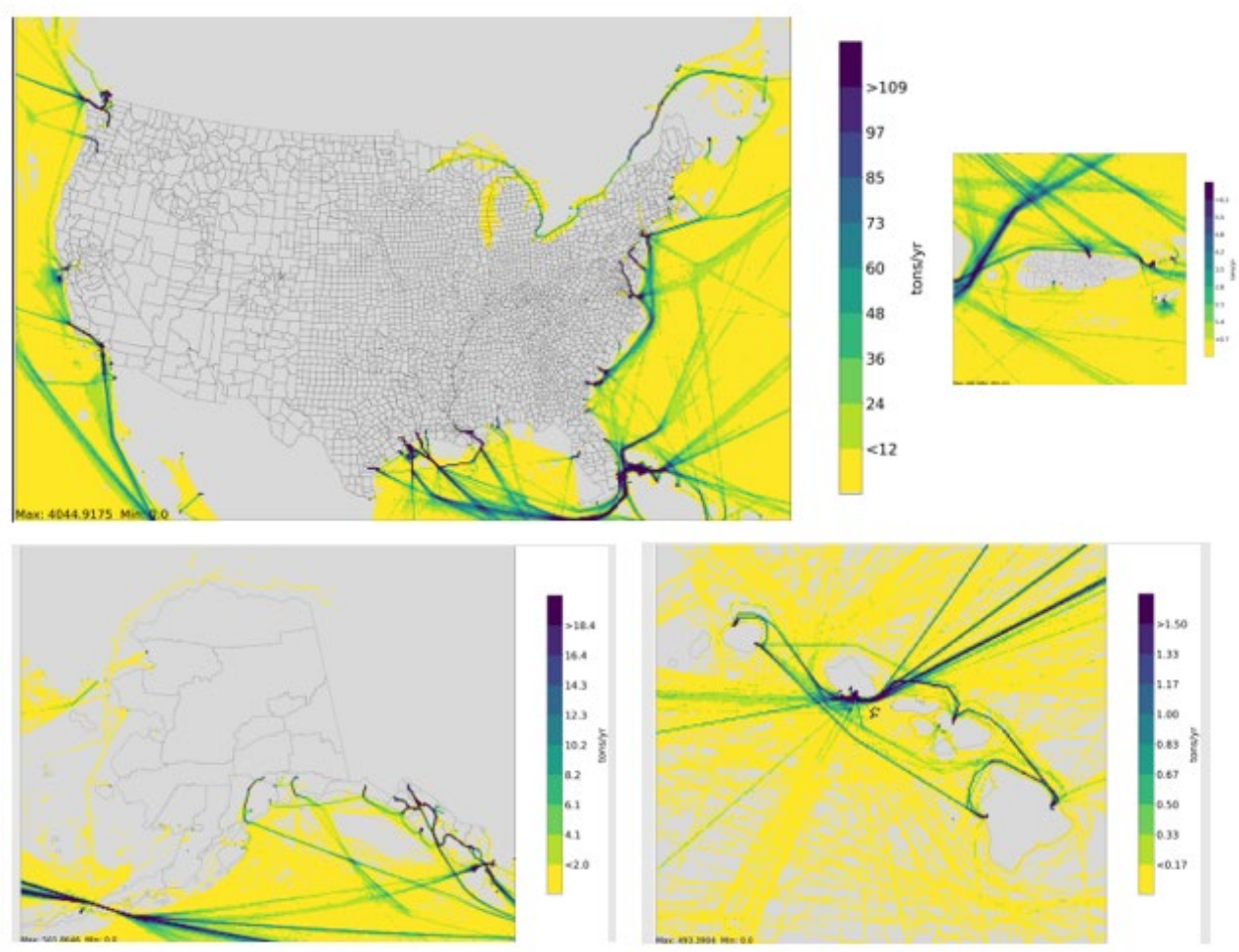


Table 10 Total 2023 Category 1 and 2 Emissions in Tons by Ship Type

Ship Type	CO	CO2	NOX	PM10	PM25	SO2	VOC
Bulk Carrier	399.42	186,869.16	2,537.80	66.49	64.37	1.72	81.10
Commercial Fishing	4,670.00	1,988,198.11	30,126.37	765.81	742.84	18.28	926.75
Container Ship	14.62	15,065.34	82.40	3.01	2.85	0.14	3.31
Ferry Excursion	4,403.08	1,967,919.84	28,369.63	733.71	711.70	18.09	1,008.36
General Cargo	2,544.07	1,508,674.27	16,830.57	480.41	462.17	13.87	545.60
Government	3,309.43	1,427,024.40	20,951.27	529.27	513.39	13.12	631.37
Miscellaneous	926.50	614,971.83	5,652.82	146.41	142.02	5.65	282.18
Offshore support	5,809.64	2,892,170.84	36,917.14	941.56	913.32	26.59	1,359.25
Pilot	4.05	2,886.59	25.27	0.57	0.55	0.03	1.69
Reefer	27.67	19,175.34	175.26	4.94	4.74	0.18	5.37
Ro Ro	838.30	470,372.27	5,327.27	142.42	137.52	4.32	183.03
Tanker	183.22	124,328.08	1,152.98	31.78	30.53	1.14	36.32
Tug	7,483.06	4,392,760.45	47,378.96	1,259.50	1,221.72	40.38	2,619.81
Work Boat	897.74	420,773.66	5,707.22	149.79	145.30	3.87	207.19

Energy consumption in units of Kilowatt-hours (kWhrs) was calculated for each engine type for each vessel by multiplying the activity durations per AIS interval and the assigned power estimation based on AIS reported speed, and Clarksons installed power ratings and service speed. The energy consumption was summed by ship type and by SCC. Figure 5 illustrates the relative energy consumption for each ship type by SCC while Table 11 provides total emissions by SCC.

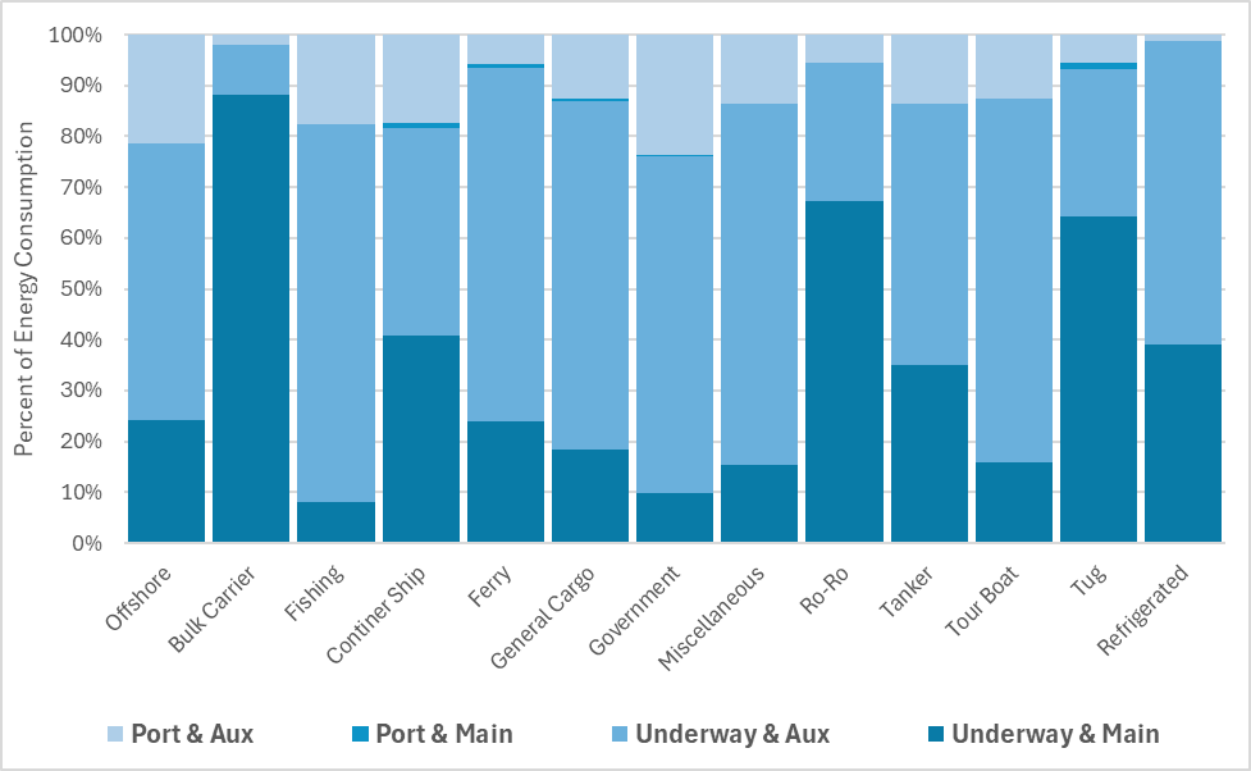


Figure 6 Ship Type Energy Distribution by SCC

Table 11 2023 Category 1 and 2 Emissions by Port/Underway and Engine Type (tons)

	Engine	CO	CO2	NOx	PM2.5	PM10	SO2	VOC
Port	**Total**	**4,475.8**	**2,146,139.3**	**28,171.2**	**694.1**	**715.6**	**19.7**	**980.3**
	Aux	4,335.1	2,069,334.0	26,845.5	653.2	673.4	19.0	849.9
	Main	140.6	76,805.3	1,325.7	41.0	42.2	0.7	130.4
Underway	**Total**	**26,906.1**	**13,268,325.1**	**171,774.9**	**4,306.9**	**4,440.1**	**122.0**	**6,843.2**
	Aux	17,331.3	8,232,955.8	107,469.6	2,623.2	2,704.3	75.7	3,419.6
	Main	9,574.8	5,035,369.2	64,305.3	1,683.7	1,735.8	46.3	3,423.6

7 Limitations

Use of AIS data to develop emission inventories is a significant improvement over earlier methods that required assumptions about vessel power, operating load, and level of activity. Assumptions made in these earlier inventories are replaced with actual vessel specific power data and other attributes provided by classification societies, calculated load factors based on the vessel's actual speed relative to its service speed, and other details related to vessel location and time stamp included in the AIS data stream.

These data are more complete and readily available for larger C3 vessels, but when it comes to smaller C1C2 vessels, many of the earlier assumptions about power and operating load are still required, as is the question about whether the dataset represent a complete inventory of these smaller vessels.

The AIS system continues to evolve and expand coverage, but there are still areas where the VHF signals are missing and there are vessels that do not have transponders or turn off their transponders. In processing the AIS data for 2023, record counts varied significantly from day to day indicating possible data gaps, suggesting that the AIS data may underestimate actual activities. These data gaps are not limited to a specific region and occur throughout the entire NEI area.

Earlier AIS approaches estimated duration relative to the last known observation. By creating a buffer that extended into international waters, it was possible to identify and address vessels that leave federal waters and return later generating very unreasonably large duration times. But for some vessels, not near the federal/international boundary, there may be long periods of time between observations. It is impossible to tell if these vessels are not operating or if there is a problem with the AIS transponder or receiver. Further study is needed to better understand these events.

Though AIS has been instrumental in improving the overall quality of propulsion engine emission estimates, similar improvements are needed for auxiliary engines and boilers, specifically better methods to estimate auxiliary engine operating loads. Further study of dockside operations is needed to better understand when vessels shut off their engines dockside to reduce fuel consumption and emissions.

As use of shore power expands, it would be helpful to have ports provide information about utilization rates by vessel categories to enable adjustments of dockside emissions and avoid double counting with landside Electricity Generating Units (EGUs).

In 2020, states provided vessel specific information about strategic engine and vessel replacements targeted to improve local air quality – these data were retained in this 2023 inventory. This information was linked directly to the vessels' attribute data to account for emission reductions associated with the use of higher tiered engines. We encourage provision of such information.

Unlike Category 3 vessels, available vessel characteristics data for most Category 1 and 2 vessels is limited; often there is not vessel-specific data for main and auxiliary power, engine specifications, design max speed and vessels dimensions. It should be noted that these data gaps are filled by averaging data from a relatively small number of vessels for which data are available in a suitable format, such that there is considerable uncertainty associated with these default values. Further study is needed to expand Category 1 and 2 vessel attributes to allow for better matching of vessels to appropriate characteristics. It would also be helpful to develop a better understanding of the variance within the key surrogate data elements to help quantify uncertainty.

8 Reference

[1] Spire Global, Spire Maritime Data: Satellite, Terrestrial, and Dynamic-AIS, purchased Nov. 2024
[2] IMO (International Maritime Organization), *SOLAS Chapter V, Regulation 19 - Carriage Requirements for Shipborne Navigational Systems and Equipment*. https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MSCResolutions/MSC.99(73).pdf, 2002
[3] 80 FR 5281
[4] USCG Navigation Center, *Maritime Mobile Service Identity*. https://www.navcen.uscg.gov/maritime-mobile-service-identity, Accessed Aug. 2025
[5] U.S. EPA, Commercial Marine Vessel GIS Shape Files (port and underway, current and retired), https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data, 2020
[6] U.S. Census Bureau, 2023 TIGER/Line Shapefiles, https://www.census.gov/geographies/mapping-files/2023/geo/tiger-line-file.html, 2023
[7] Clarksons, *World Fleet Register,* Accessed Jan. 2018
[8] U.S. Coast Guard, *Merchant Vessels of the United States,* Accessed Sept. 2017
[9] U.S. Coast Guard, *U. S. Coast Guard Vessel Data,* Accessed 2018
[10] U.S. Department of Transportation, *2016 National Census of Ferry Operator Database,* Accessed May 2017
[11] Marine Cadastre, *AIS Vessel Type and Group Codes Used by the Marine Cadastre Project*. https://coast.noaa.gov/data/marinecadastre/ais/VesselTypeCodes2018.pdf, May 23, 2018
[12] U.S. Army Corps of Engineers, The U. S. Coastal and Inland Navigation System - 2023 Transportation Facts & Information. March 2025
[13] National Fisherman, *AIS Rule Becomes Effective March 2*. February 24, 2015. https://www.nationalfisherman.com/viewpoints/boats-gear/ais-rule-becomes-effective-march-2/
[14] Organization of Economic Cooperation and Development, *Fishing fleet*. https://stats.oecd.org/Index.aspx?DataSetCode=FISH_FLEET (2019)
[15] Diesel & Gas Turbine, 2013 Global Sourcing Guide. Diesel & Gas Turbine Publications, Waukesha, WI, 2013
[16] EPA, Ports Emissions Inventory Guidance: Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emissions, EPA-420-B-22-011, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1014J1S.pdf, 2022
[17] U.S. EPA, Marine Emissions Tools Beta 2. https://github.com/USEPA/Marine_Emissions_Tools, 2022
[18] U.S. NOAA Office for Coastal Management, Anchorage Areas, https://www.fisheries.noaa.gov/inport/item/48849, 2022
[19] EPA, *Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories*, April 2009.
[20] Entec, UK, *Quantification of Emissions from Ships Associated with Ship Movements between Ports in the European Community – Final Report*, European Commission, 2002.
[21] EPA, *EPA and Port Everglades Partnership: Emission Inventories and Reduction Strategies*. US Environmental Protection Agency, Office of Transportation and Air Quality, June 2018. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100UKV8.pdf.

