

CATEGORY 1 and 2 COMMERCIAL MARINE VESSEL 2023 EMISSIONS INVENTORY

Prepared for:

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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 and hazardous air pollutants (HAPs) for mobile, point, and nonpoint emissions sources. The hazardous air pollutants that are included in the NEI are based on Section 112(b) of the Clean Air Act. State, local and tribal air agencies submit emission estimates to the Environmental Protection Agency (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 While the adoption rate of AIS by C1C2 vessels generally lags that of C3 vessels, EPA assumes that any C1C2 vessels omitted from the inventory due to lack of AIS adoption are deemed to have a negligible impact on national C1C2 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). The emissions that comprise the NEI fall within the blue areas in Figure 1, while data for the modeling platform extends throughout the region within the dashed line.

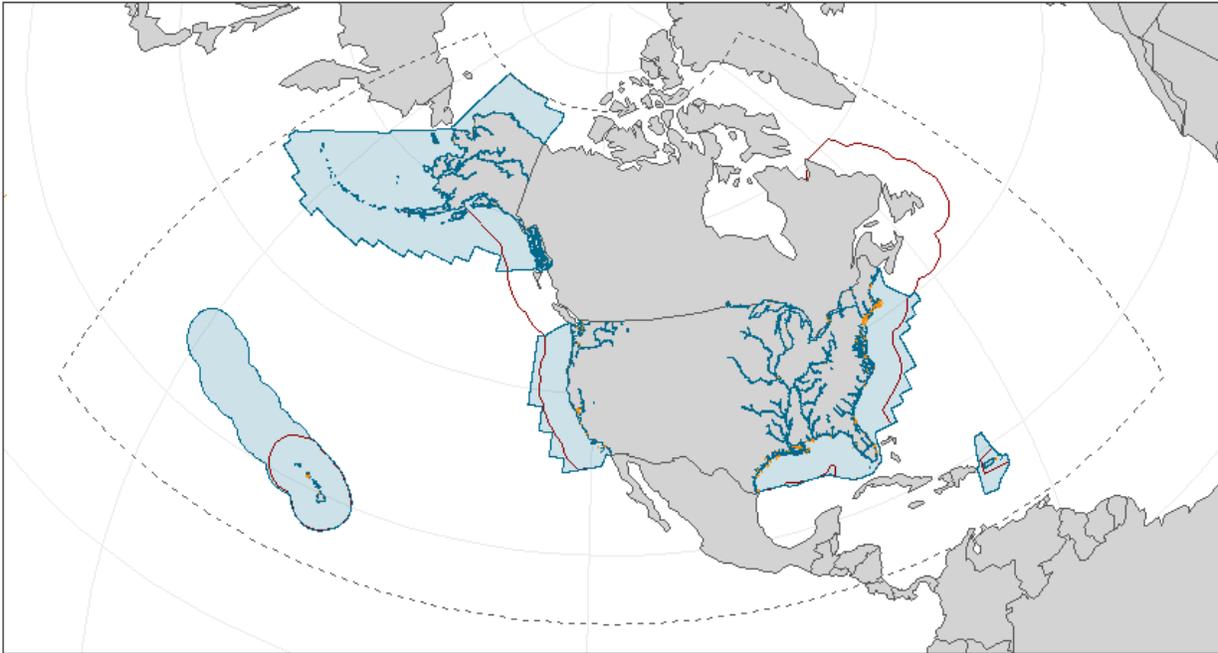


Figure 1 Geographic Regions used for the C1C2 Emissions Inventory NEI Geographic Extent (blue), North American and Caribbean ECAs (red outline), Ports and Anchorages (orange dots), AIS area of interest encompassing the air quality modeling domain (dashed outline)

2.1 AIS Pre-Processing

The data were 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 ($\pm 180^\circ$). 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 each averaged over the five-minute interval. For the other fields the most frequently 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 a 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 one hour, to ensure that hourly rasterized emissions properly represent 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. The Haversine method calculates the great-circle distance – the shortest distance over the Earth's surface – between two points on a sphere given their latitude and longitude coordinates. 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 a port in the NEI Port Shapefile, it would receive the FIPS code associated with that port polygon. In addition, 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 province and Mexican state waters.

3 Ship Characteristics Dataset

To calculate a ship’s emissions, additional information about the ship is needed beyond its position and speed. For those 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 may 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 in for each of these fields.

Table 1 Ship Parameters

Vessel Identification	Vessel Category Determination	Vessel Power Parameters	Vessel Grouping/Emission Factor Parameters
<ul style="list-style-type: none"> • IMO number • MMSI 	<ul style="list-style-type: none"> • Engine bore • Engine stroke 	<ul style="list-style-type: none"> • Total installed propulsive power (kW) • Service Speed (kn) 	<ul style="list-style-type: none"> • 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 are not available for all vessel types, so vessel types were aggregated into 16 different ship types for which surrogate data were available. Figure 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 (Figure 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.

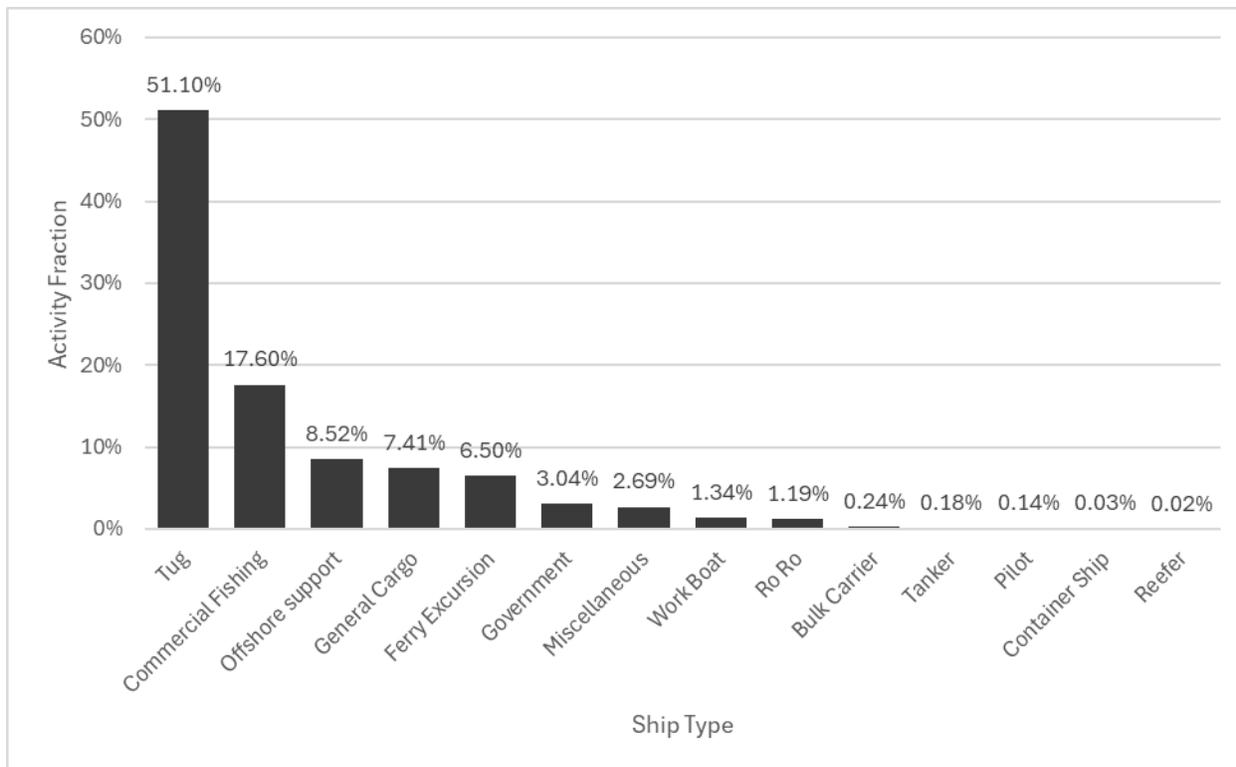


Figure 2 Breakdown of Category 1 and 2 AIS Activity by Ship Type

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, so the AIS may not include such smaller ferry 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, the 6,415 general cargo ships 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.

A total of 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 75,231 vessels, suggesting that the 2023 inventory is still underreporting commercial fishing vessels.¹⁴ This underreporting may indicate that most of the fleet is composed of smaller vessels that do not trigger AIS 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 as 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 (ED) vessels (MSD-ED or GT-ED). Currently, no standardized identification methods are available for liquefied 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 filled 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. A

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

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

Table 4 below contains counts of C1C2 vessels with total installed propulsive power (kW) and service speed (kn) values in the ship characteristics dataset by ship type. This table also contains the activity time-weighted average for both metrics by ship type. The activity time-weighted average values in Table 4 are

used as surrogates to gap-fill missing total installed propulsive power (kW) and service speed (kn) values within the ship characteristics dataset for iterative step 6 in Appendix B.1. Appendix B.2 shows the distribution of original and gap-filling parameter values for each ship type.

Table 4 Count and Time Weight Average of Total Installed Propulsive Power and Service Speed Values by C1C2 Ship Type

Ship Type	Time-Weighted Average of Total Installed Propulsive Power (kW)	Number of Vessels with Total Installed Propulsive Power (kW)	Time-Weighted Average of Service Speed (kn)	Number of Vessels with Service Speed Value (kn)
Bulk Carrier	5,832.81	79	14.17	55
Commercial Fishing	597.45	9,831	12.03	566
Container Ship	4,054.42	46	14.17	12
Ferry Excursion	3,011.66	462	22.57	337
General Cargo	1,369.05	487	11.14	879
Government	4,147.85	275	12.86	467
Miscellaneous	3,563.64	750	13.34	714
Offshore support	3,941.32	1,420	15.78	1,404
Pilot	1,518.02	10	25.85	4
Reefer	2,206.21	23	11.66	20
Ro Ro	3,144.27	299	13.96	277
Tanker	4,287.50	545	14.06	378
Tug	2,502.99	3,488	11.54	1,350
Work Boat	1,564.56	240	11.95	197

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 (Equation 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

<i>Time</i>	= length of time between AIS messages, measured in hours
<i>Power</i>	= 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
<i>EF</i>	= assigned emission factors for each engine group on the vessel
<i>LLAF</i>	= 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 C1C2 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.

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

where:

<i>LF</i>	= load factor
<i>P_{ref}</i>	= total installed propulsive power (kW)
<i>V</i>	= AIS-reported speed (kn)
<i>V_{ref}</i>	= 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} 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.⁹ 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.

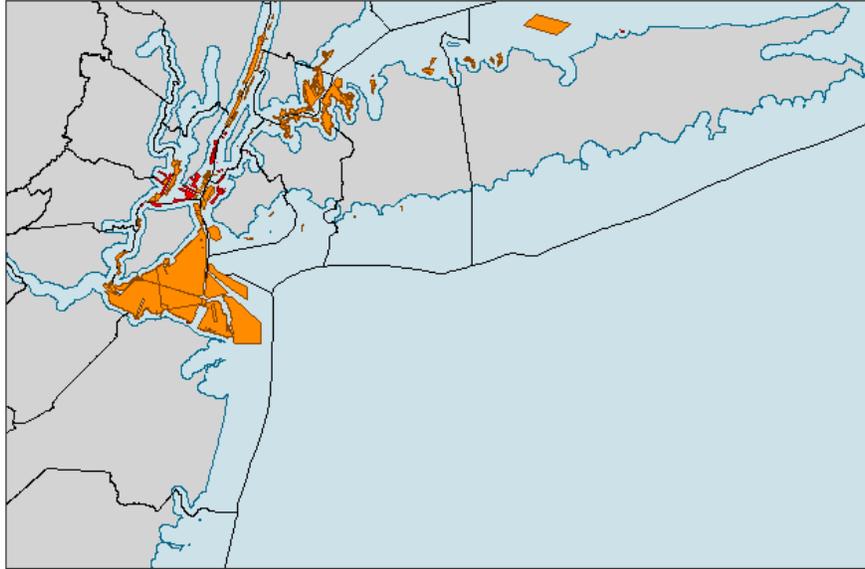


Figure 3 Example map illustrating the shape files used for assigning operating mode.

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.^{17,18}

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 kW's were developed by adjusting the average auxiliary power rating by the load factors presented in Table 5. 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 5 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, container ships, 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 6 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 7 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 6 C1C2 Propulsive and Auxiliary Emission Factors

Tier	CO (g/kWhr)	CO ₂ (g/kWhr)	NO _x (g/kWhr)	PM _{2.5} (g/kWhr)	PM ₁₀ (g/kWhr)	SO ₂ (g/kWhr)	VOC (g/kWhr)
Tier 0	1.61	679.47	10.28	0.25	0.26	0.0062	0.30
Tier 1	1.61	679.47	9.62	0.25	0.26	0.0062	0.30
Tier 2	0.92	679.47	5.64	0.14	0.15	0.0062	0.30
Tier 3	0.92	679.47	4.75	0.08	0.08	0.0062	0.12
Tier 4	0.92	679.47	1.30	0.03	0.03	0.0062	0.12

Table 7 C1C2 Auxiliary Boiler Emission Factors

CO (g/kWhr)	CO ₂ (g/kWhr)	NO _x (g/kWhr)	PM _{2.5} (g/kWhr)	PM ₁₀ (g/kWhr)	SO ₂ (g/kWhr)	VOC (g/kWhr)
0.20	961.80	2.00	0.19	0.20	0.0088	0.11

4.5 Low Load Adjustment Factor

Emission Factors (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 8 below shows the emission factor adjustments by load and pollutant, based on the data compiled for the Port Everglades 2015 Emission Inventory.²¹

Table 8 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

Load	CO	CO ₂	NO _x	PM _{2.5}	PM ₁₀	SO ₂	VOC
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. The HAP augmentation was done within the Emissions Inventory System (EIS).