9 Appendices

A Ship Type Assignments

A.1 Ship Type Map

Vessel Type	**Ship Type**
Aggregates Carrier	Bulk Carrier
Bulk Carrier	Bulk Carrier
Bulk Cement Carrier (Inland)	Bulk Carrier
Cement Carrier	Bulk Carrier
Gravel/Stone Discharge	Bulk Carrier
Ore Carrier	Bulk Carrier
Palletised Cargo Carrier	Bulk Carrier
dredge_fishing	Commercial Fishing
drifting_longlines	Commercial Fishing
driftnets	Commercial Fishing
Factory Stern Trawler	Commercial Fishing
Fish Factory Ship	Commercial Fishing
Fishery Support Vessel	Commercial Fishing
Fishing	Commercial Fishing
fishing	Commercial Fishing
fishing vessel	Commercial Fishing
Fishing Vessel	Commercial Fishing
Fishing, Fishing Vessel	Commercial Fishing
Fishing, Motorboat	Commercial Fishing
Fishing, Passenger Ship	Commercial Fishing
Fishing;Passenger	Commercial Fishing
fixed_gear	Commercial Fishing
Live Fish Carrier (Well Boat)	Commercial Fishing
Merchant, Fishing Vessel	Commercial Fishing
other_fishing	Commercial Fishing
other_purse_seines	Commercial Fishing
other_seines	Commercial Fishing
pole_and_line	Commercial Fishing
pots_and_traps	Commercial Fishing
purse_seines	Commercial Fishing
seiners	Commercial Fishing
set_gillnets	Commercial Fishing
set_longlines	Commercial Fishing
squid_jigger	Commercial Fishing
Stern Trawler	Commercial Fishing
Trawler	Commercial Fishing
trawlers	Commercial Fishing
trollers	Commercial Fishing

tuna_purse_seines	Commercial Fishing
Container Ship (Inland)	Container Ship
Fully Cellular Container	Container Ship
Air Cushion Ferry	Ferry Excursion
Catamaran	Ferry Excursion
Cruise (Inland)	Ferry Excursion
Cruise Ship	Ferry Excursion
Excursion / Sightseeing Vessel	Ferry Excursion
Ferry	Ferry Excursion
Pass./Car Catamaran Vessel	Ferry Excursion
Passenger	Ferry Excursion
Passenger (Inland)	Ferry Excursion
Passenger Carrier	Ferry Excursion
Passenger Catamaran Vessel	Ferry Excursion
Passenger Vessel	Ferry Excursion
Cargo	General Cargo
cargo	General Cargo
Cargo and Passenger	General Cargo
Cargo;Fishing	General Cargo
Deck Cargo Carrier	General Cargo
General Cargo	General Cargo
General Cargo (Inland)	General Cargo
General Cargo Barge, Propelled	General Cargo
Merchant	General Cargo
Merchant, Passenger Ship	General Cargo
Miscellaneous Cargo	General Cargo
Monohull	General Cargo
Passenger/Cargo Vessel	General Cargo
Product Carrier	General Cargo
Small Commercial	General Cargo
Transport (Heavy Lift)	General Cargo
Attack Vessel, Naval	Government
Buoy/Lighthouse Tender	Government
Cargo;Military	Government
Coast Guard	Government
Command Vessel	Government
Crew Boat, Naval Auxiliary	Government
Destroyer	Government
Diving Vessel, Naval Auxiliary	Government
ERRV	Government
Fire	Government
Fishery Patrol Vessel	Government
Fishing;Military	Government

Frigate	Government
Government	Government
Icebreaker	Government
Icebreaker AGB	Government
Landing Craft	Government
Logistics Vessel (Naval RoRo Cargo)	Government
Military	Government
Minehunter	Government
Minesweeper	Government
Naval	Government
Naval Small Craft	Government
Patrol Vessel	Government
Patrol Vessel, Naval	Government
Rescue	Government
Research Vessel, Naval Auxiliary	Government
Salvage Vessel, Naval Auxiliary	Government
SAR	Government
Search & Rescue	Government
Standby Safety/Guard	Government
Submarine Tender	Government
Tank Landing Craft	Government
Torpedo Recovery Vessel	Government
Torpedo Trials Vessel	Government
Training Ship	Government
Training Ship, Naval Auxiliary	Government
Tug, Naval Auxiliary	Government
Unknown Function, Naval/Auxiliary	Government
USCG	Government
Cargo;Fishing;Military;Other;Passenger;Pleasure Craft/Sailing;Tanker;Tug Tow	Miscellaneous
Cargo;Fishing;Military;Other;Pleasure Craft/Sailing;Tanker;Tug Tow	Miscellaneous
Cargo;Fishing;Military;Other;Pleasure Craft/Sailing;Tug Tow	Miscellaneous
Cargo;Fishing;Other;Passenger;Pleasure Craft/Sailing	Miscellaneous
Cargo;Fishing;Other;Passenger;Pleasure Craft/Sailing;Tanker;Tug Tow	Miscellaneous
Cargo;Fishing;Other;Passenger;Pleasure Craft/Sailing;Tug Tow	Miscellaneous
Cargo;Fishing;Other;Pleasure Craft/Sailing;Tanker;Tug Tow	Miscellaneous
Cargo;Fishing;Other;Pleasure Craft/Sailing;Tug Tow	Miscellaneous
Cargo;Fishing;Other;Tanker	Miscellaneous
Cargo;Fishing;Passenger;Pleasure Craft/Sailing;Tanker;Tug Tow	Miscellaneous
Cargo;Military;Pleasure Craft/Sailing	Miscellaneous
Cargo;Military;Pleasure Craft/Sailing;Tanker;Tug Tow	Miscellaneous
Cargo;Other;Passenger;Pleasure Craft/Sailing	Miscellaneous
Cargo;Other;Passenger;Pleasure Craft/Sailing;Tanker	Miscellaneous

Cargo;Other;Passenger;Pleasure Craft/Sailing;Tanker;Tug Tow	Miscellaneous
Cargo;Other;Passenger;Pleasure Craft/Sailing;Tug Tow	Miscellaneous
Cargo;Other;Pleasure Craft/Sailing	Miscellaneous
Cargo;Other;Pleasure Craft/Sailing;Tanker	Miscellaneous
Cargo;Other;Pleasure Craft/Sailing;Tanker;Tug Tow	Miscellaneous
Cargo;Other;Pleasure Craft/Sailing;Tug Tow	Miscellaneous
Cargo;Other;Tanker;Tug Tow	Miscellaneous
Cargo;Passenger	Miscellaneous
Cargo;Passenger;Pleasure Craft/Sailing	Miscellaneous
Cargo;Passenger;Pleasure Craft/Sailing;Tanker	Miscellaneous
Cargo;Passenger;Pleasure Craft/Sailing;Tanker;Tug Tow	Miscellaneous
Cargo;Passenger;Pleasure Craft/Sailing;Tug Tow	Miscellaneous
Cargo;Pleasure Craft/Sailing	Miscellaneous
Cargo;Pleasure Craft/Sailing;Tanker	Miscellaneous
Cargo;Pleasure Craft/Sailing;Tanker;Tug Tow	Miscellaneous
Cargo;Pleasure Craft/Sailing;Tug Tow	Miscellaneous
Cargo;Tanker	Miscellaneous
Cargo;Tanker;Tug Tow	Miscellaneous
Cargo;Tug Tow	Miscellaneous
Dredging (Inland)	Miscellaneous
Electricity Generating Vessel	Miscellaneous
Exhibition Vessel	Miscellaneous
Fishery Research Vessel	Miscellaneous
Fishing;Military;Other;Passenger;Tug Tow	Miscellaneous
Fishing;Military;Other;Pleasure Craft/Sailing;Tanker;Tug Tow	Miscellaneous
Fishing;Other;Pleasure Craft/Sailing	Miscellaneous
Fishing;Other;Pleasure Craft/Sailing;Tug Tow	Miscellaneous
Fishing;Passenger;Pleasure Craft/Sailing	Miscellaneous
Fishing;Pleasure Craft/Sailing	Miscellaneous
Hospital Vessel	Miscellaneous
Landing Ship (Dock Type)	Miscellaneous
Livestock Carrier	Miscellaneous
Maintenance	Miscellaneous
Marine Research	Miscellaneous
Military;Other;Passenger;Tug Tow	Miscellaneous
Military;Other;Tug Tow	Miscellaneous
Military;Pleasure Craft/Sailing	Miscellaneous
Multi-Purpose	Miscellaneous
Multi-Purpose Support	Miscellaneous
Other Activities (Inland)	Miscellaneous
Passenger;Pleasure Craft/Sailing;Tanker	Miscellaneous
Passenger;Pleasure Craft/Sailing;Tanker;Tug Tow	Miscellaneous
Passenger;Pleasure Craft/Sailing;Tug Tow	Miscellaneous

Passenger;Tanker;Tug Tow	Miscellaneous
Research	Miscellaneous
Research Vessel	Miscellaneous
Rocket Salvage Ship	Miscellaneous
Waste Disposal Carrier	Miscellaneous
Yacht Support Vessel	Miscellaneous
Accommodation Vessel	Offshore support
Anchor Handling Tug	Offshore support
Anchor Handling Tug Supply	Offshore support
Anchor Handling Tug/Supply	Offshore support
Anti-Pollution Vessel	Offshore support
Backhoe/Dipper/Grab Dredger	Offshore support
Cable Layer (Fibre Optic)	Offshore support
Cable, Umbilicals & FP/Flowline Lay	Offshore support
Cable/Pipe Layer	Offshore support
Construction Service Operations Vsl	Offshore support
Container / Vehicle / Trailer (RO-RO) Carrier	Offshore support
Crew Boat	Offshore support
Crew Tender	Offshore support
Crew/Fast Supply Vessel	Offshore support
Crew/Supply Vessel	Offshore support
Crewboat / Supply / Utility Vessel	Offshore support
Cutter Suction/Bucket Wheel Dredger	Offshore support
Derrick/Lay Vessel	Offshore support
Diving Support	Offshore support
Diving Support Vessel	Offshore support
Dredge	Offshore support
Dredger	Offshore support
Dredgers (Stone Dumping, Fallpipe)	Offshore support
Drilling	Offshore support
Drillship	Offshore support
Extended Well Test Vessel	Offshore support
Fleet Ocean Tug ATF	Offshore support
Floating Crane	Offshore support
Floating Production Unit	Offshore support
FPSO	Offshore support
FSRU	Offshore support
Geophysical Survey	Offshore support
Heavy Lift/Crane Ship	Offshore support
Hydrographic Survey	Offshore support
Merchant, Barge	Offshore support
Merchant, Cargo and Passenger	Offshore support
Merchant, Pilot Tender	Offshore support

Merchant, Research or Survey Ship	Offshore support
Merchant, Supply Vessel	Offshore support
Miscellaneous Offshore Service	Offshore support
Oceanographic Survey	Offshore support
Official Service Shp	Offshore support
Official Service Shp, Auxiliary Ship	Offshore support
Official Service Shp, Supply Vessel	Offshore support
Offshore Construction Vessel, jack up	Offshore support
Offshore Oil and Gas Support	Offshore support
Offshore Support Vessel	Offshore support
Offshore Tug/Supply Ship	Offshore support
Oil and Gas	Offshore support
Oilfield Pollution Control	Offshore support
Other Dredger	Offshore support
Pipe Layer	Offshore support
Platform Supply	Offshore support
Platform Supply Ship	Offshore support
Rescue	Offshore support
Research Survey Vessel	Offshore support
ROV/Submersible Support	Offshore support
Salvage Vessel	Offshore support
Seismic Support	Offshore support
Seismic Survey	Offshore support
seismic_vessel	Offshore support
Service	Offshore support
Service Operations Vessel	Offshore support
Special Equipment Dredger	Offshore support
Submarine Salvage Vessel	Offshore support
Suction Dredger	Offshore support
Suction Hopper Dredger	Offshore support
Supply	Offshore support
Supply Tender	Offshore support
Support Vessel	Offshore support
Survey	Offshore support
Tender	Offshore support
Trailing Suction Hopper Dredger	Offshore support
Tug, Anchor Hoy	Offshore support
Well Stimulation	Offshore support
Pilot	Pilot
pilot	Pilot
Pilot Vessel	Pilot
Fruit Juice Carrier	Reefer
Reefer	Reefer

Reefer Fish Carrier	Reefer
Reefer/Pallets Carrier	Reefer
Pass./Car Ferry	Ro Ro
Passenger/Ro-Ro (Inland)	Ro Ro
Product Carrier/Ro-Ro	Ro Ro
Pure Car Carrier	Ro Ro
Pure Car Carrier (Inland)	Ro Ro
Ro-Ro	Ro Ro
Ro-Ro Cargo (Inland)	Ro Ro
Ro-Ro Freight/Passenger	Ro Ro
Ro-Ro/Lo-Lo	Ro Ro
Asphalt & Bitumen Carrier	Tanker
Chemical & LPG Carrier	Tanker
Chemical & Oil Carrier	Tanker
Chemical Tanker (Inland)	Tanker
Chemical/Products Tanker	Tanker
Chemical/Products Tanker (Inland)	Tanker
Crude Oil Tanker	Tanker
Edible Oil Carrier	Tanker
Ethylene/LPG	Tanker
FSU	Tanker
LCO2 Carrier	Tanker
LNG & Oil Bunkering Vessel	Tanker
LNG Bunkering Tanker (Inland)	Tanker
LNG Bunkering Vessel	Tanker
LNG Carrier	Tanker
LPG Carrier	Tanker
LPG Carrier (Inland)	Tanker
LPG Tanker	Tanker
Molten Sulphur Carrier	Tanker
Oil Bunkering Tanker	Tanker
Oil Tanker (Inland)	Tanker
Passenger;Tanker	Tanker
Products Tanker	Tanker
Products Tanker Barge, Propelled	Tanker
Replenishment Tanker	Tanker
Tanker	Tanker
tanker	Tanker
Water Carrier	Tanker
Water Tanker (Inland)	Tanker
Fire-fighting Tug	Tug
Fishing;Tug Tow	Tug
Merchant, Tug	Tug

Miscellaneous	Tug
Ocean-going Salvage Tug	Tug
Ocean-going Tug	Tug
Passenger;Tug Tow	Tug
Pleasure Craft/Sailing;Tug Tow	Tug
Tanker;Tug Tow	Tug
Towing/Pushing (Inland)	Tug
Tug	Tug
tug	Tug
Tug Tow	Tug
Tugboat	Tug
Utility/Workboat	Work Boat
Work/Repair Vessel	Work Boat