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 CMV 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:

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

and

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

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.

For C1C2 CMV emissions, stray AIS messages converted to emissions can cause emissions to appear in areas where CMV emissions would not be expected. A list of counties that would reasonably have C1C2 CMV emissions was developed and any emissions in counties not in that list were dropped as a first pass towards cleaning up the inventory. A further refinement to address residual emissions in counties that

can have emissions but in areas where there are not waterways was to develop a gridded mask based on an analysis of GIS Shapefiles showing land and also navigable waterways and lakes. The resulting mask was then applied to remove all emissions from grid cells in locations where CMV emissions were not appropriate. This mask also supported removal of stray emissions over land in Canada and Mexico. An example of emissions derived from stray signals is shown in the left panel of Figure 4, where yellow dots can be seen in New Mexico, Colorado, Oklahoma, Kansas, western Texas, and northern Mexico. Those emissions are not present in the masked emissions shown in the right panel of Figure 4. The final emissions for the NEI and modeling platform do not include emissions that resulted from stray signals over land.

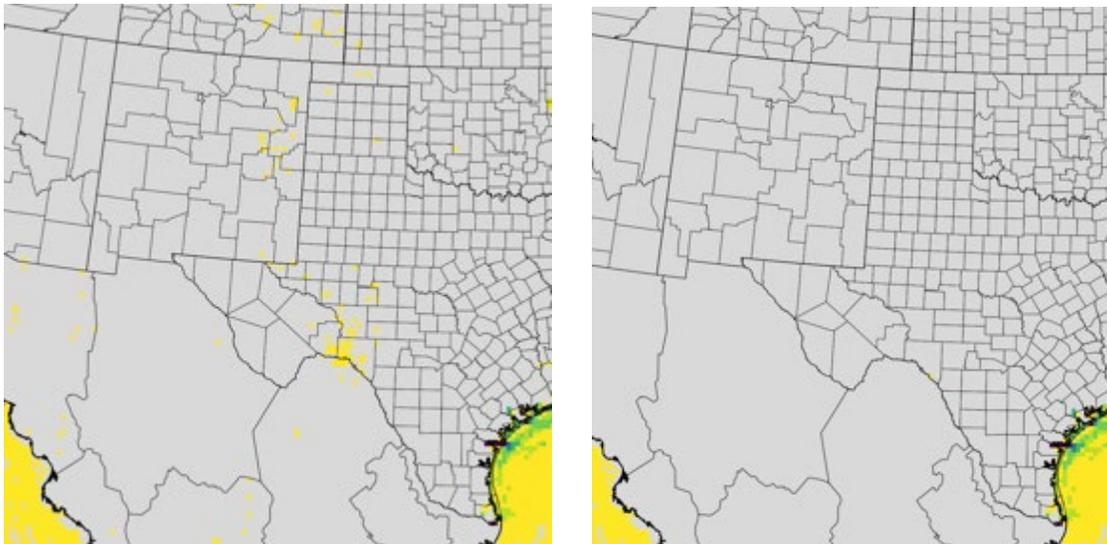


Figure 4 Example of Emissions Resulting from Rogue AIS Messages and Remaining Emissions after Masking

6 Emissions Summary

Table 9 represents 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 NO_x 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 Section 5.

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 ₁₀	PM _{2.5}	SO ₂	VOC
Alaska	2,420	1,098,727	15,404	392	380	10	486
Hawaii	387	172,992	2,482	63	61	2	80
Puerto Rico + Virgin Islands	314	65,649	858	22	22	1	30
CONUS	22,561	11,655,984	144,312	3,796	3,677	107	5,858

Region	CO	CO ₂	NO _x	PM ₁₀	PM _{2.5}	SO ₂	VOC
Alaska	2,420	1,098,727	15,404	392	380	10	486
Federal Waters	6,656	3,335,929	42,362	1,090	1,057	31	1,588
TOTAL	32,338	16,413,432	206,585	5,393	5,227	151	8,082

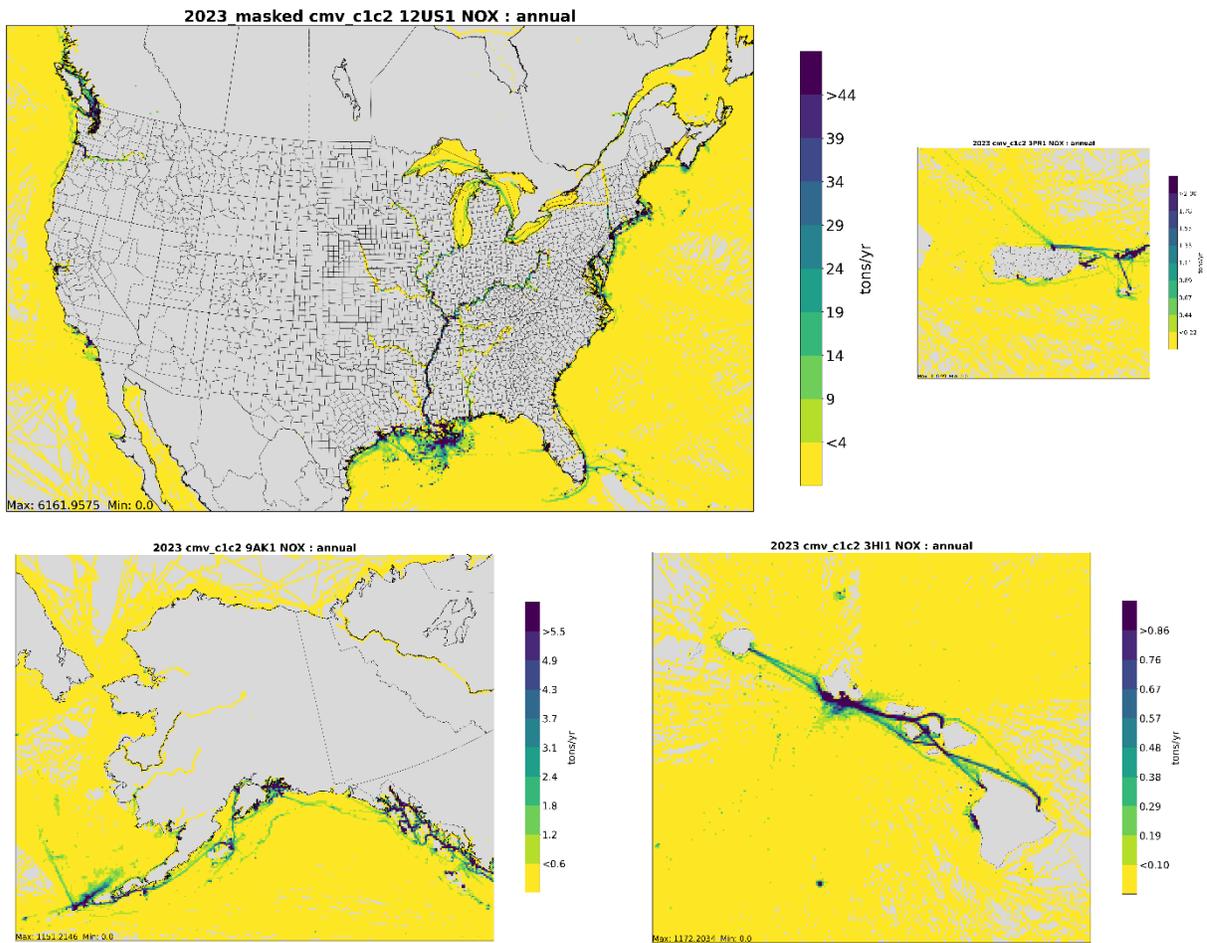


Figure 5 2023 Annual C1C2 NO_x Emissions

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

Ship Type	CO	CO2	NOX	PM10	PM25	SO2	VOC
Barge	1	218	3	0	0	0	0
Bulk Carrier	401	187,634	2,548	67	65	2	81
Container Ship	15	15,065	82	3	3	0	3
Ferry	112	49,937	746	19	19	0	27
Fishing	5,156	2,202,034	33,387	852	826	20	1,045
General Cargo	2,374	1,407,165	15,702	448	431	13	510
Government	3,391	1,473,453	21,387	540	524	14	651
Miscellaneous	2,568	1,326,008	16,274	419	407	12	635
Offshore	5,375	2,762,436	34,112	876	850	25	1,281
Refrigerated	5	4,921	28	1	1	0	1
Ro-Ro	847	474,403	5,385	144	139	4	185
Tanker	193	129,414	1,208	33	32	1	38
Tour Boat	4,293	1,920,668	27,623	715	693	18	983
Tug	7,609	4,460,075	48,098	1,277	1,238	41	2,643
TOTAL	32,338	16,413,432	206,585	5,393	5,227	151	8,082

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 10 provides total emissions by SCC.

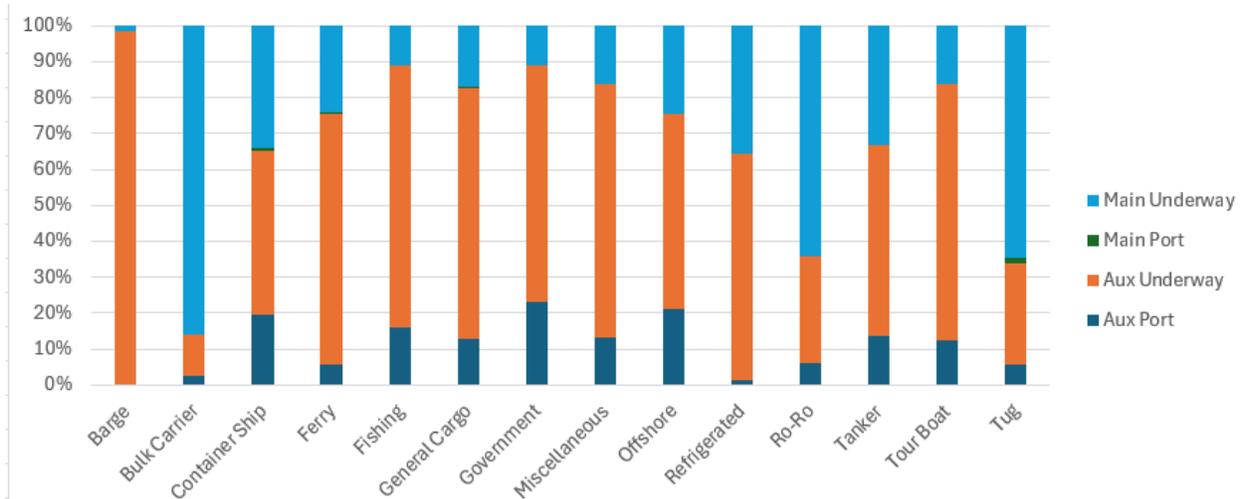


Figure 6 Ship Type Energy Distribution by Ship Type, Engine Type, and Port/Underway

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	4,497	2,247,548	28,381	732	709	21	991
	Aux	4,356	2,170,743	27,055	690	668	20	861
	Main	141	76,805	1,326	42	41	1	130
Underway	Total	27,842	14,165,884	178,204	4,661	4,517	130	7,091
	Aux	17,812	8,914,223	110,905	2,848	2,758	82	3,546
	Main	10,030	5,251,660	67,299	1,814	1,759	48	3,545

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 represents 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.

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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

Vessel Type	Ship Type
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

Vessel Type	Ship Type
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

Vessel Type	Ship Type
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

Vessel Type	Ship Type
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

Vessel Type	Ship Type
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

Vessel Type	Ship Type
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

Vessel Type	Ship Type
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

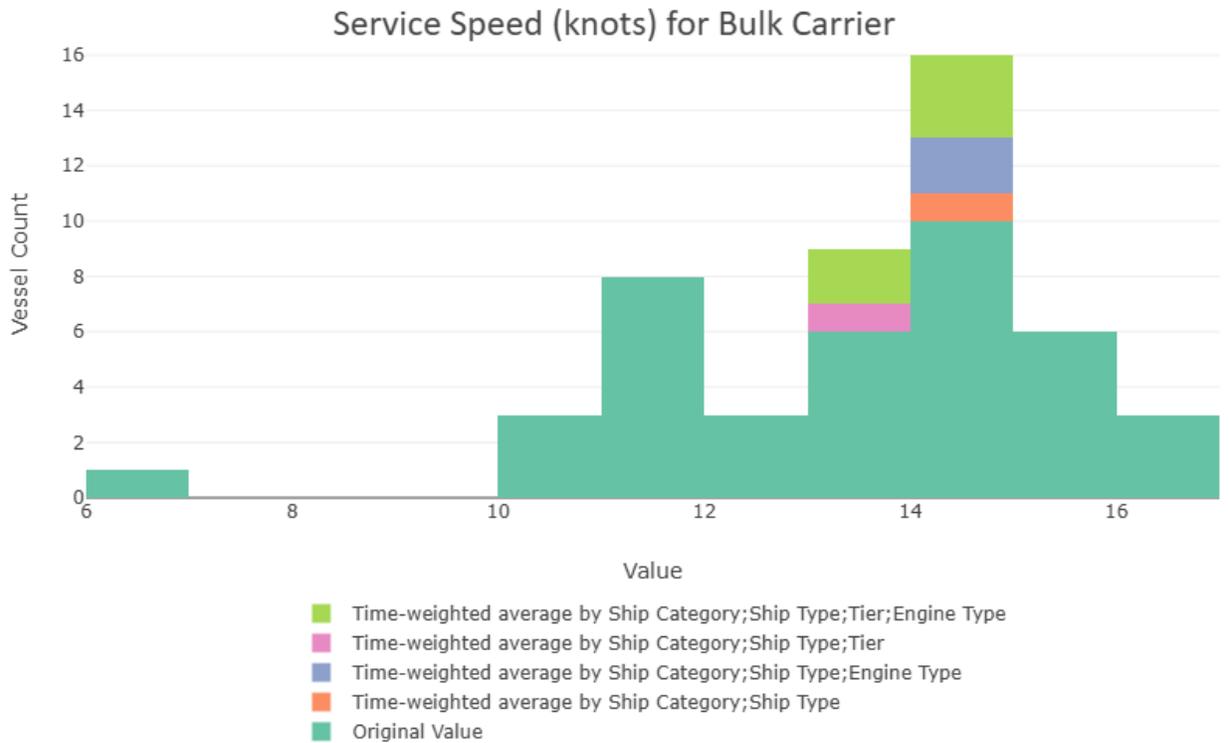
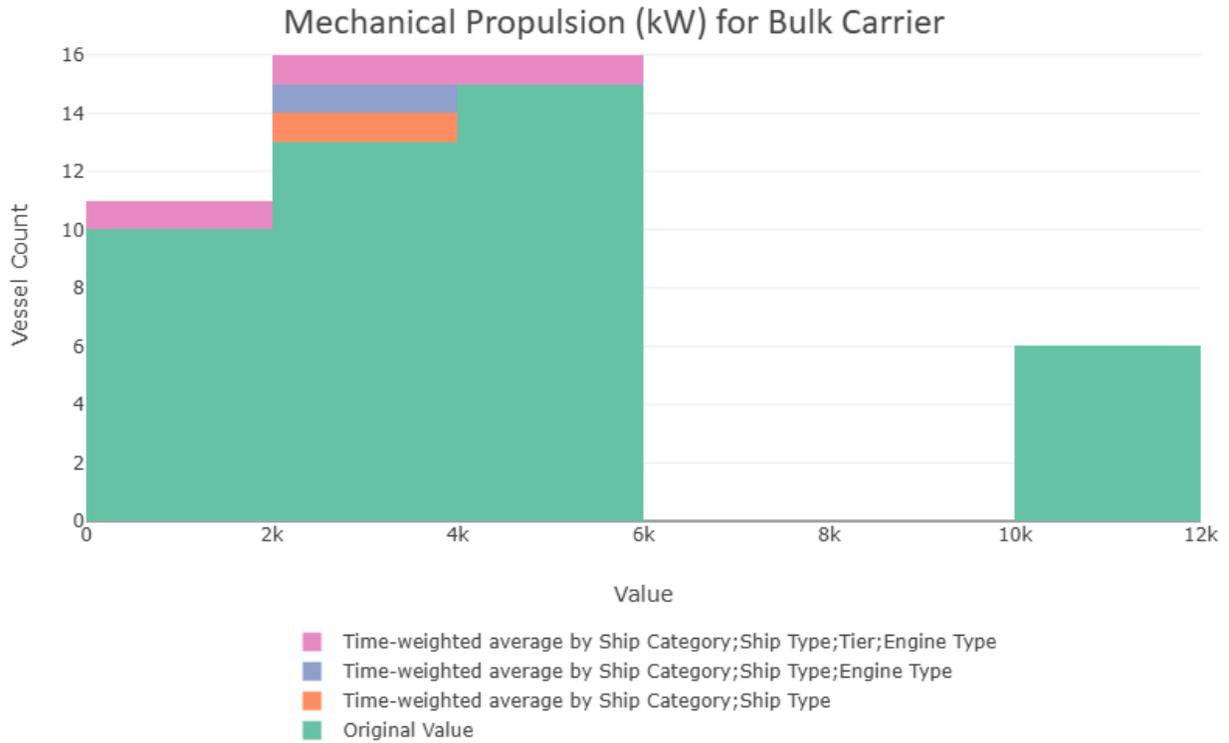
B Vessel Parameter Gap Filling Methods

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

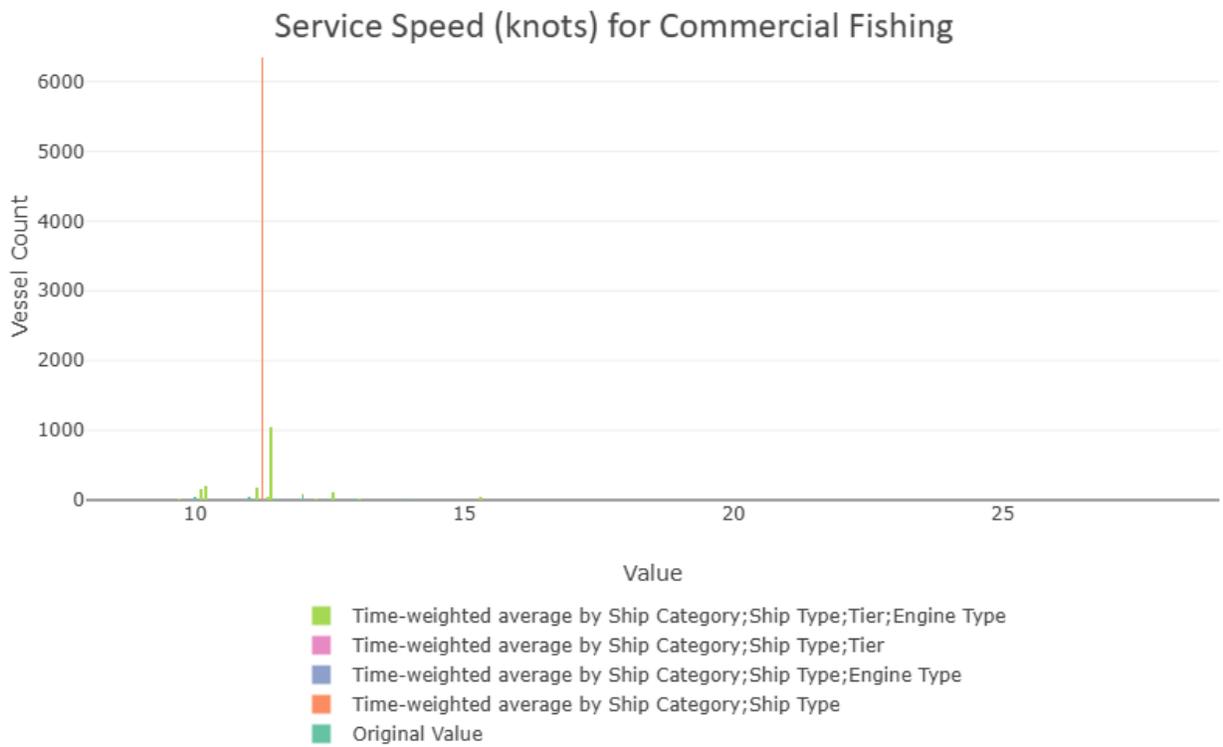
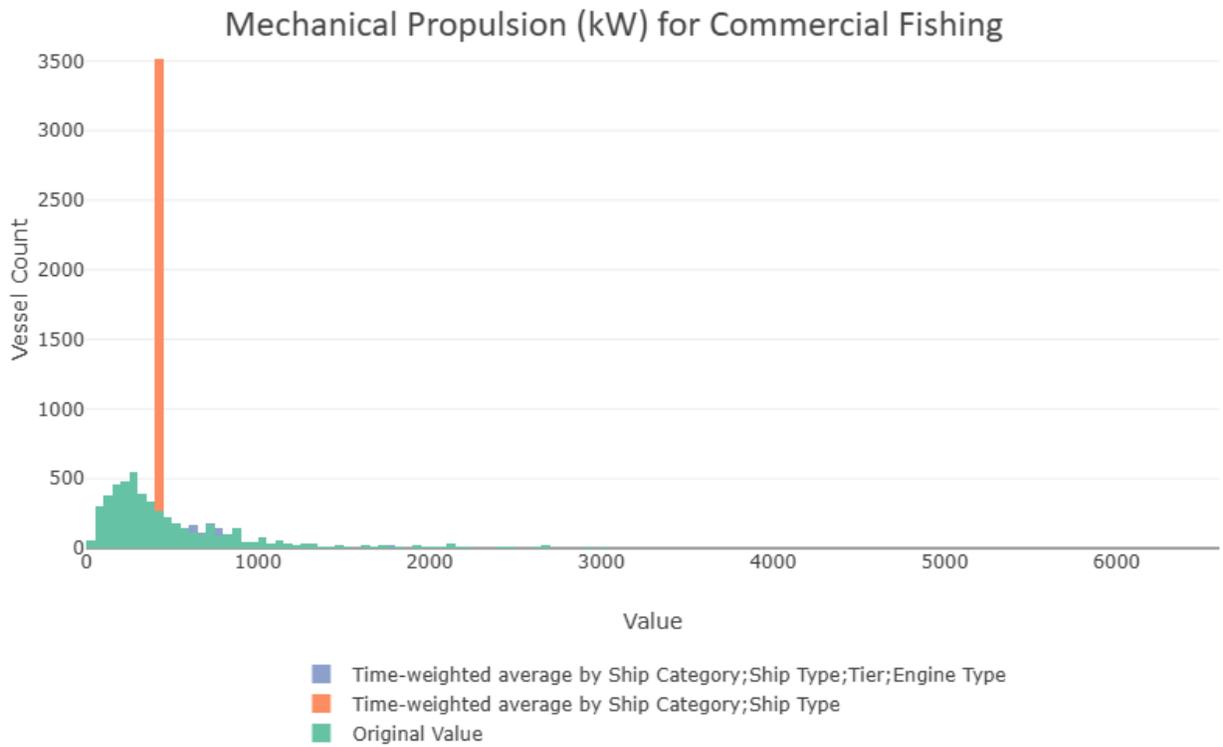
Iterative Step	Ship Characteristics used in Iterative Activity Time Weighted Average Gap-Filling
1	Ship Category, Ship Type, Tier, and Engine Type
2	Ship Category, Ship Type, Tier
3	Ship Category, Ship Type, Engine Type
4	Ship Category, Ship Type
5	Ship Category Group, Ship Type, Engine Type
6	Ship Category 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

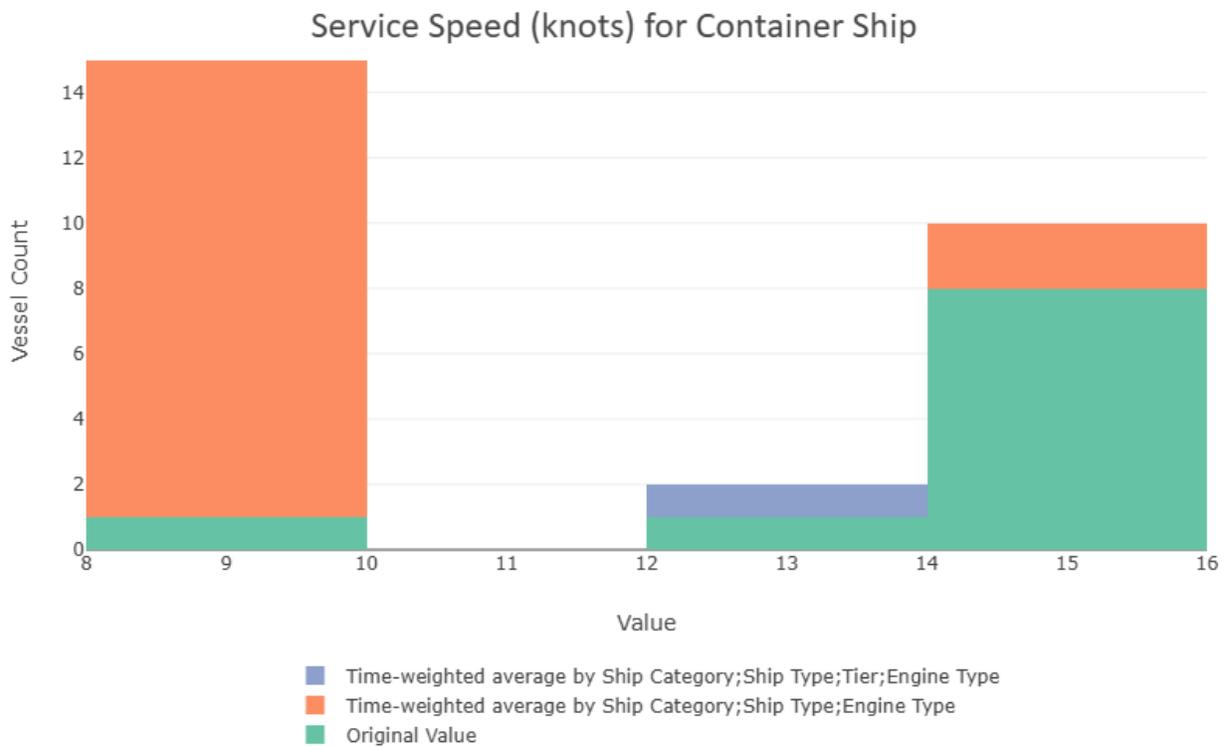
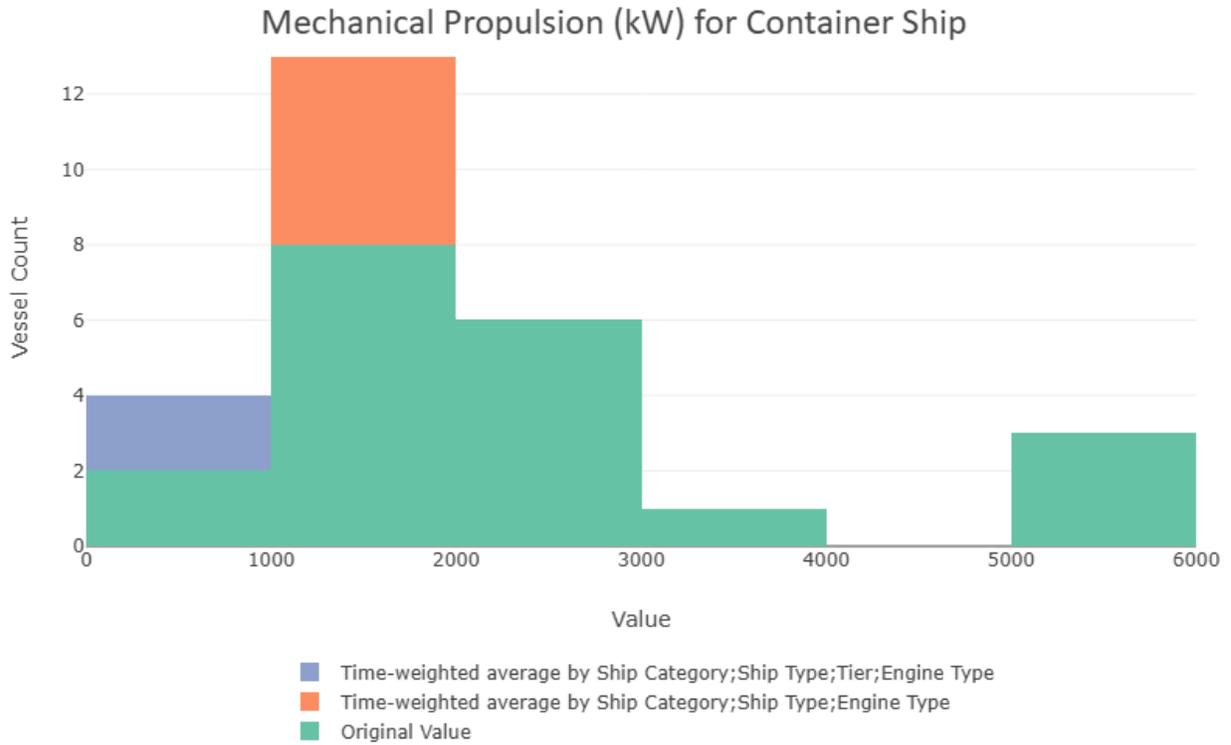
B.2.1 Mechanical Propulsion and Service Speed Surrogate Values for Bulk Carriers