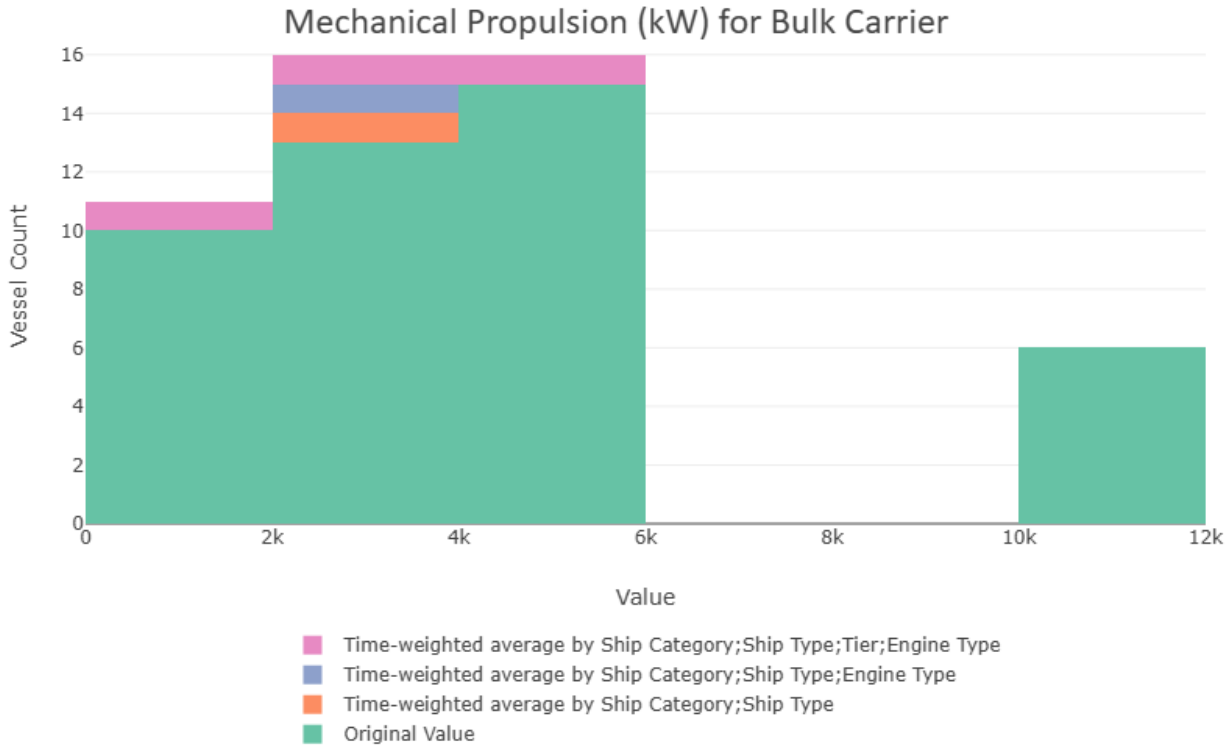
B Vessel Parameter Gap Filling Methods

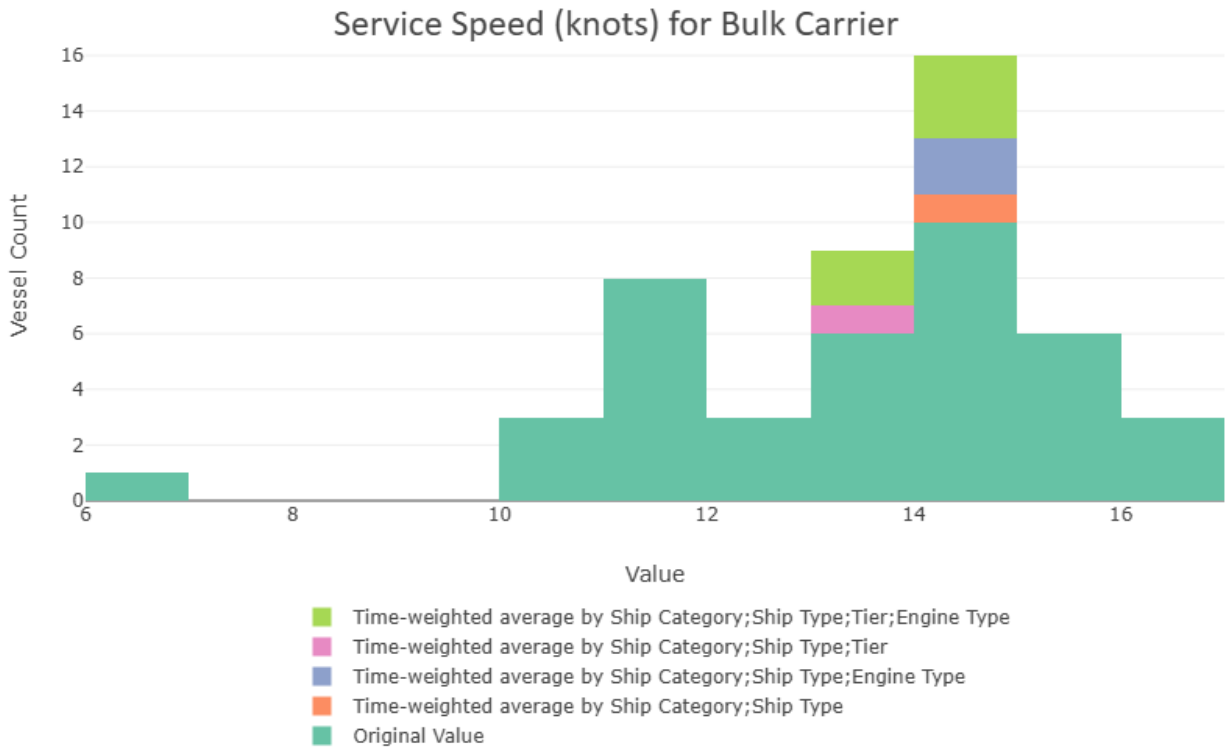
B.1 Order of Ship Characteristics used in Iterative Activity Time Weighted Average Gap-Filling

Order Number	**Ship Characteristics used in Iterative Activity Time Weighted Average Gap-Filling**
1	Ship Category, Ship Type, Tier, and Engine Type
2	Ship Category, Ship Type, Tier
3	Ship Category, Ship Type, Engine Type
4	Ship Category, Ship Type
5	Ship Category Group, Ship Type, Engine Type
6	Ship Category Group, Ship Type
7	Ship Category Group, Tier, Engine Type
8	Ship Category, Tier
9	Ship Category, Engine Type
10	Ship Category Group, Tier
11	Ship Category Group, Engine Type
12	Ship Category
13	Ship Category Group

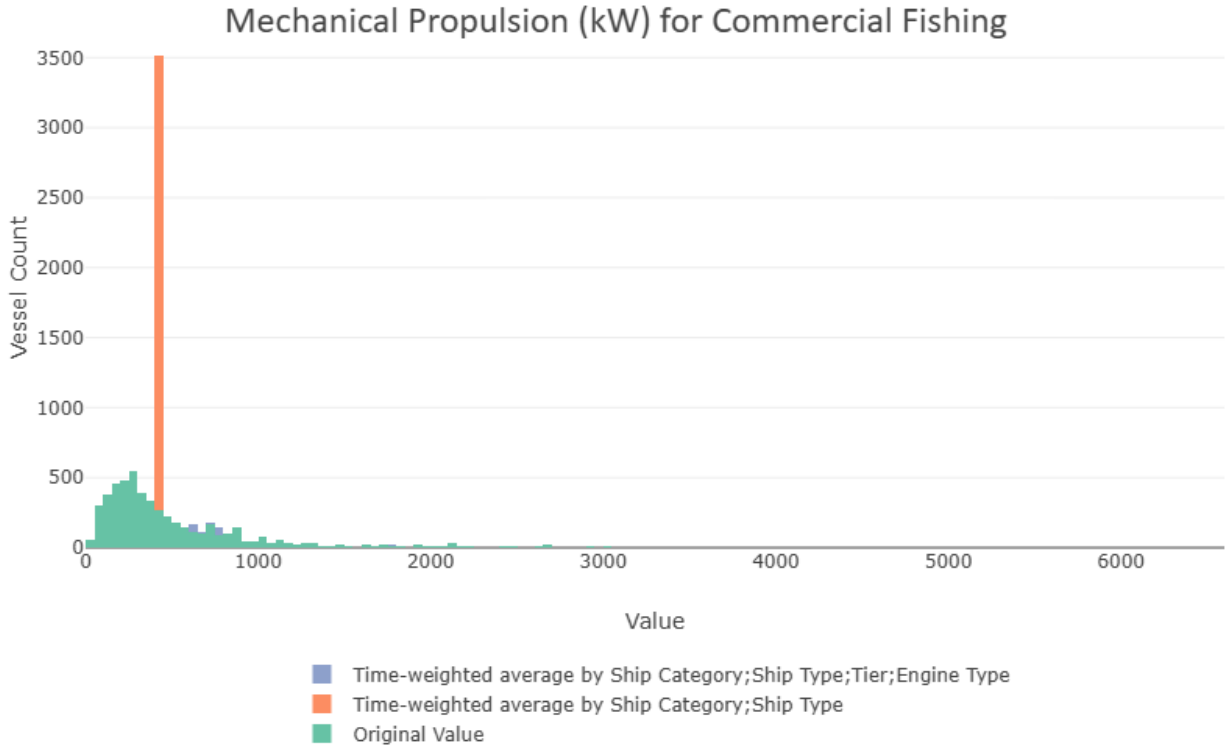
B.2 Mechanical Propulsion and Service Speed Surrogate Values for…

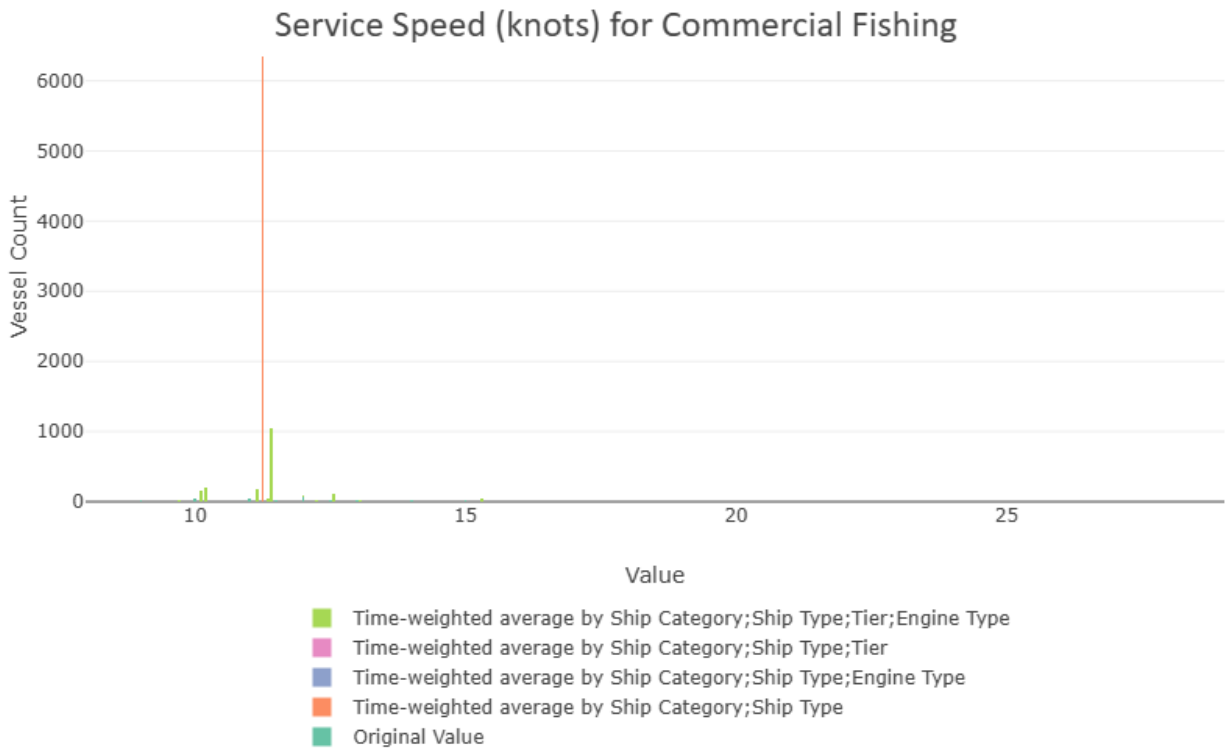
B.2.1 Mechanical Propulsion and Service Speed Surrogate Values for Bulk Carriers