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

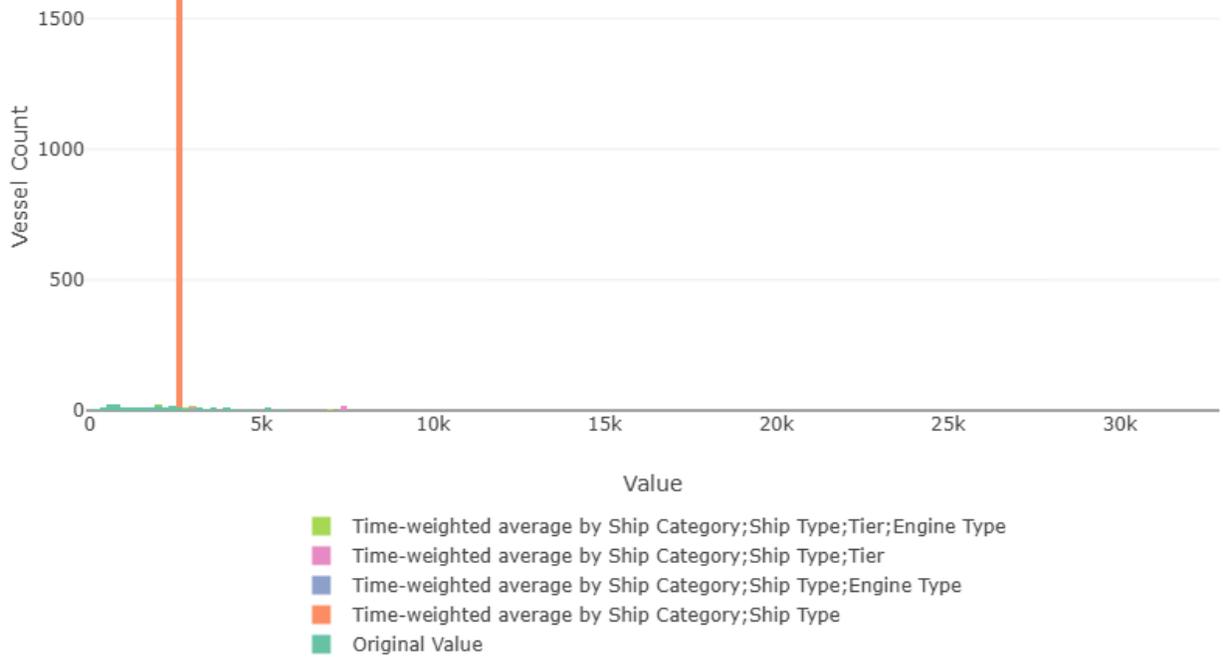


B.2.3 Mechanical Propulsion and Service Speed Surrogate Values for Container Ship

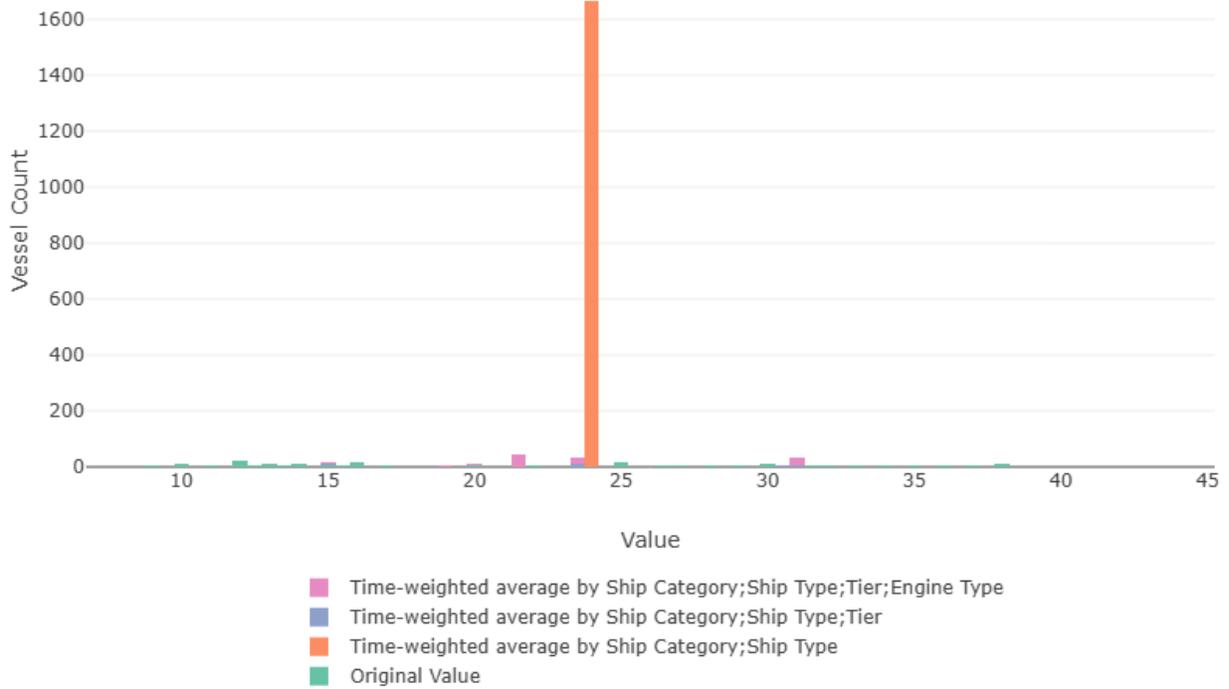


B.2.4 Mechanical Propulsion and Service Speed Surrogate Values for Ferry Excursion

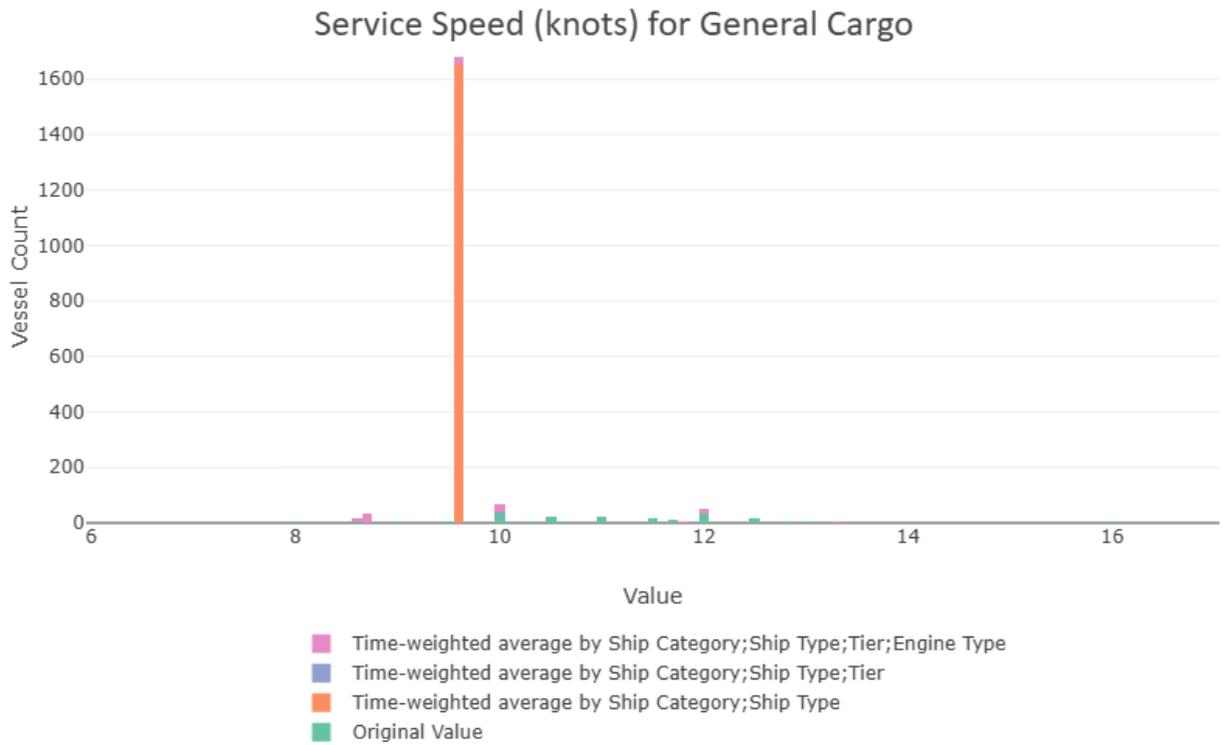
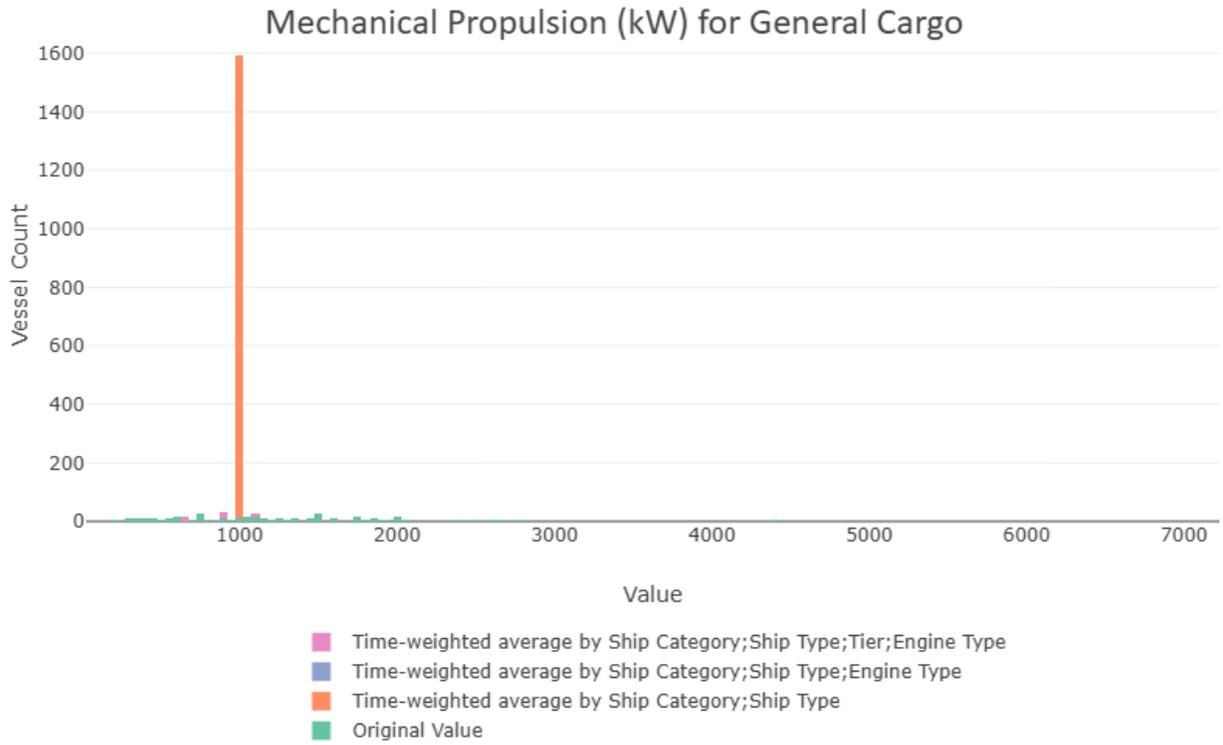
Mechanical Propulsion (kW) for Ferry Excursion