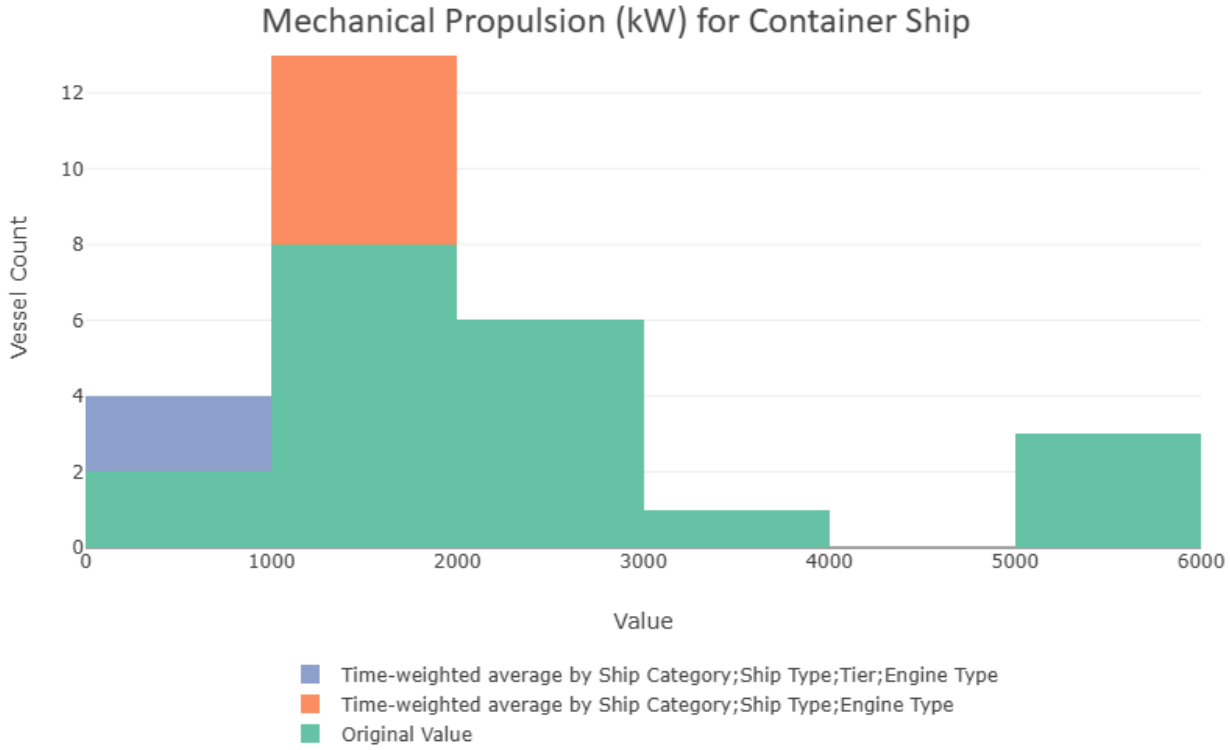


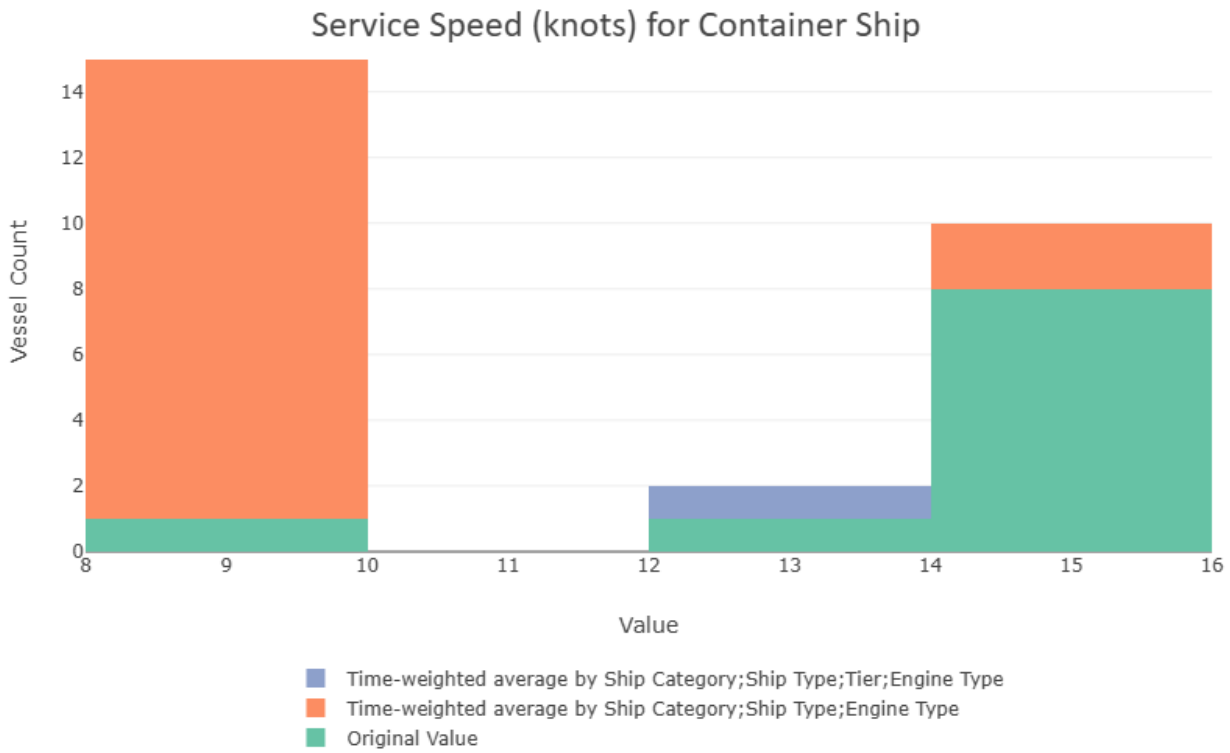
B.2.2 Mechanical Propulsion and Service Speed Surrogate Values for Commercial Fishing



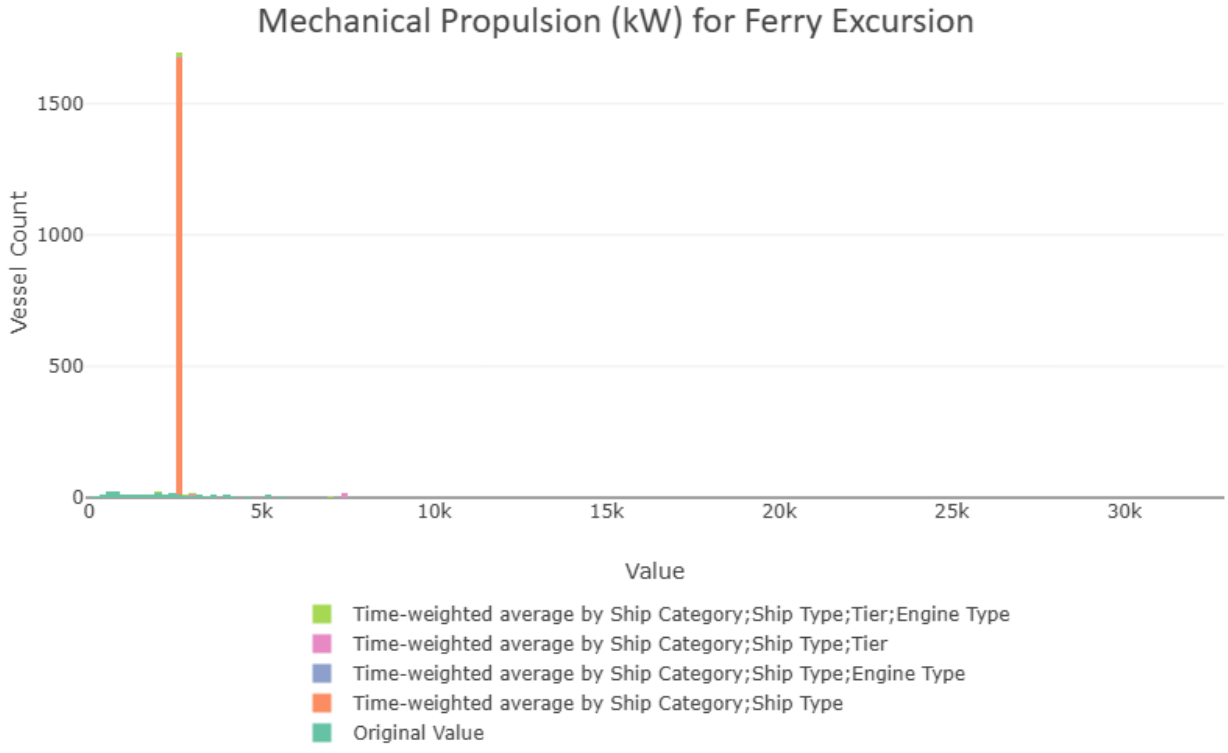


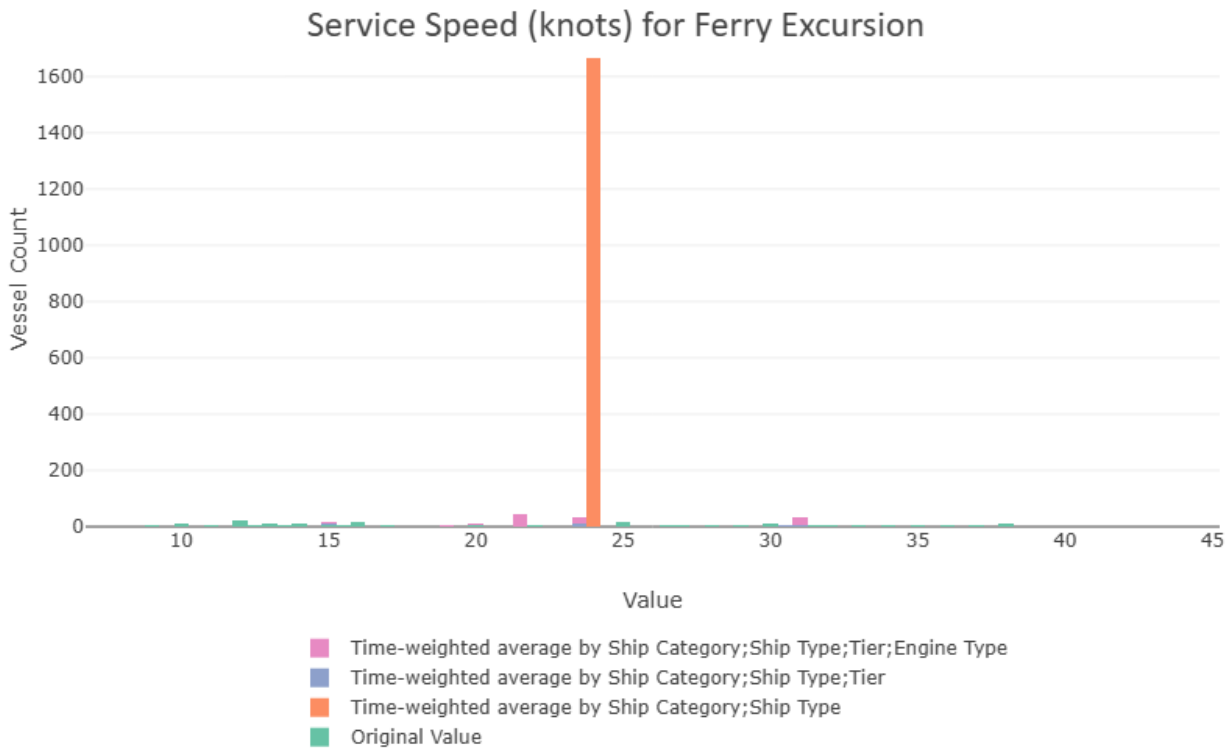
B.2.3 Mechanical Propulsion and Service Speed Surrogate Values for Container Ship



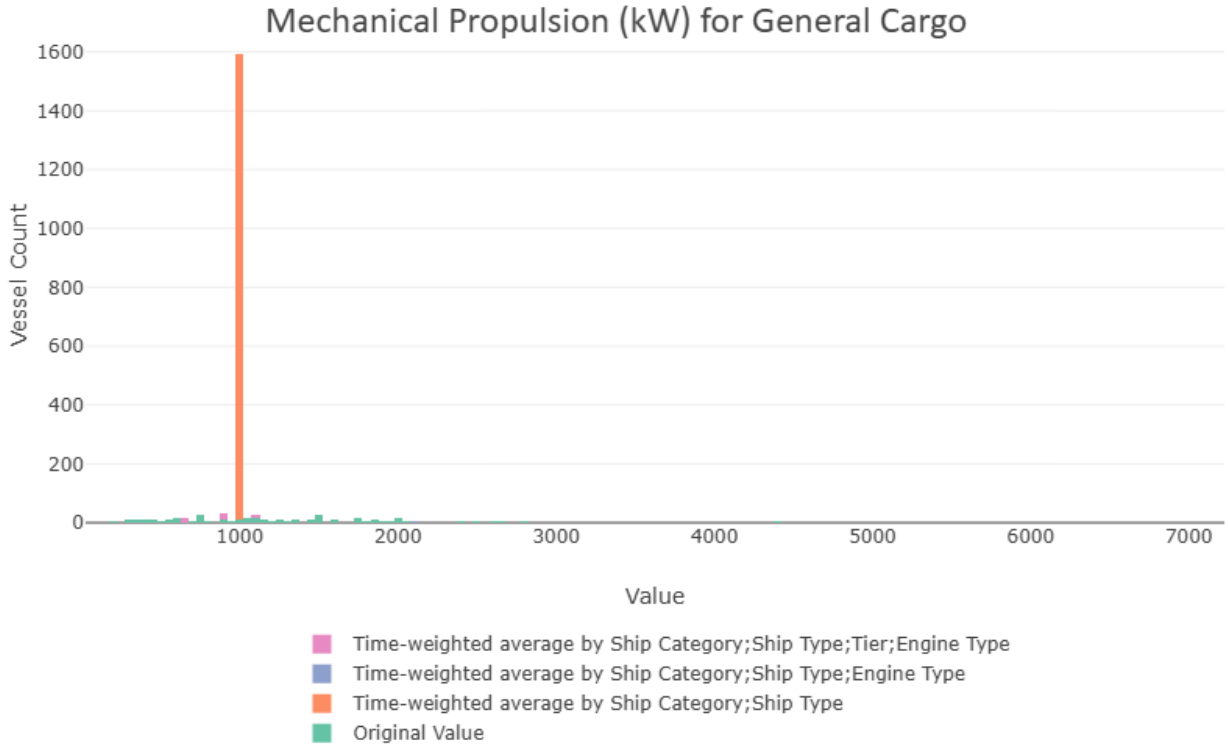


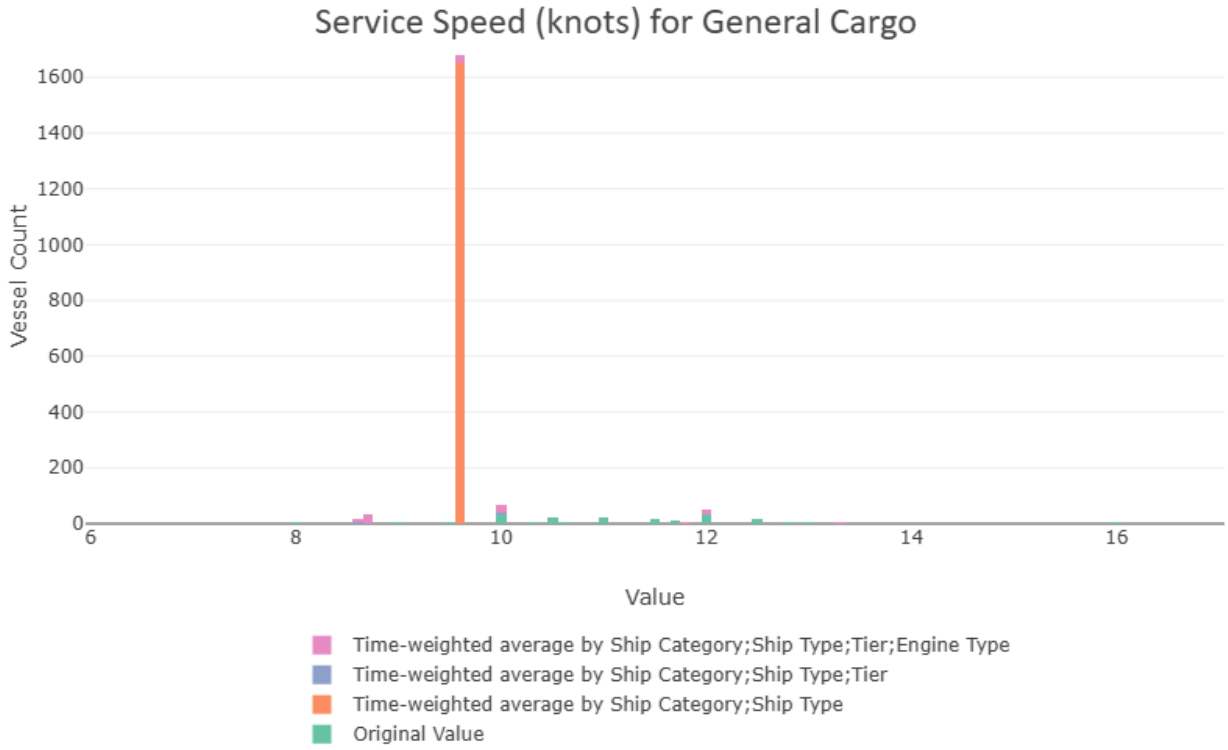
B.2.4 Mechanical Propulsion and Service Speed Surrogate Values for Ferry Excursion



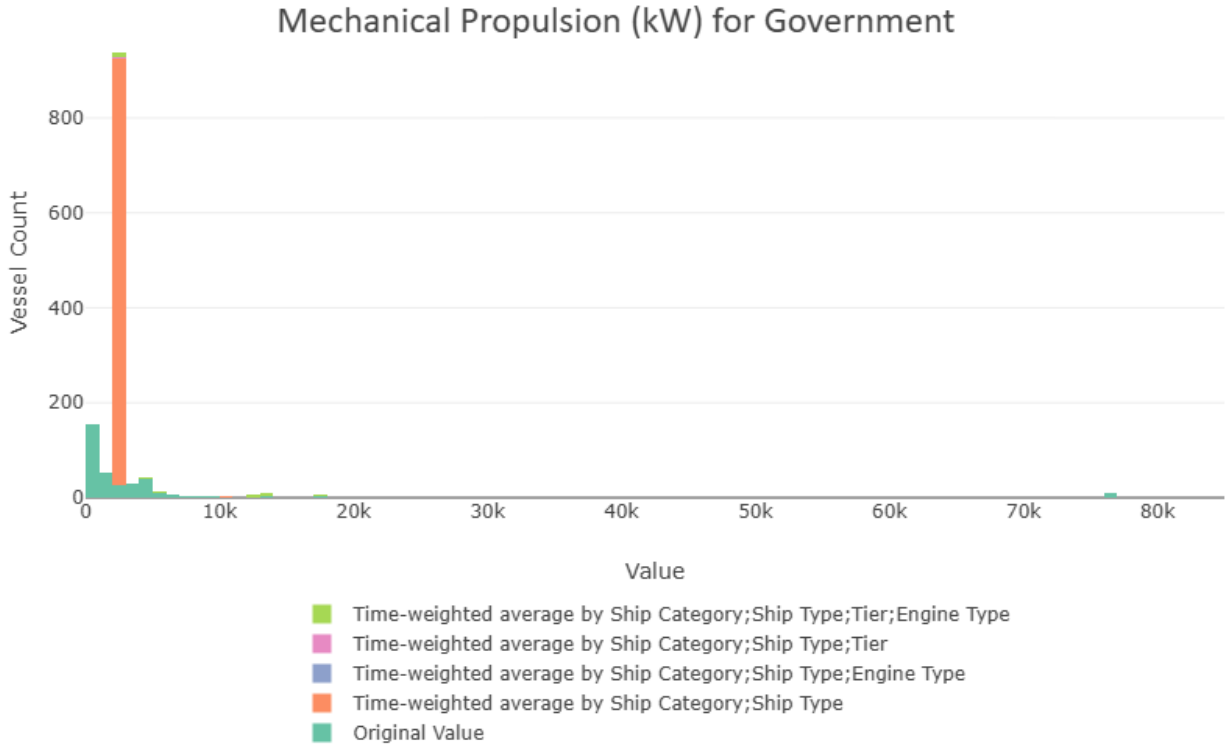


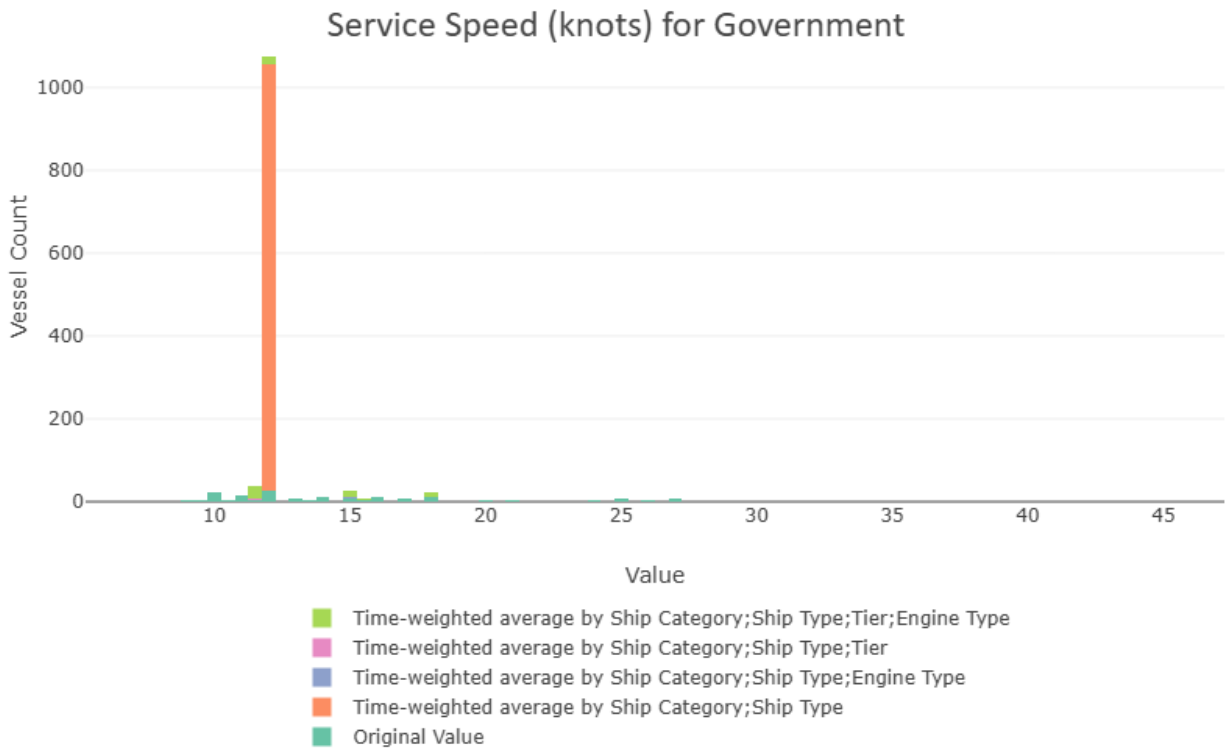
B.2.5 Mechanical Propulsion and Service Speed Surrogate Values for General Cargo



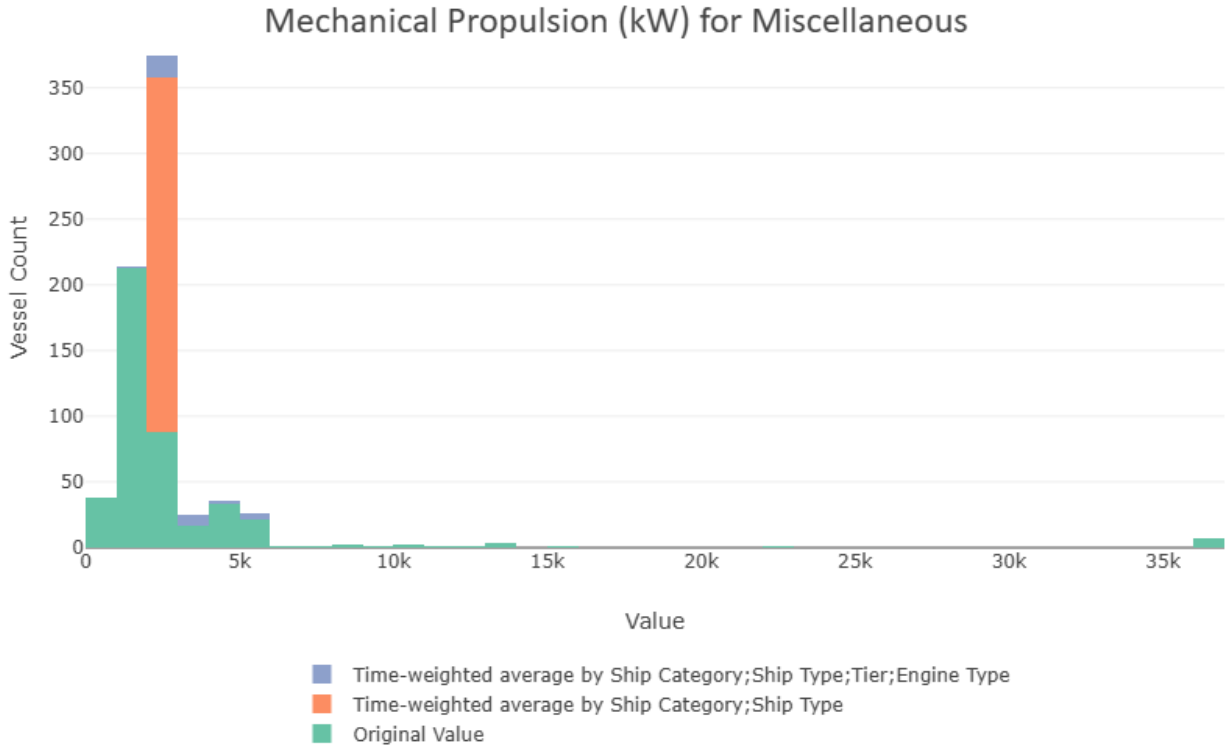


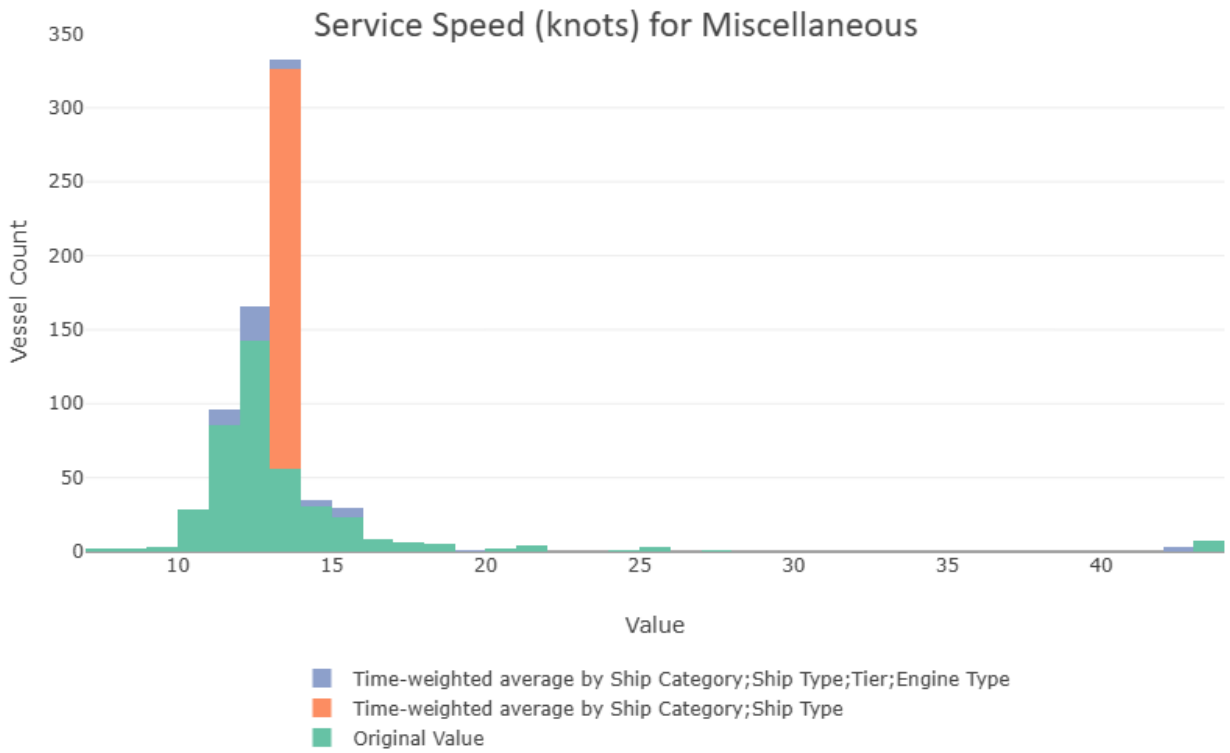
B.2.6 Mechanical Propulsion and Service Speed Surrogate Values for Government