Service Speed (knots) for Ferry Excursion

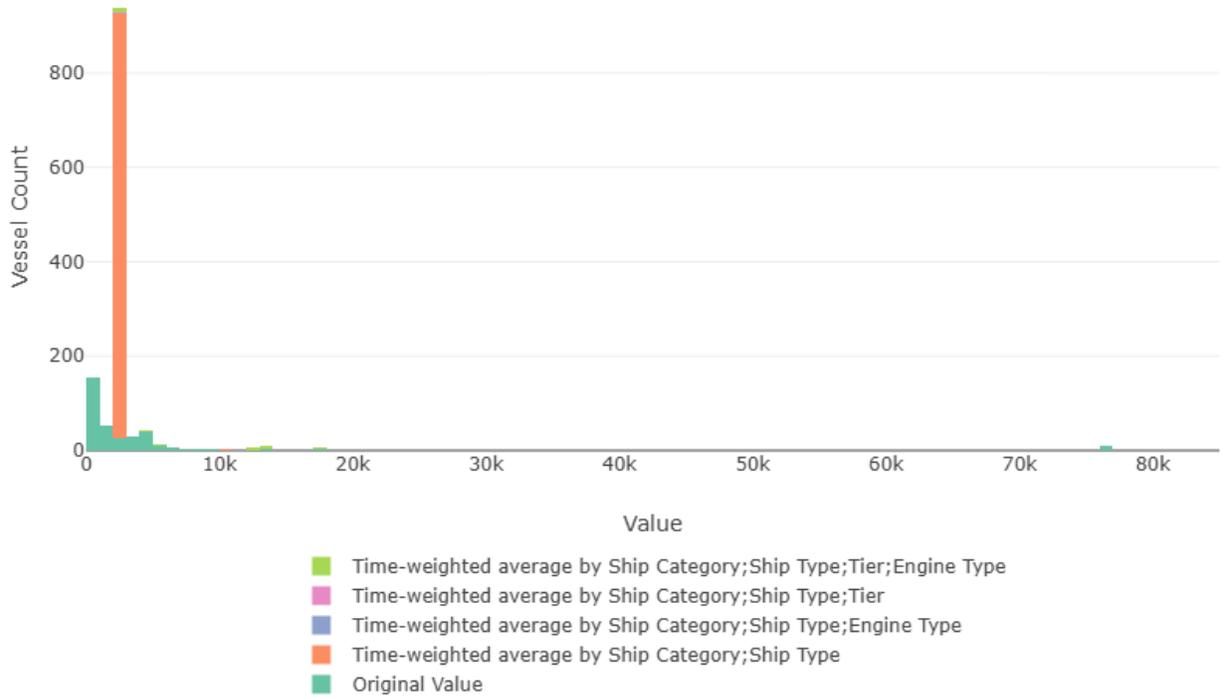


B.2.5 Mechanical Propulsion and Service Speed Surrogate Values for General Cargo

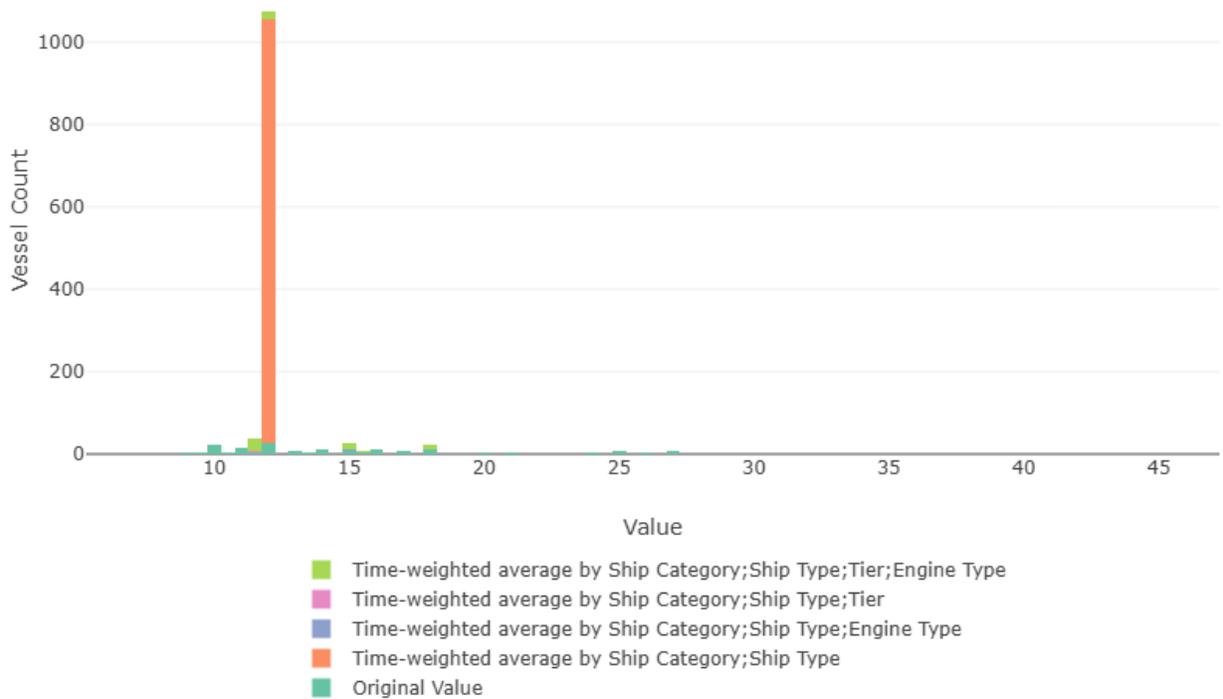


B.2.6 Mechanical Propulsion and Service Speed Surrogate Values for Government

Mechanical Propulsion (kW) for Government

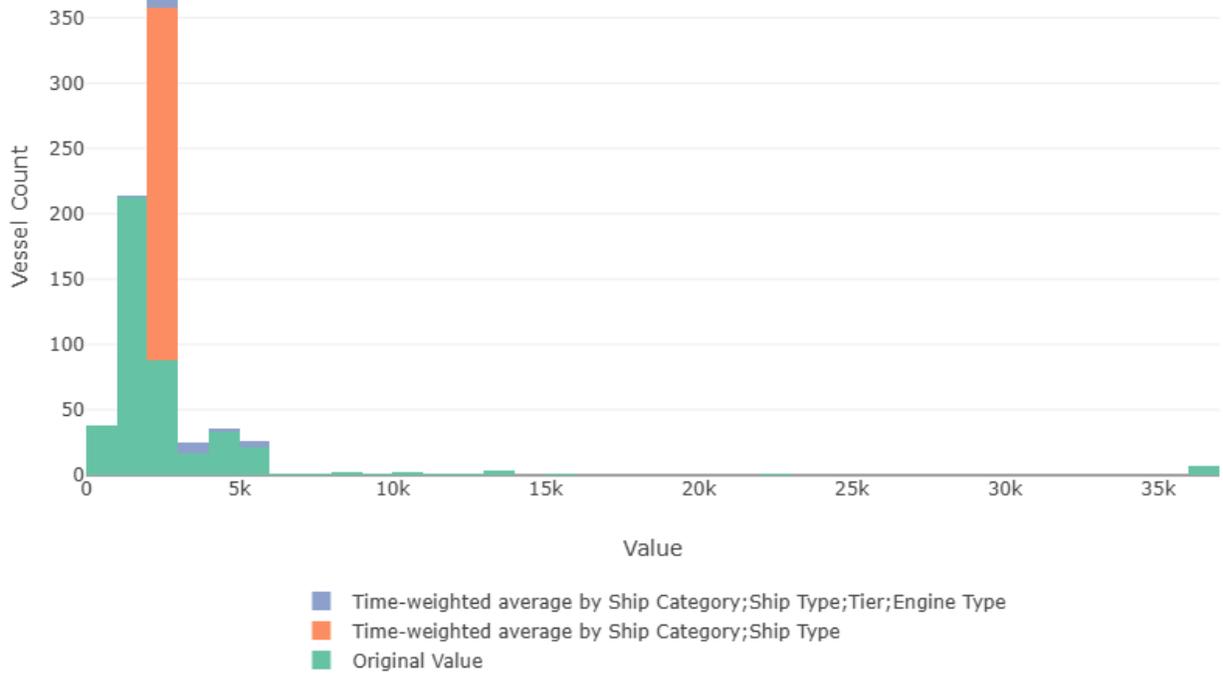


Service Speed (knots) for Government

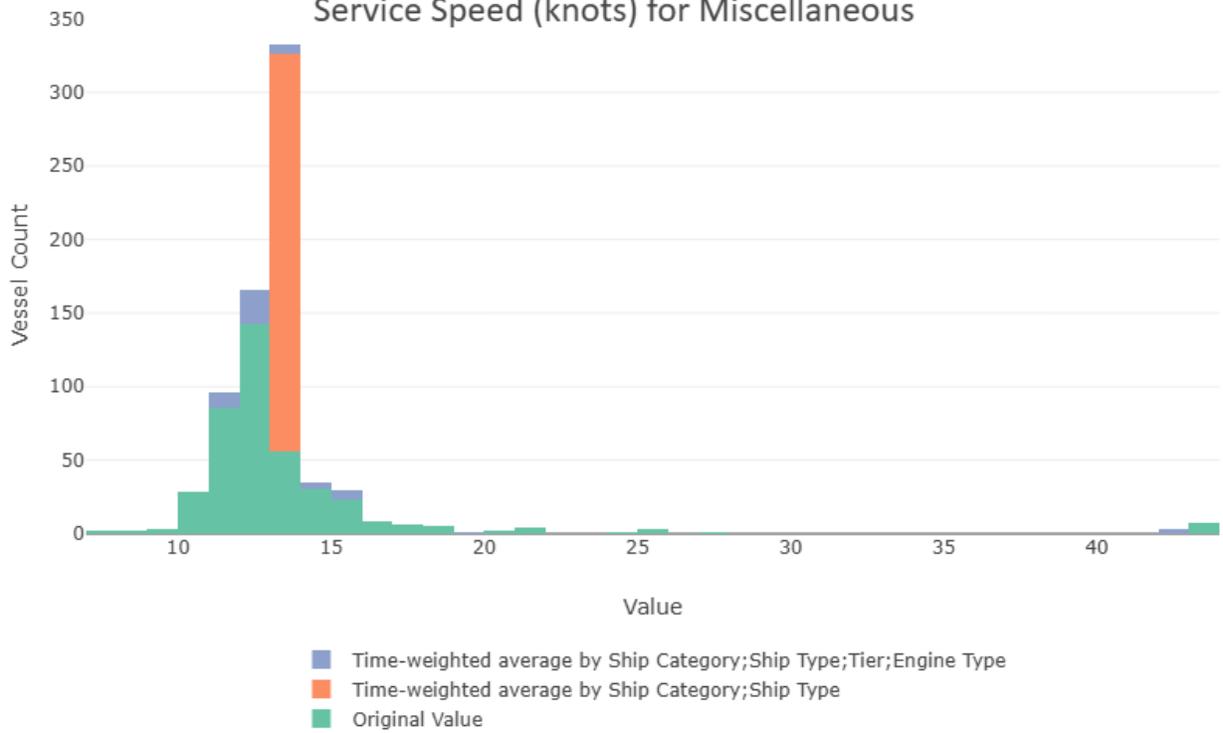


B.2.7 Mechanical Propulsion and Service Speed Surrogate Values for Miscellaneous

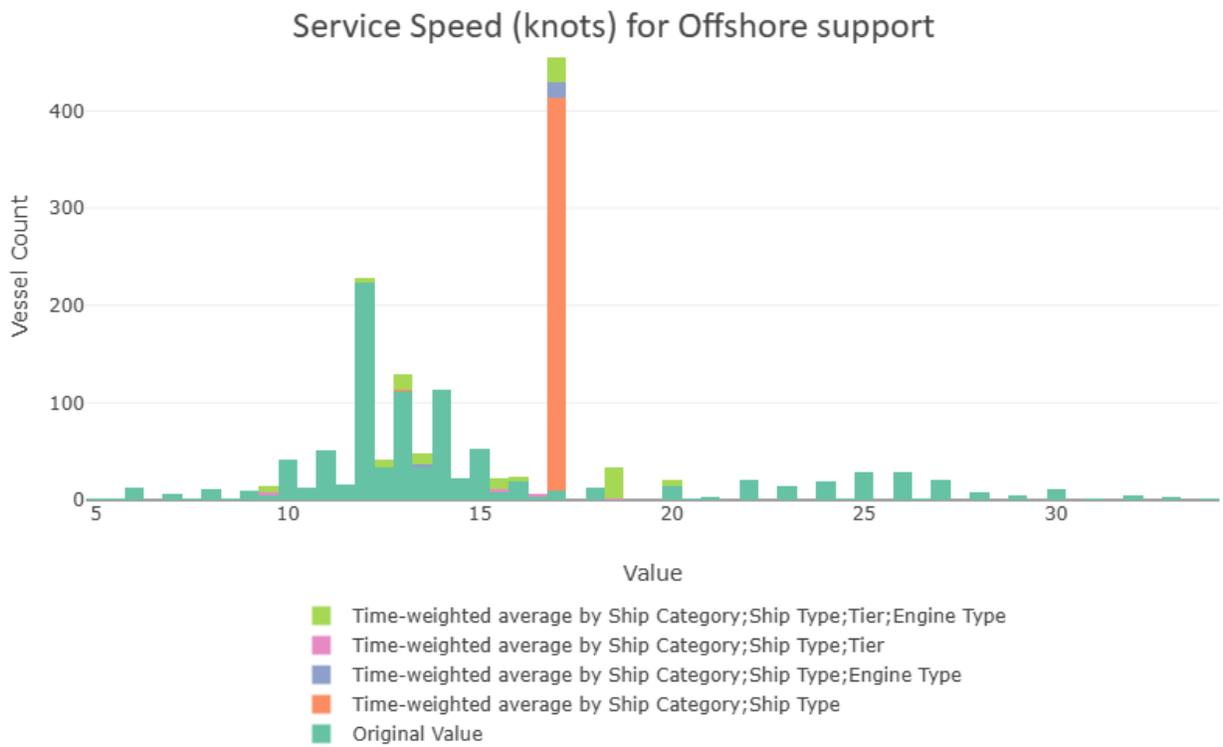
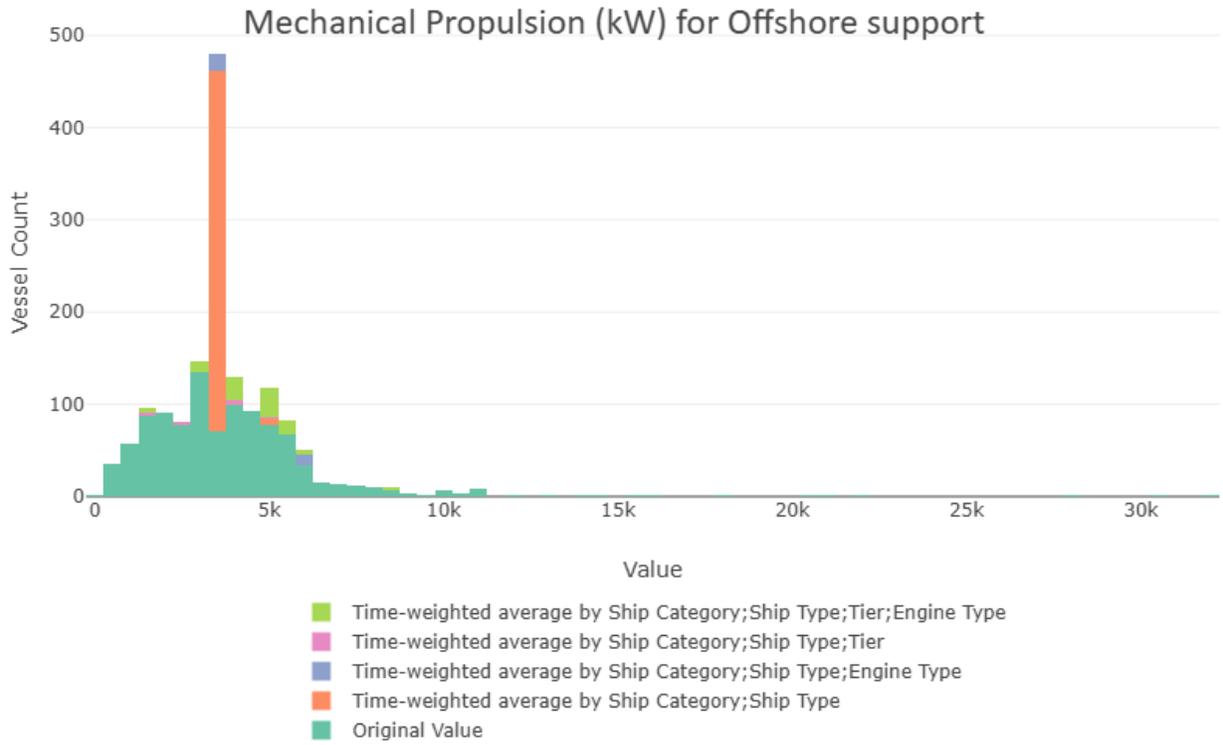
Mechanical Propulsion (kW) for Miscellaneous



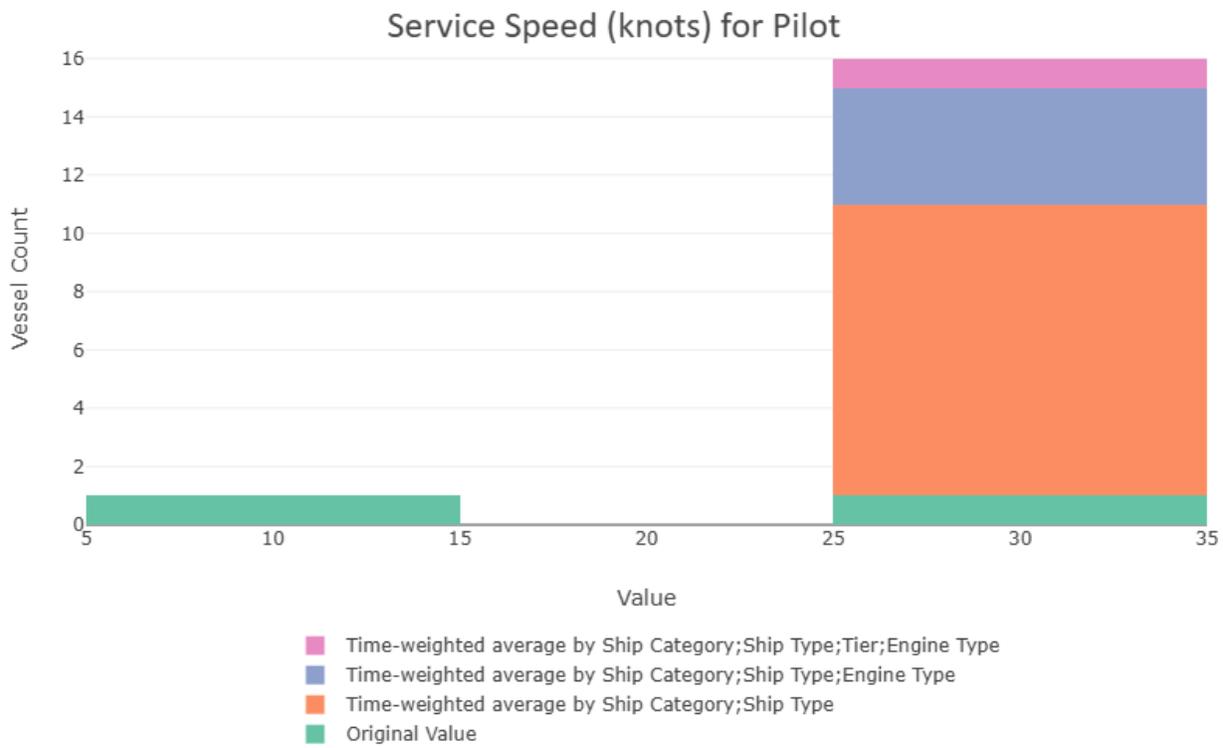
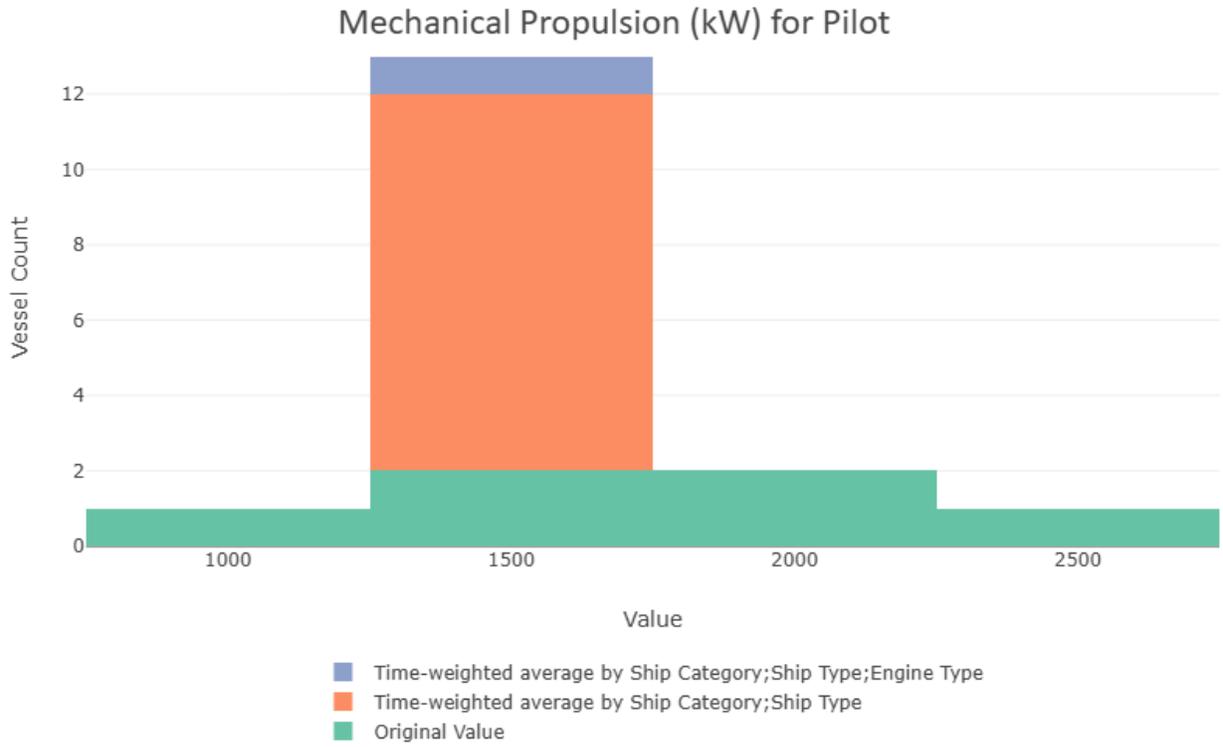
Service Speed (knots) for Miscellaneous