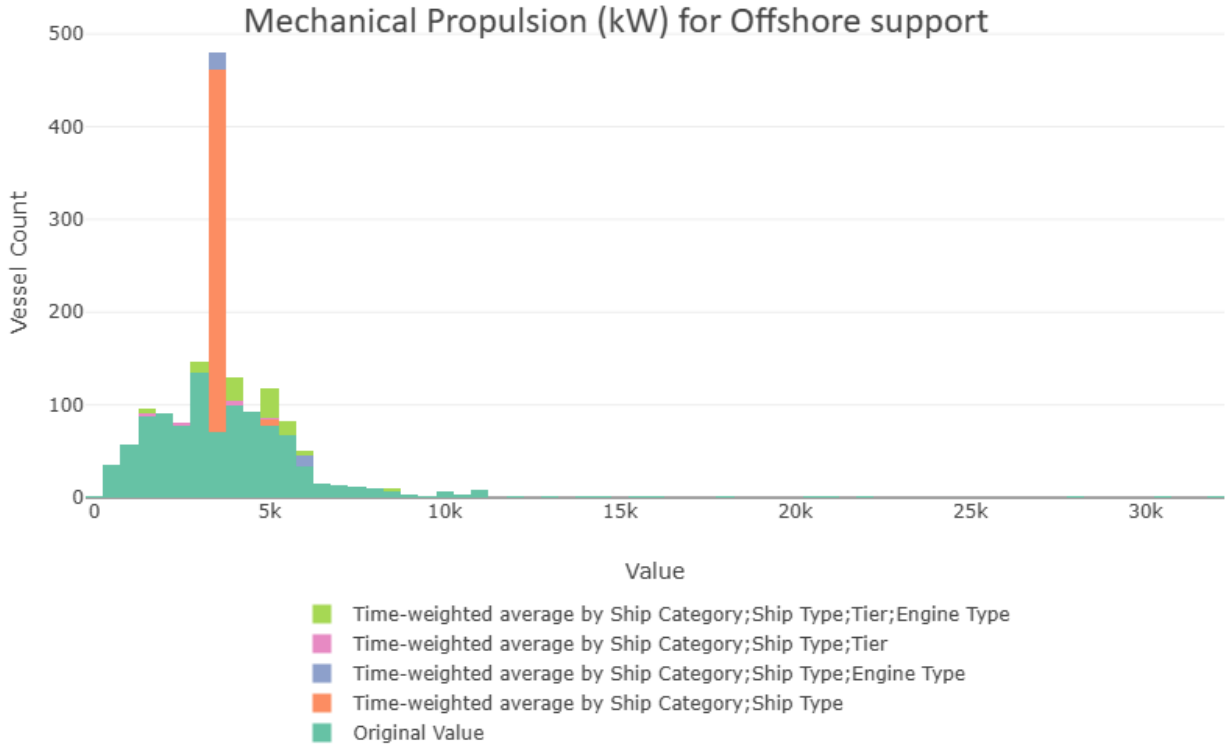


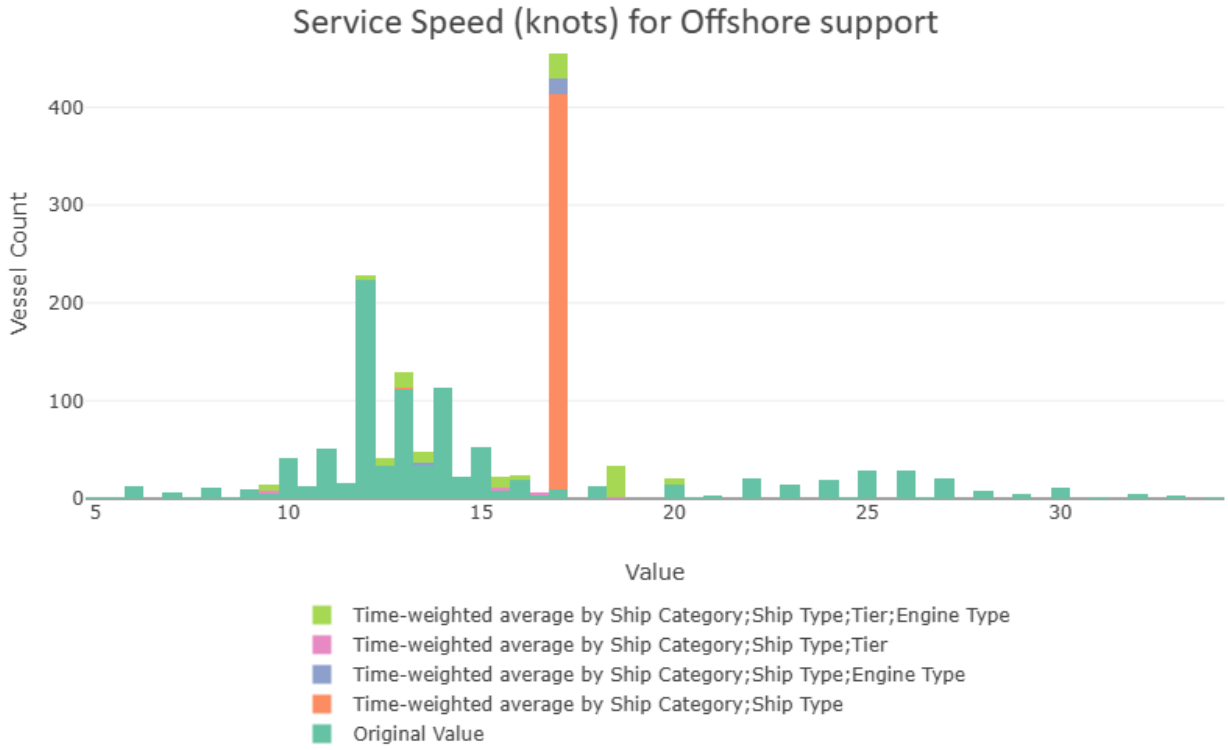
B.2.7 Mechanical Propulsion and Service Speed Surrogate Values for Miscellaneous



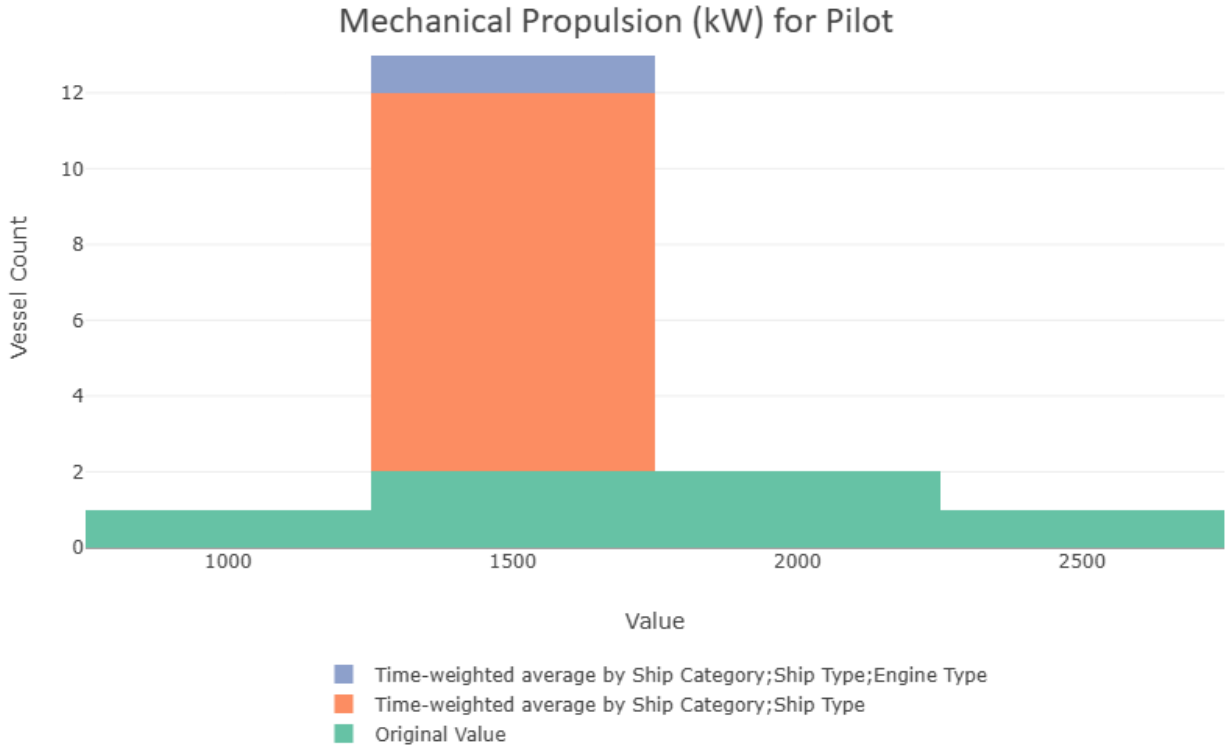


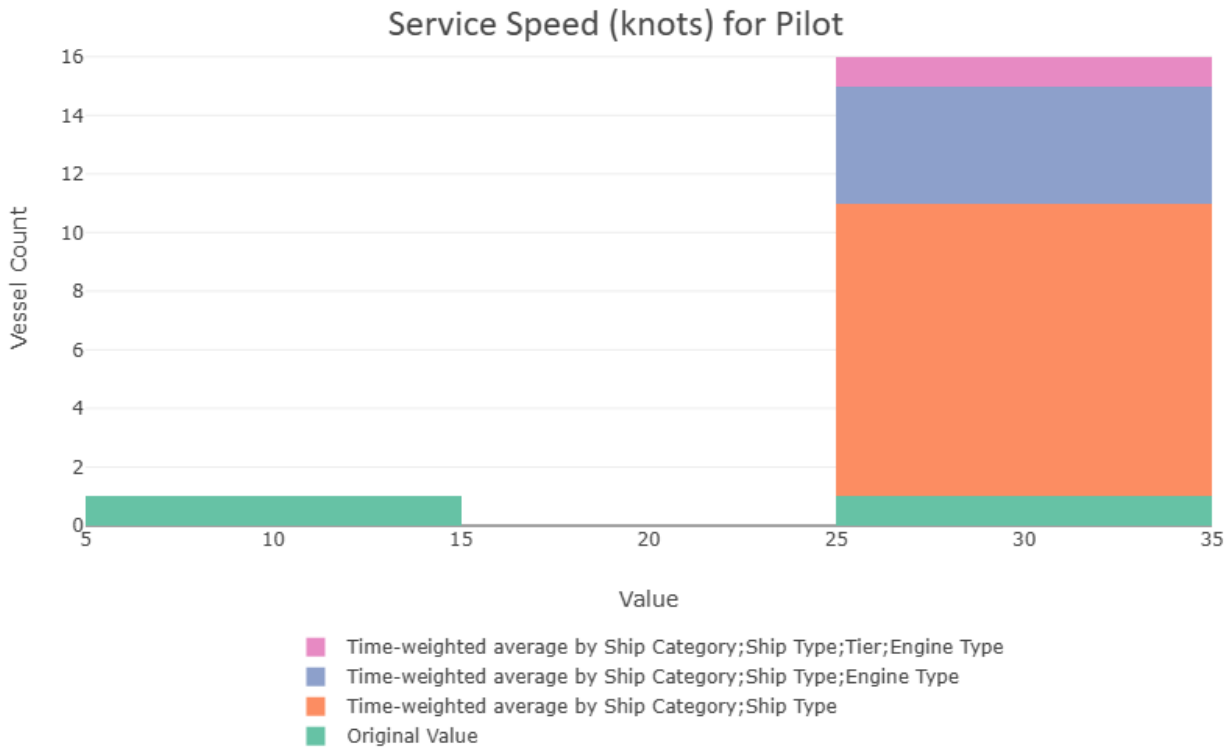
B.2.8 Mechanical Propulsion and Service Speed Surrogate Values for Offshore support



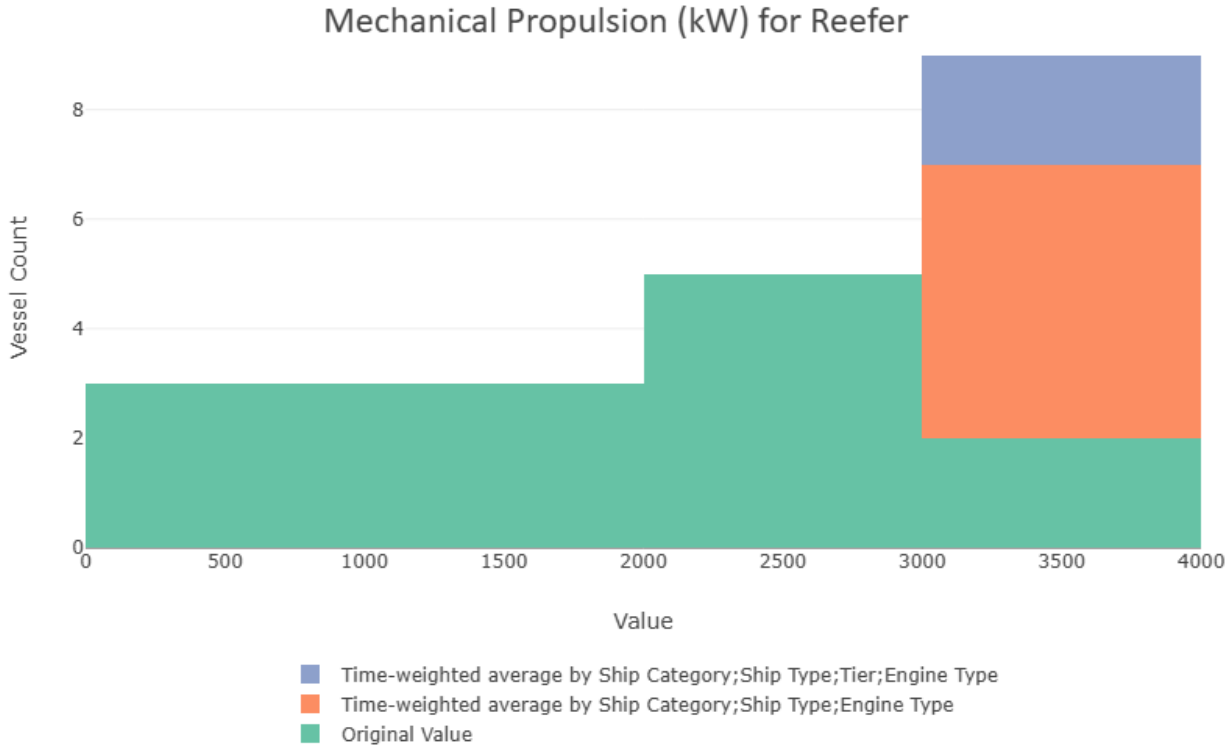


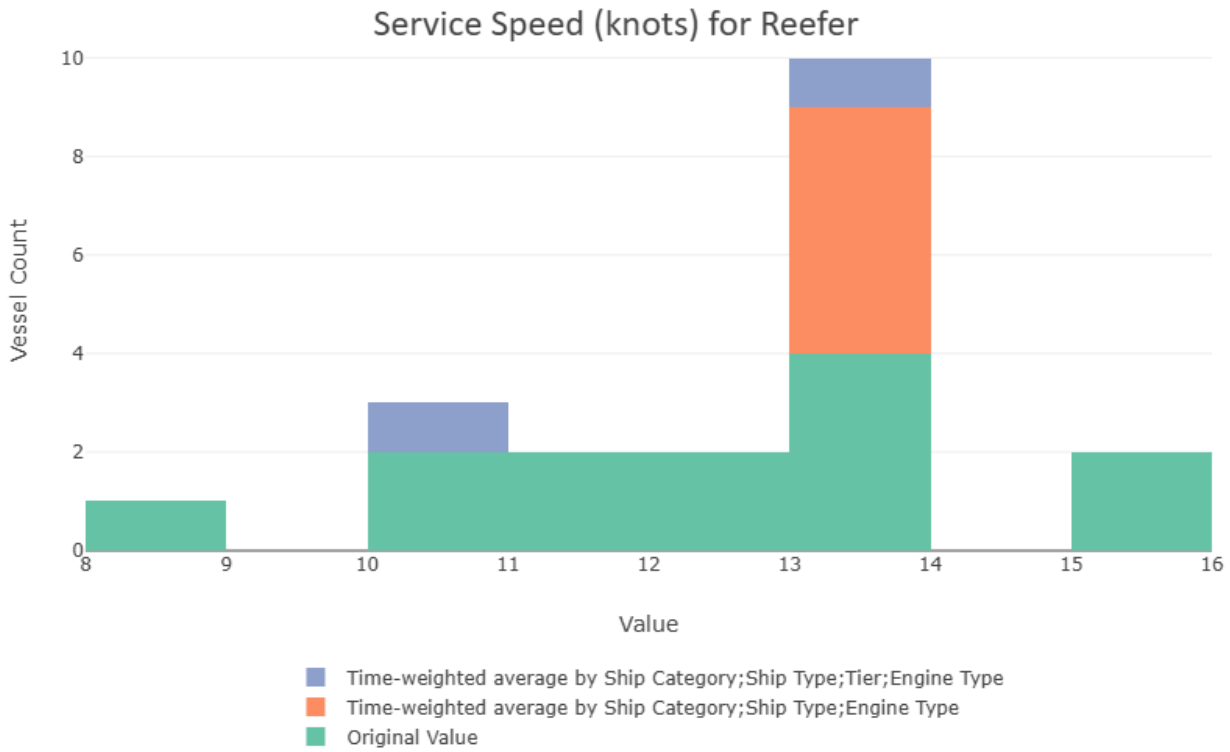
B.2.9 Mechanical Propulsion and Service Speed Surrogate Values for Pilot