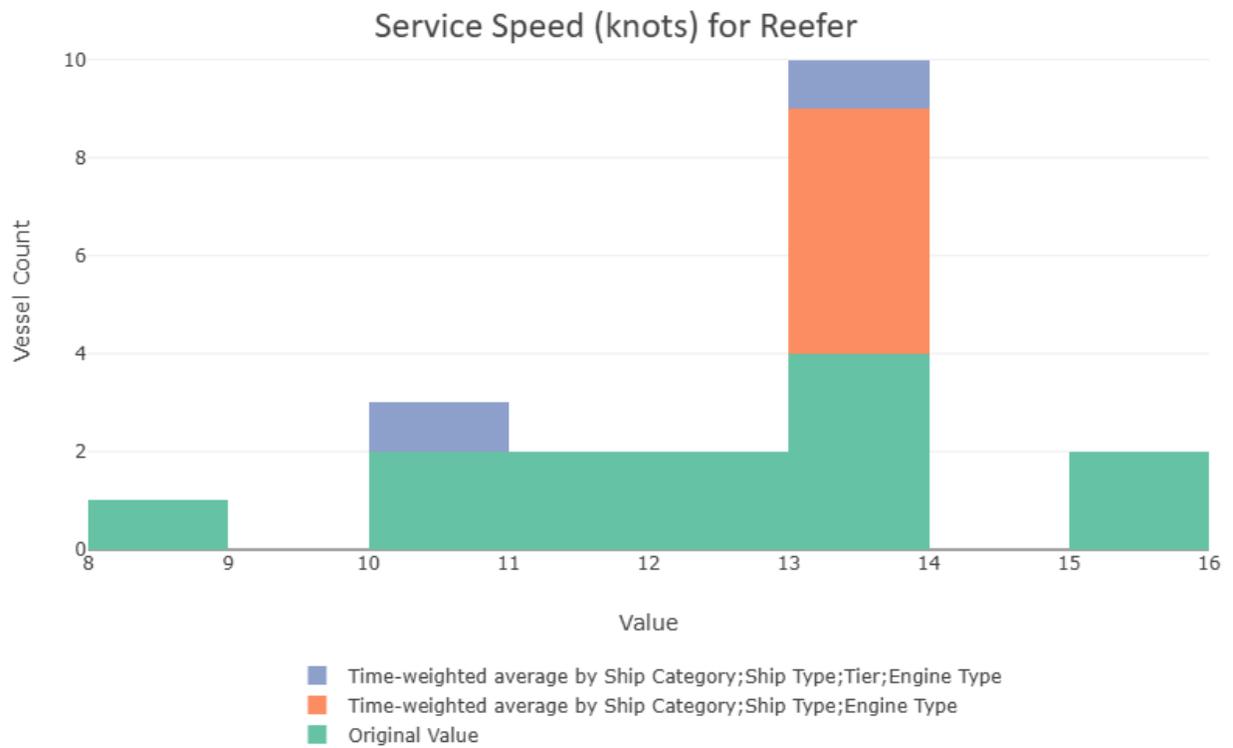
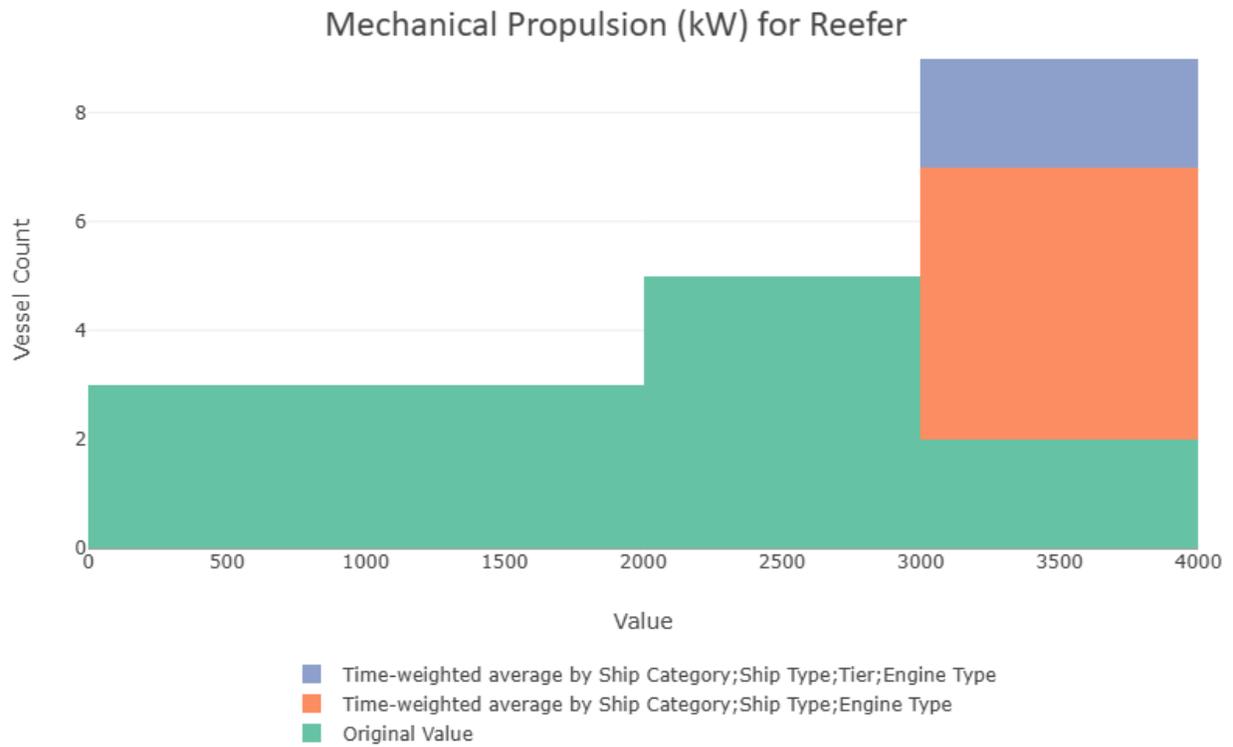
B.2.8 Mechanical Propulsion and Service Speed Surrogate Values for Offshore support



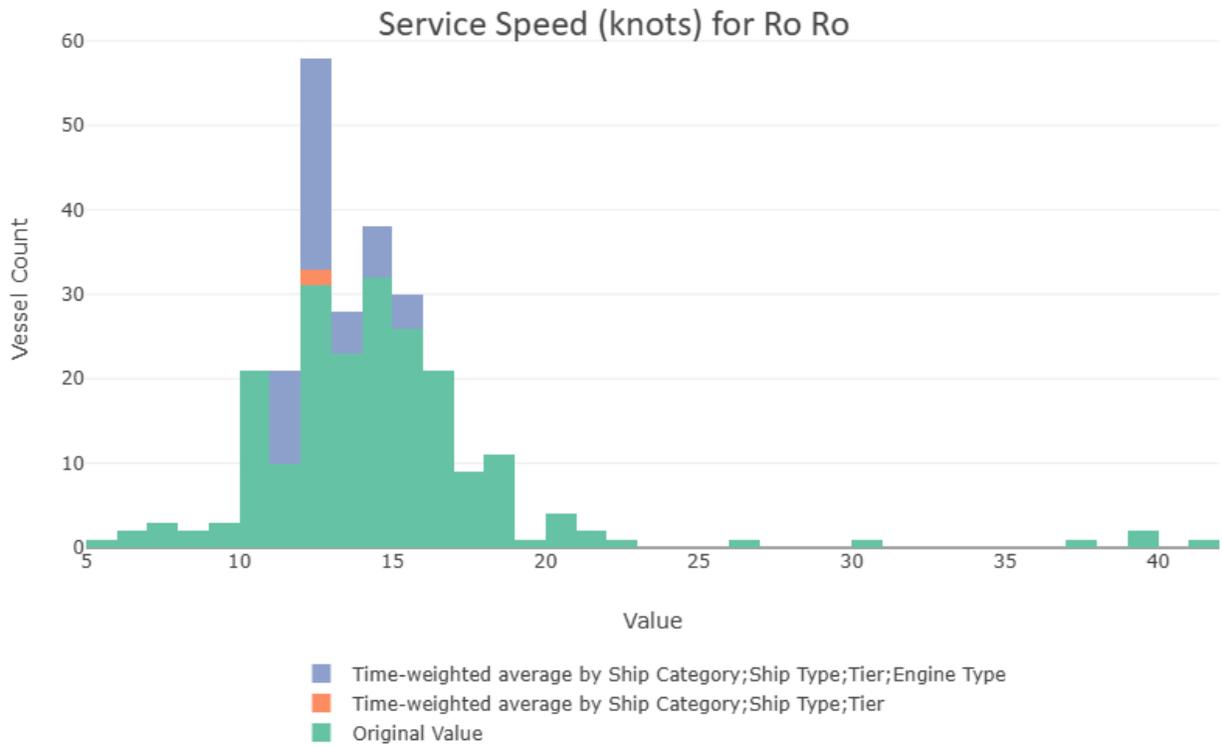
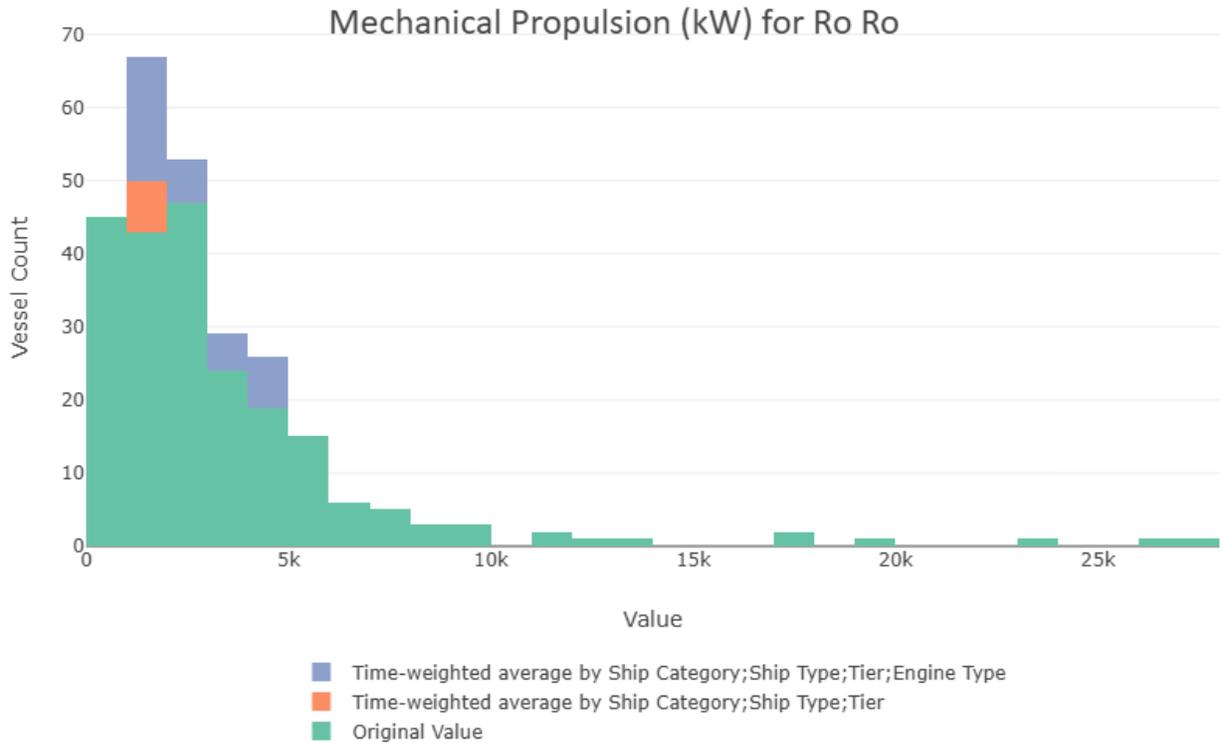
B.2.9 Mechanical Propulsion and Service Speed Surrogate Values for Pilot



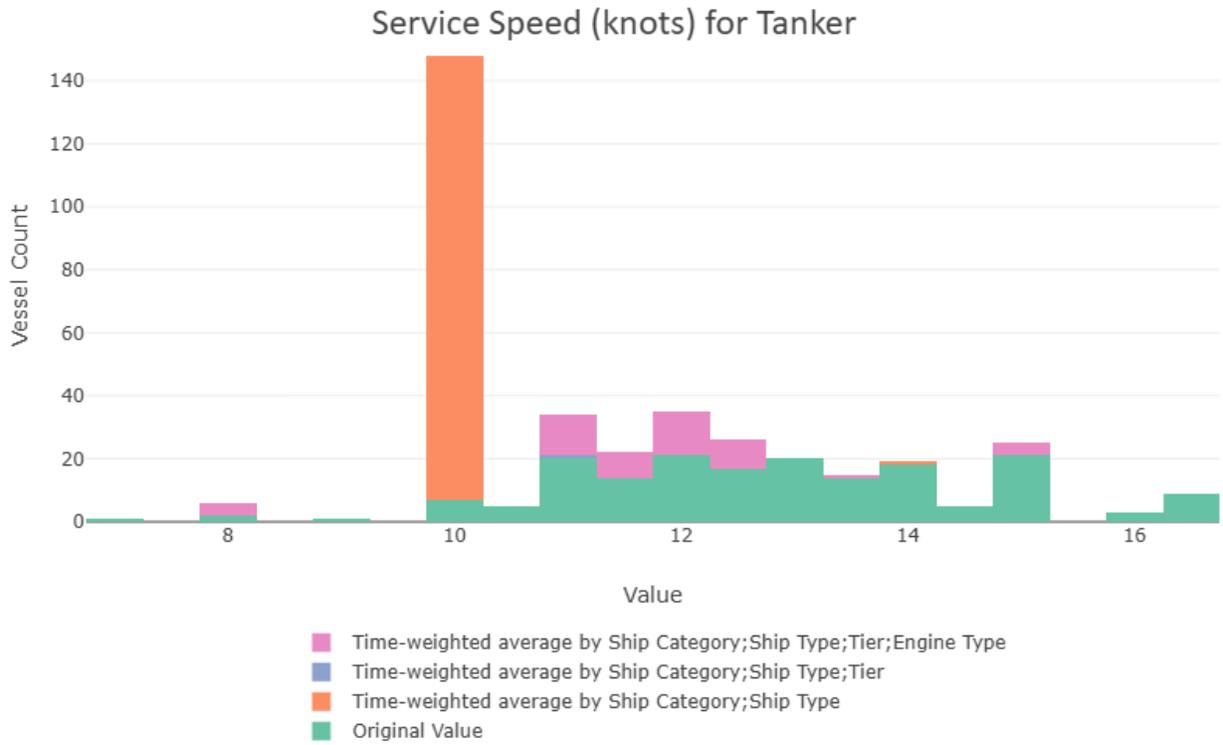
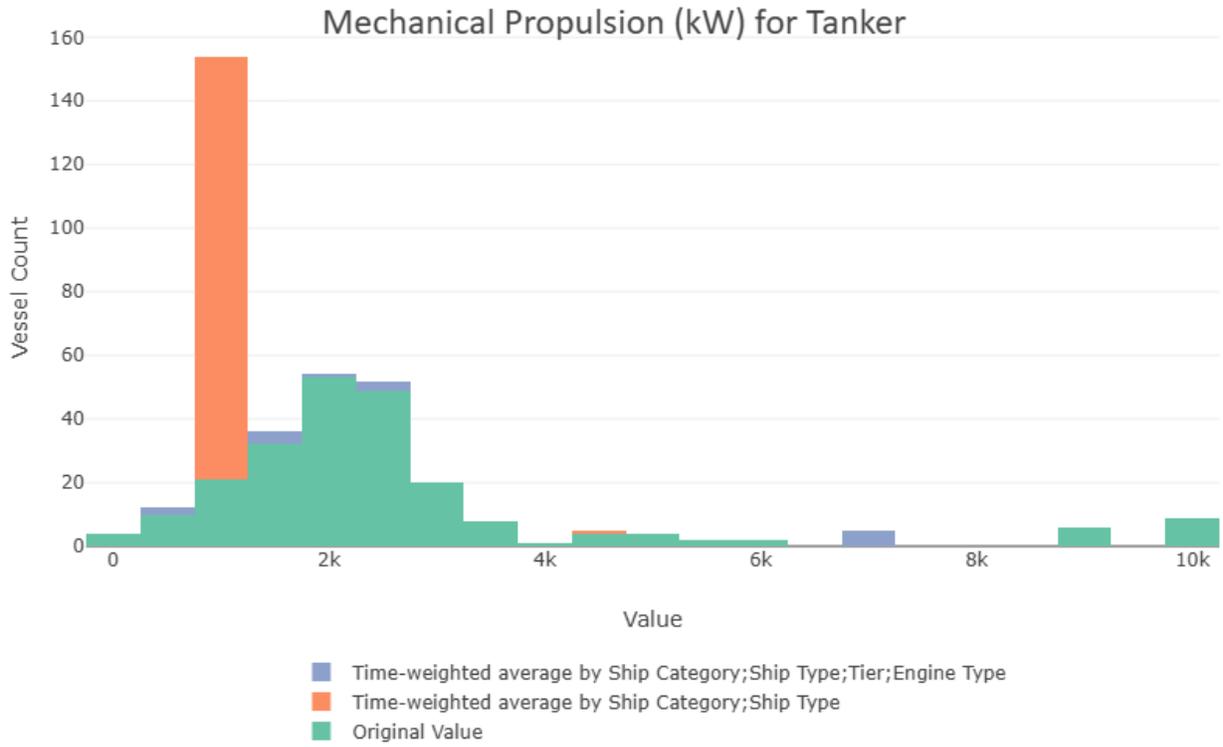
B.2.10 Mechanical Propulsion and Service Speed Surrogate Values for Reefer