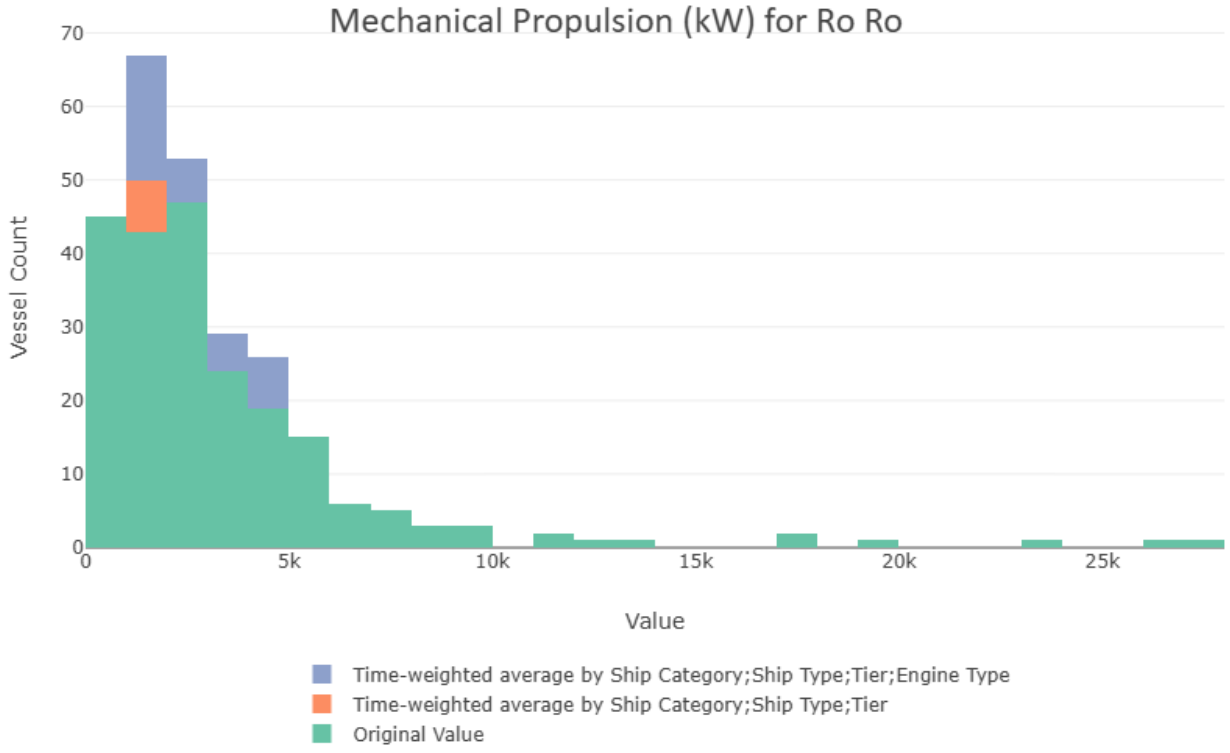


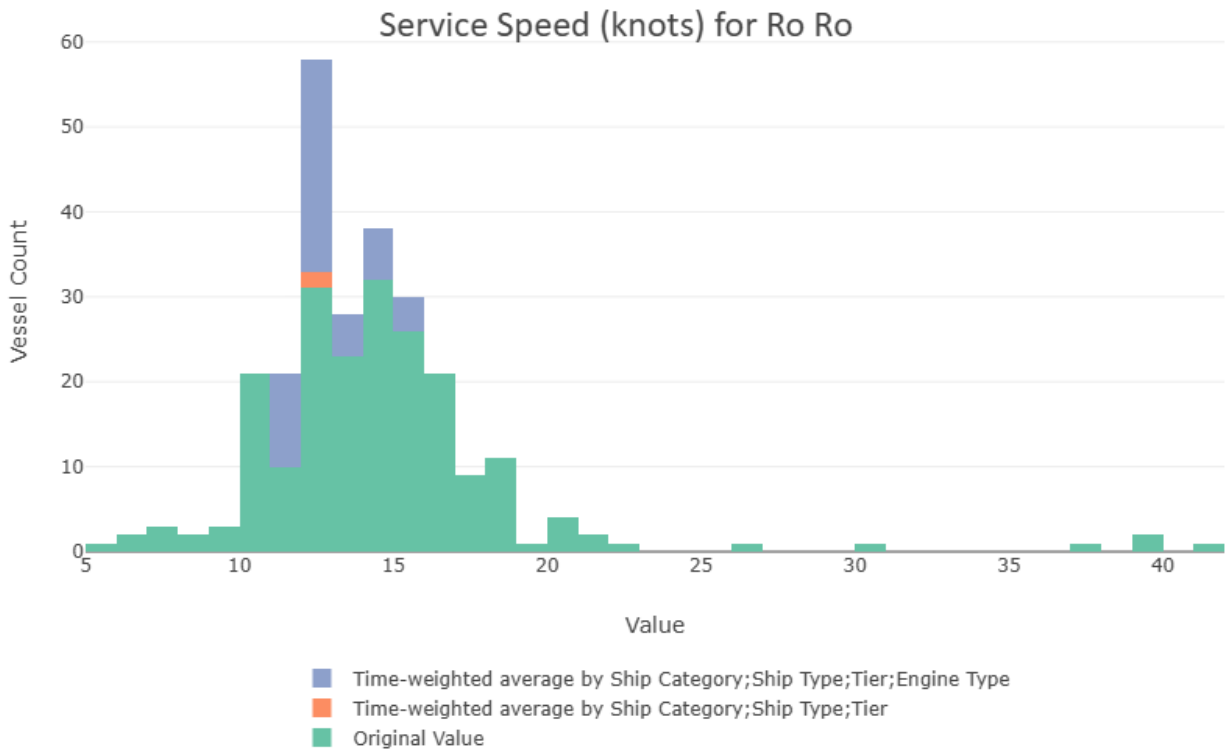
B.2.10 Mechanical Propulsion and Service Speed Surrogate Values for Reefer



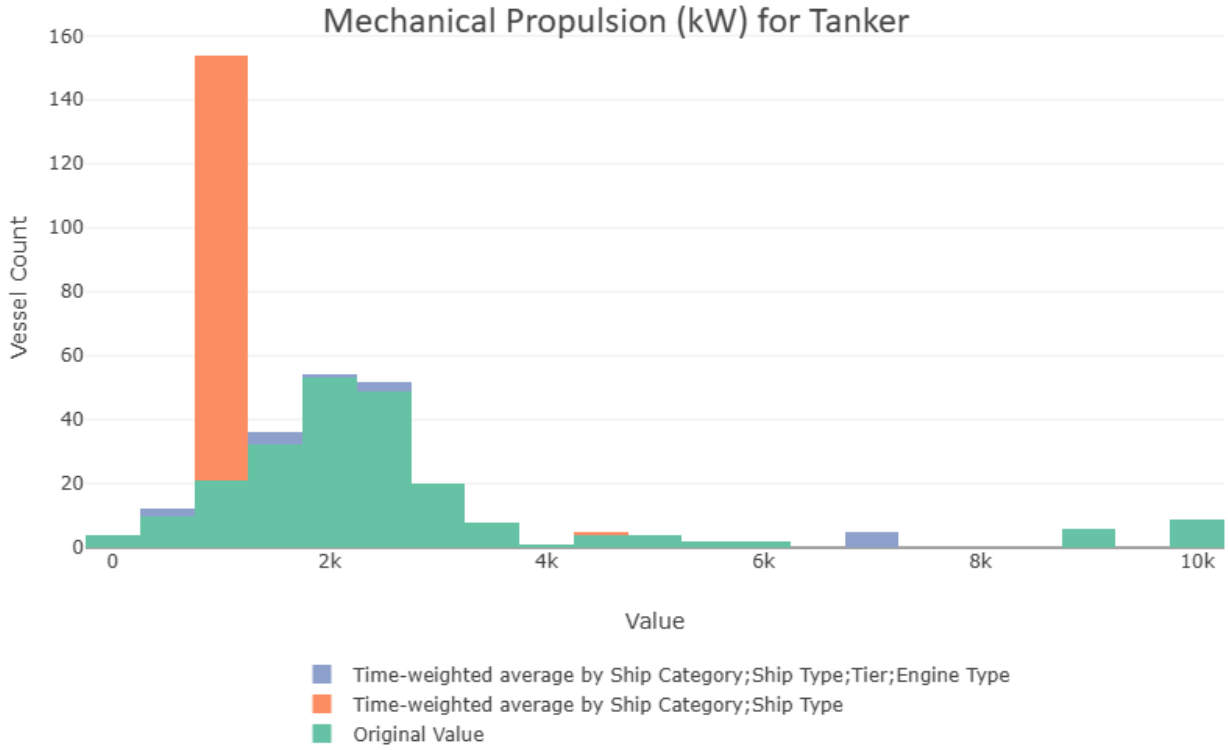


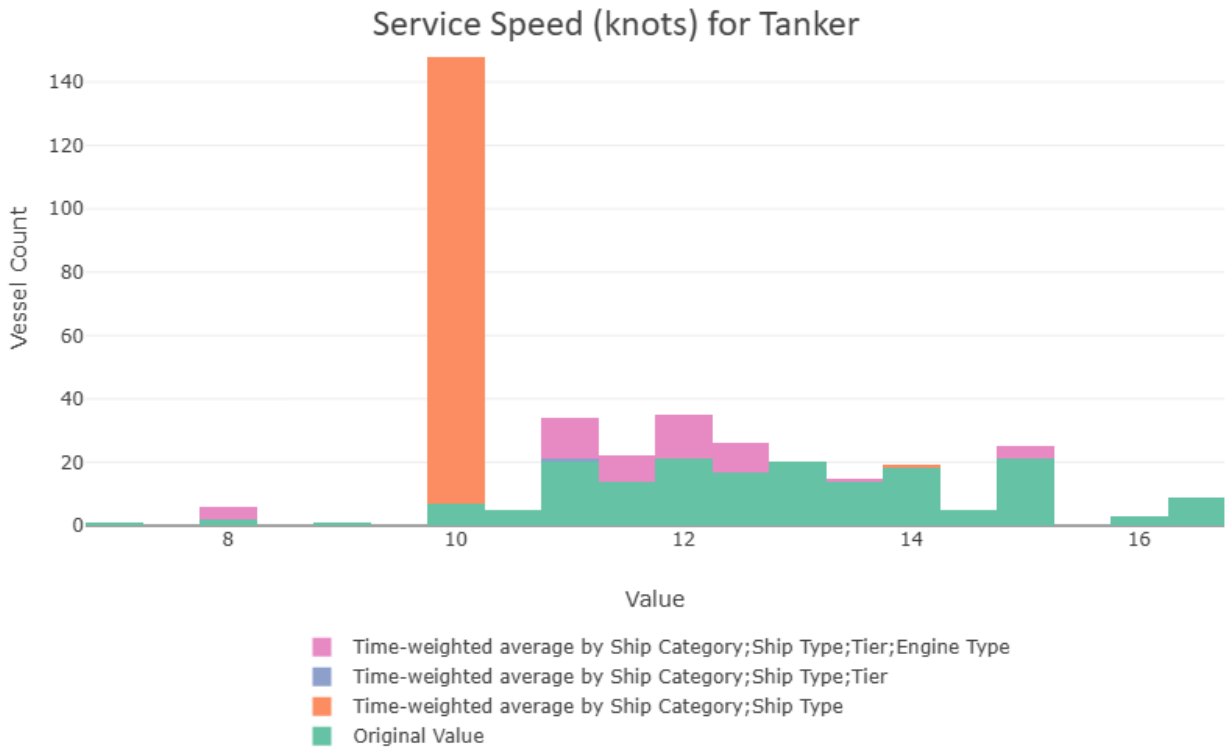
B.2.11 Mechanical Propulsion and Service Speed Surrogate Values for Ro Ro



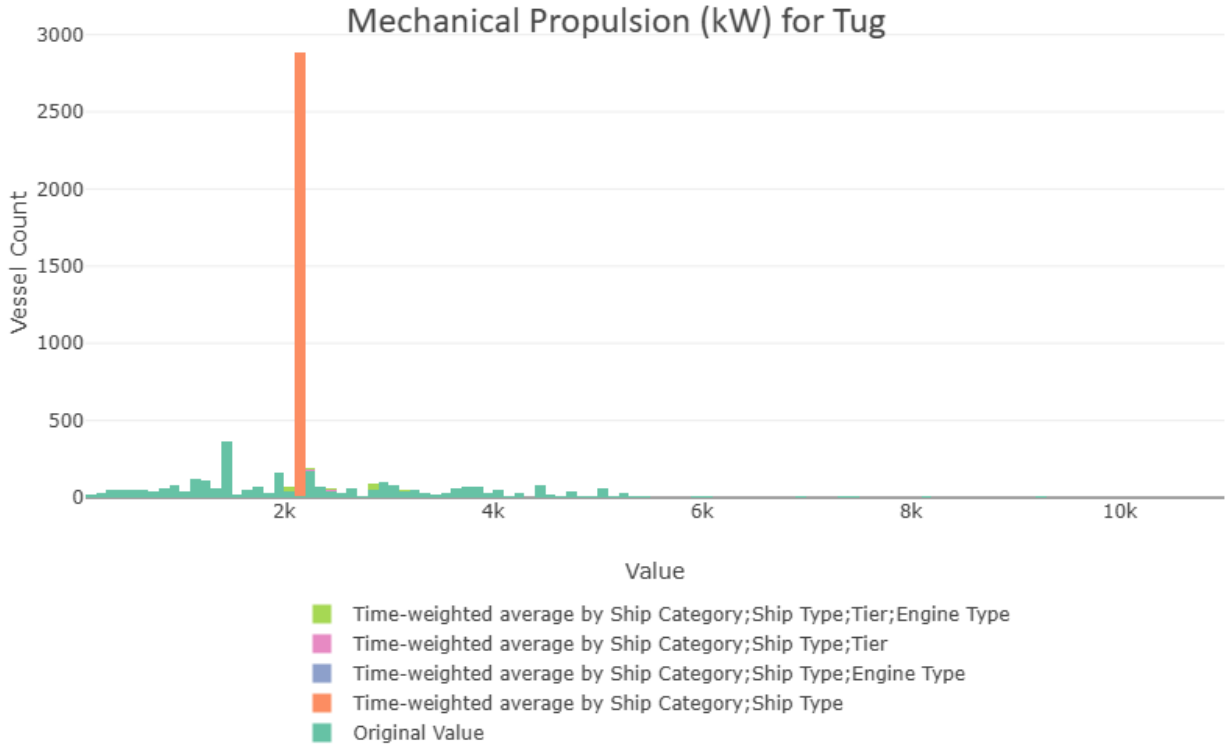


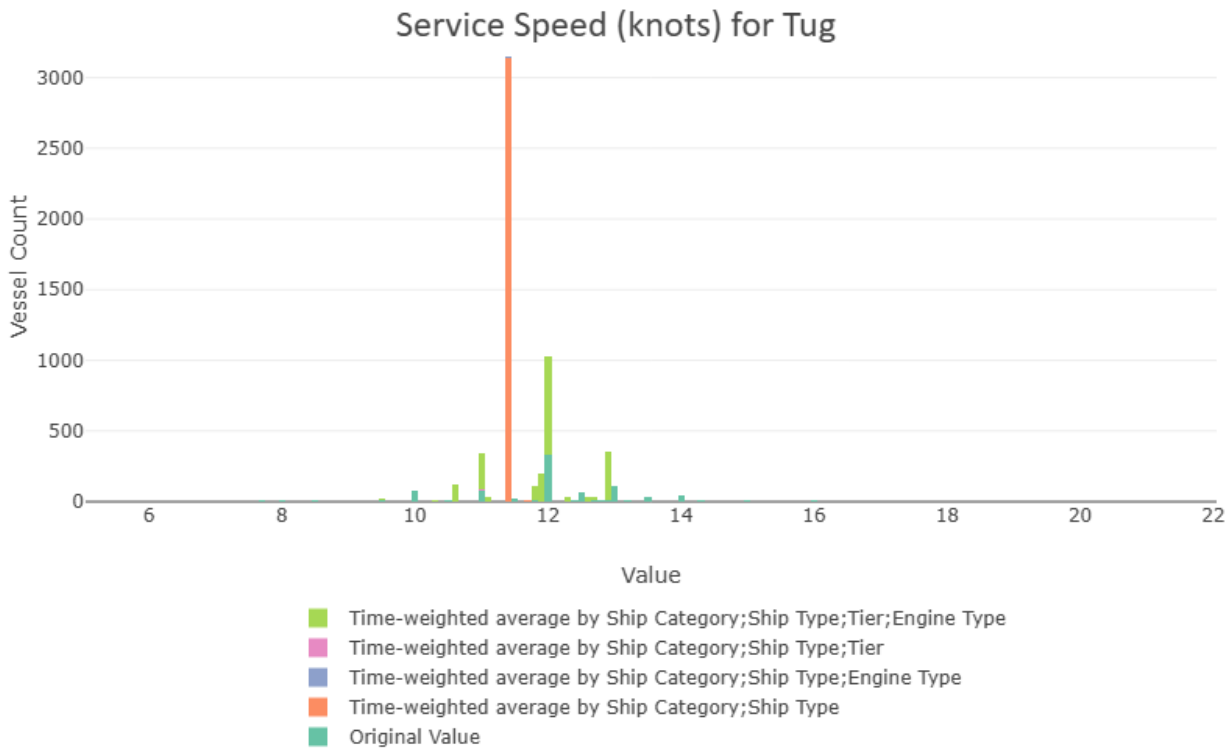
B.2.12 Mechanical Propulsion and Service Speed Surrogate Values for Tanker



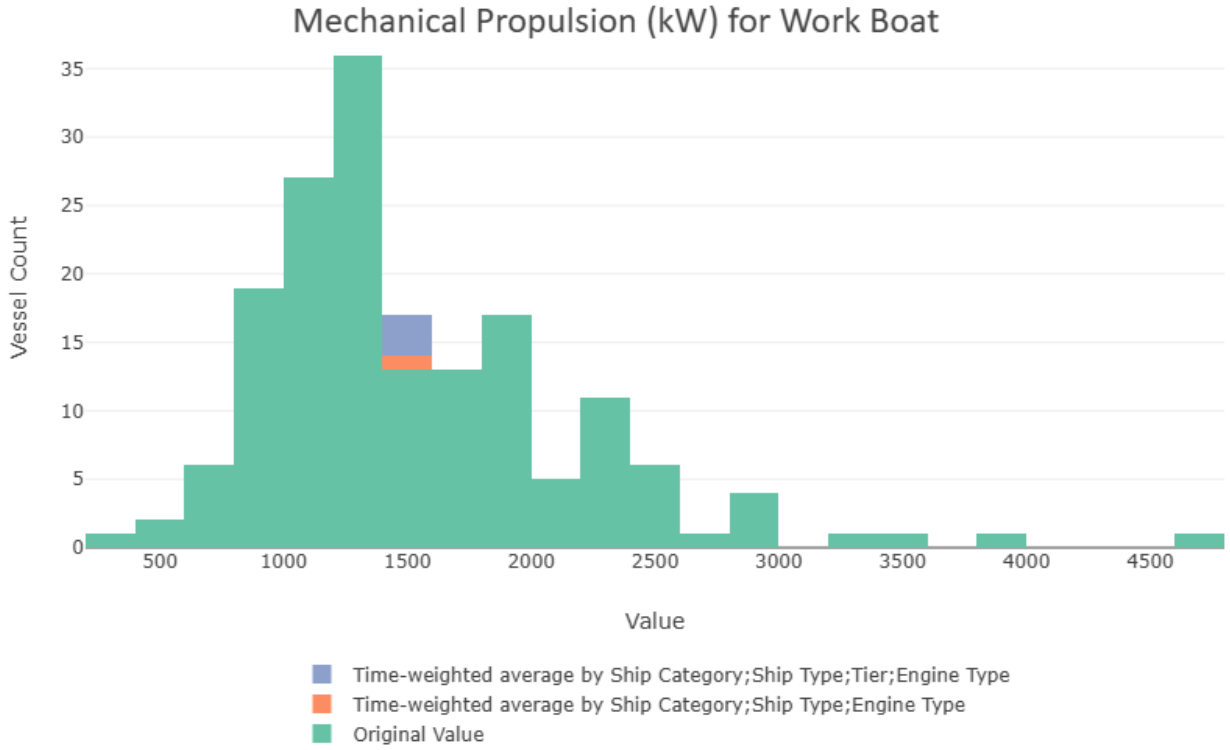


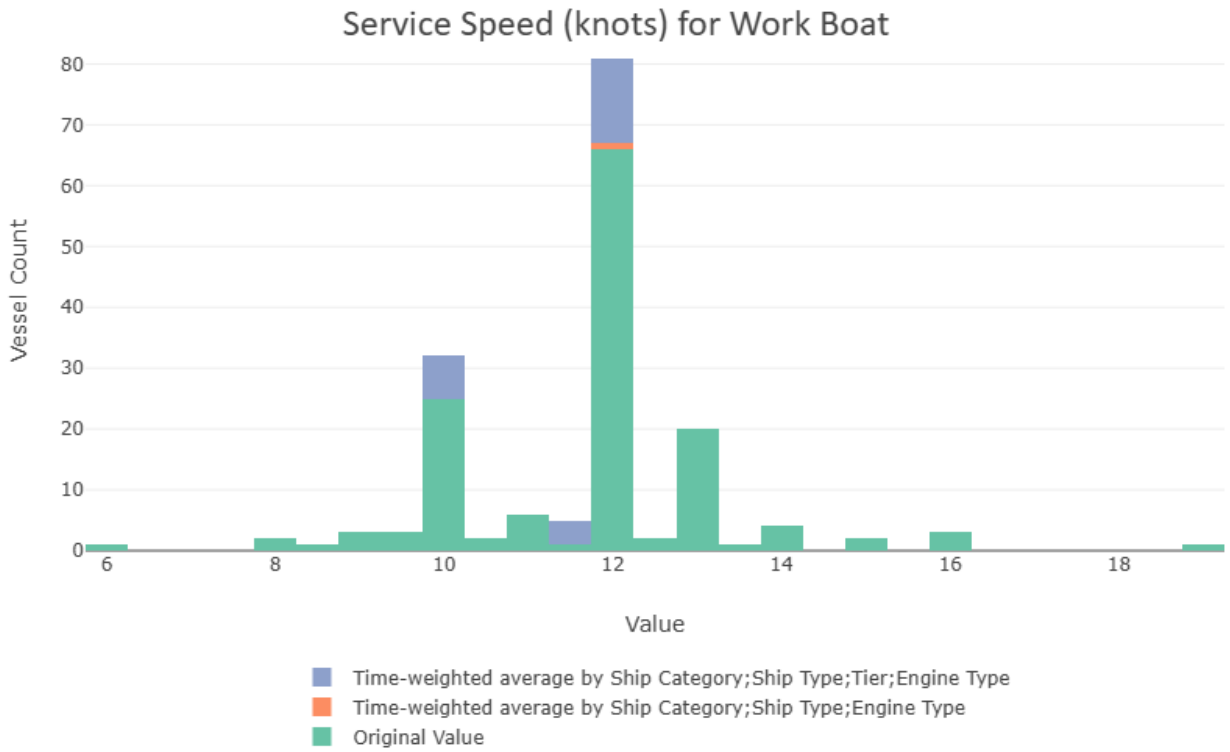
B.2.13 Mechanical Propulsion and Service Speed Surrogate Values for Tug





B.2.14 Mechanical Propulsion and Service Speed Surrogate Values for Work Boat



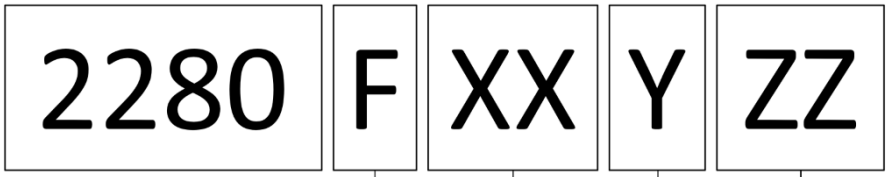


C Emissions By SCC

C.1 CMV SCC Definitions

Figure C-1 CMV SCC Definitions

CMV SCC Decoder



Fuel Type	
1	-
2	Diesel
3	Residual
4	LNG
5	-
6	-

Vessel Type	
01	Barge
02	Offshore
03	Bulk Carrier
04	Fishing
05	Container Ship
06	Ferry
07	General Cargo
08	Government
09	Miscellaneous
10	Ro-Ro
11	Tanker
12	Tour Boat
13	Tug
14	Refrigerated
15	Cruise
16	Passenger Other

Category	
1	C1,C2
3	C3

Location	
1	Port
2	Underway

Engine	
3	Main
4	Aux

C.2 2023 C1C2 Emissions by SCC

SCC	Fuel	Ship Type	Port / Underway	Engine	CO	CO2	NOX	PM25	PM10	SO2	VOC
2280202113	Diesel	Offshore	Port	Main	6	3,574	103	4	4	0	14
2280202114	Diesel	Offshore	Port	Aux	1,077	582,240	6,602	161	166	5	230
2280202123	Diesel	Offshore	Underway	Main	1,202	655,491	8,170	212	218	6	415
2280202124	Diesel	Offshore	Underway	Aux	3,020	1,490,890	18,782	462	477	14	608
2280203113	Diesel	Bulk Carrier	Port	Main	0	91	5	0	0	0	1
2280203114	Diesel	Bulk Carrier	Port	Aux	5	4,525	32	1	1	0	1
2280203123	Diesel	Bulk Carrier	Underway	Main	372	160,779	2,353	58	60	1	74
2280203124	Diesel	Bulk Carrier	Underway	Aux	22	21,474	149	5	5	0	5
2280204113	Diesel	Fishing	Port	Main	2	655	18	1	1	0	2
2280204114	Diesel	Fishing	Port	Aux	822	351,257	5,229	128	132	3	152
2280204123	Diesel	Fishing	Underway	Main	379	162,062	2,806	76	78	1	134
2280204124	Diesel	Fishing	Underway	Aux	3,491	1,488,578	22,221	543	560	14	644
2280205113	Diesel	Continer Ship	Port	Main	0	105	0	0	0	0	0
2280205114	Diesel	Continer Ship	Port	Aux	1	2,933	10	0	1	0	0
2280205123	Diesel	Continer Ship	Underway	Main	10	5,131	47	1	1	0	2
2280205124	Diesel	Continer Ship	Underway	Aux	3	6,896	25	1	1	0	1
2280206113	Diesel	Ferry	Port	Main	1	341	11	0	0	0	1
2280206114	Diesel	Ferry	Port	Aux	7	2,880	41	1	1	0	1
2280206123	Diesel	Ferry	Underway	Main	25	11,983	190	5	5	0	10
2280206124	Diesel	Ferry	Underway	Aux	80	34,733	504	12	13	0	14
2280207113	Diesel	General Cargo	Port	Main	13	5,963	106	3	3	0	6
2280207114	Diesel	General Cargo	Port	Aux	278	179,169	1,823	51	53	2	56
2280207123	Diesel	General Cargo	Underway	Main	544	232,416	3,697	95	97	2	139
2280207124	Diesel	General Cargo	Underway	Aux	1,518	979,467	9,946	279	291	9	305
2280208113	Diesel	Government	Port	Main	3	1,419	28	1	1	0	2
2280208114	Diesel	Government	Port	Aux	781	342,171	4,860	118	122	3	142
2280208123	Diesel	Government	Underway	Main	314	140,799	2,058	53	54	1	85
2280208124	Diesel	Government	Underway	Aux	2,225	955,686	14,017	342	353	9	408
2280209113	Diesel	Miscellaneous	Port	Main	3	1,421	37	1	1	0	4

2280209114	Diesel	Miscellaneous	Port	Aux	372	176,563	2,327	57	58	2	73
2280209123	Diesel	Miscellaneous	Underway	Main	402	201,580	2,915	79	81	2	163
2280209124	Diesel	Miscellaneous	Underway	Aux	1,752	927,867	10,743	264	272	9	385
2280210113	Diesel	Ro-Ro	Port	Main	1	473	13	0	0	0	1
2280210114	Diesel	Ro-Ro	Port	Aux	35	28,393	224	7	7	0	7
2280210123	Diesel	Ro-Ro	Underway	Main	632	300,872	4,017	98	101	3	138
2280210124	Diesel	Ro-Ro	Underway	Aux	171	140,634	1,073	32	34	1	36
2280211113	Diesel	Tanker	Port	Main	0	96	3	0	0	0	0
2280211114	Diesel	Tanker	Port	Aux	22	17,668	139	4	4	0	4
2280211123	Diesel	Tanker	Underway	Main	90	39,916	578	14	15	0	18
2280211124	Diesel	Tanker	Underway	Aux	71	66,648	433	12	13	1	14
2280212113	Diesel	Tour Boat	Port	Main	8	3,716	142	5	5	0	17
2280212114	Diesel	Tour Boat	Port	Aux	540	238,691	3,348	82	84	2	100
2280212123	Diesel	Tour Boat	Underway	Main	663	303,191	5,070	143	147	3	299
2280212124	Diesel	Tour Boat	Underway	Aux	3,066	1,366,660	18,975	461	475	13	563
2280213113	Diesel	Tug	Port	Main	103	58,952	859	26	26	1	82
2280213114	Diesel	Tug	Port	Aux	417	244,366	2,423	59	61	2	94
2280213123	Diesel	Tug	Underway	Main	4,940	2,819,407	32,393	850	877	26	1,947
2280213124	Diesel	Tug	Underway	Aux	2,017	1,265,326	11,660	286	295	12	493
2280214113	Diesel	Refrigerated	Port	Main	0	0	0	0	0	0	0
2280214114	Diesel	Refrigerated	Port	Aux	0	65	0	0	0	0	0
2280214123	Diesel	Refrigerated	Underway	Main	2	1,738	12	0	0	0	0
2280214124	Diesel	Refrigerated	Underway	Aux	3	3,019	15	0	0	0	0