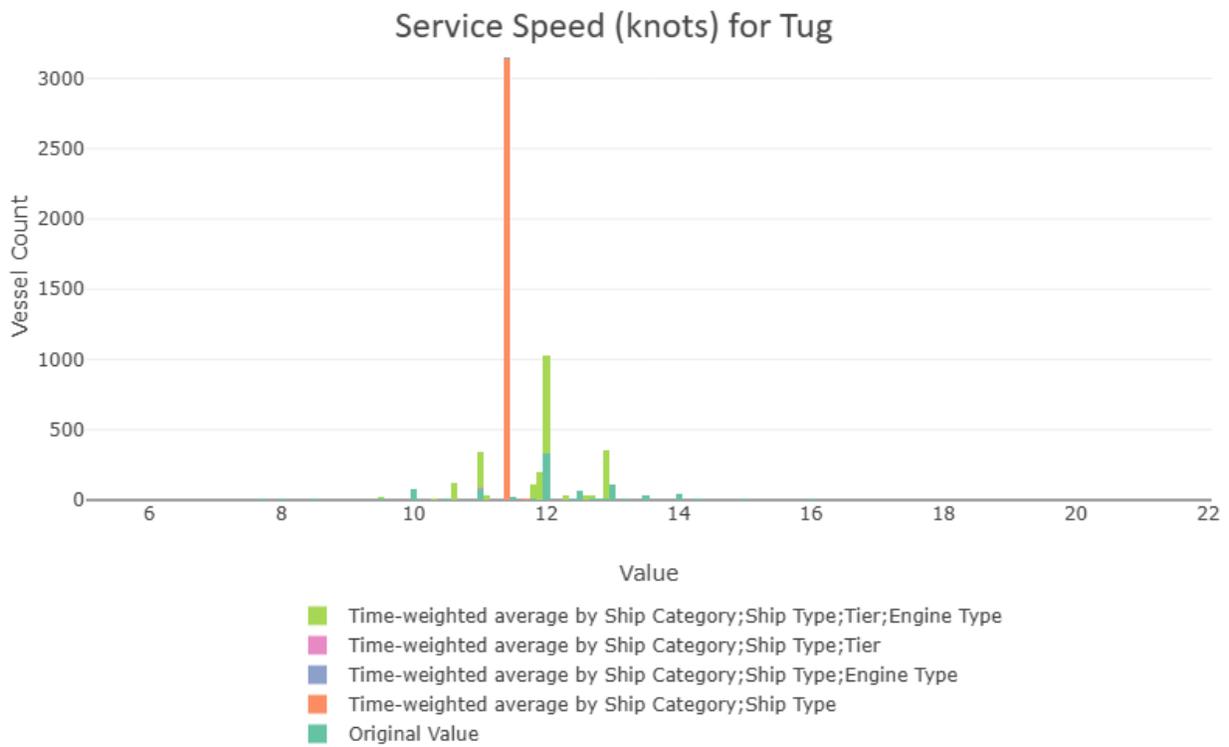
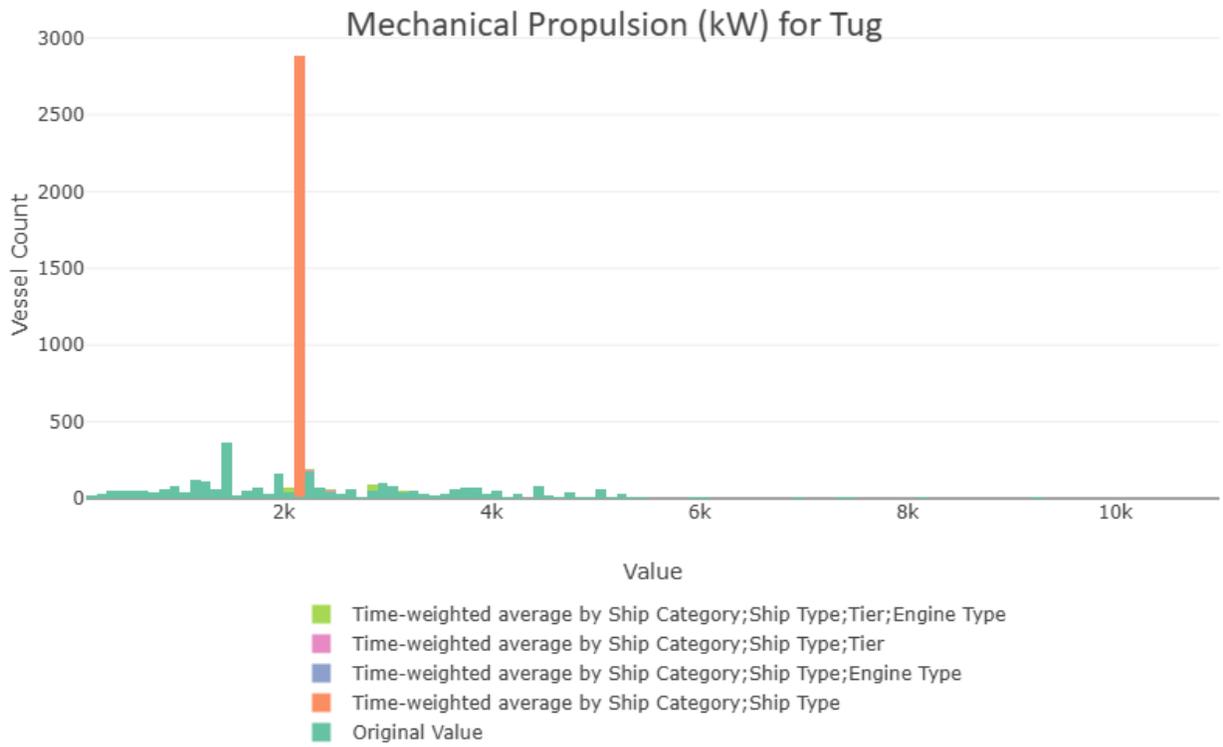
B.2.11 Mechanical Propulsion and Service Speed Surrogate Values for Ro Ro



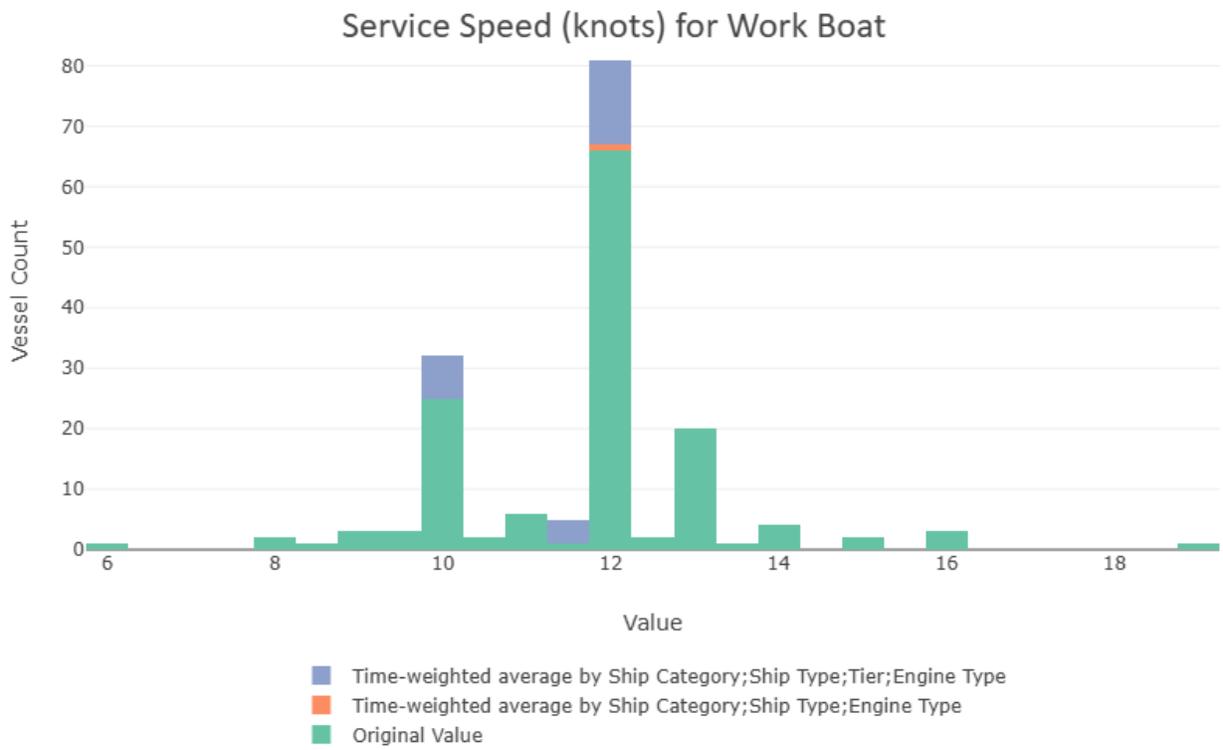
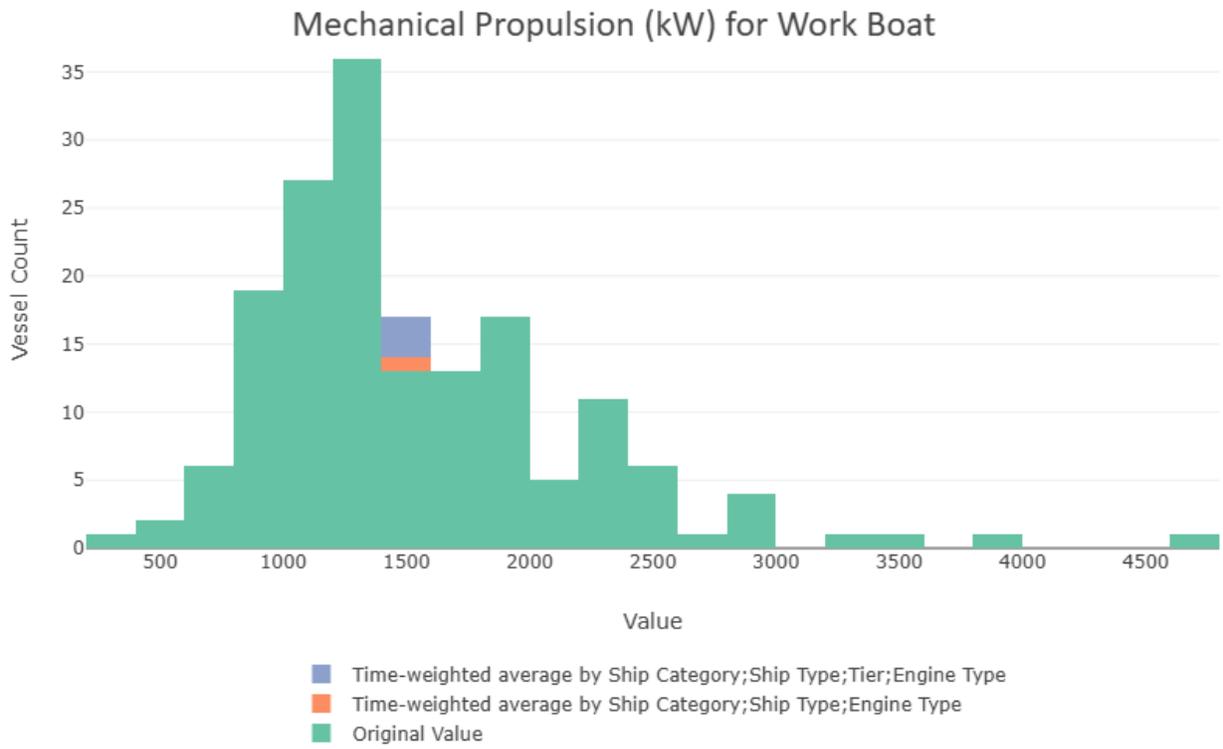
B.2.12 Mechanical Propulsion and Service Speed Surrogate Values for Tanker



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



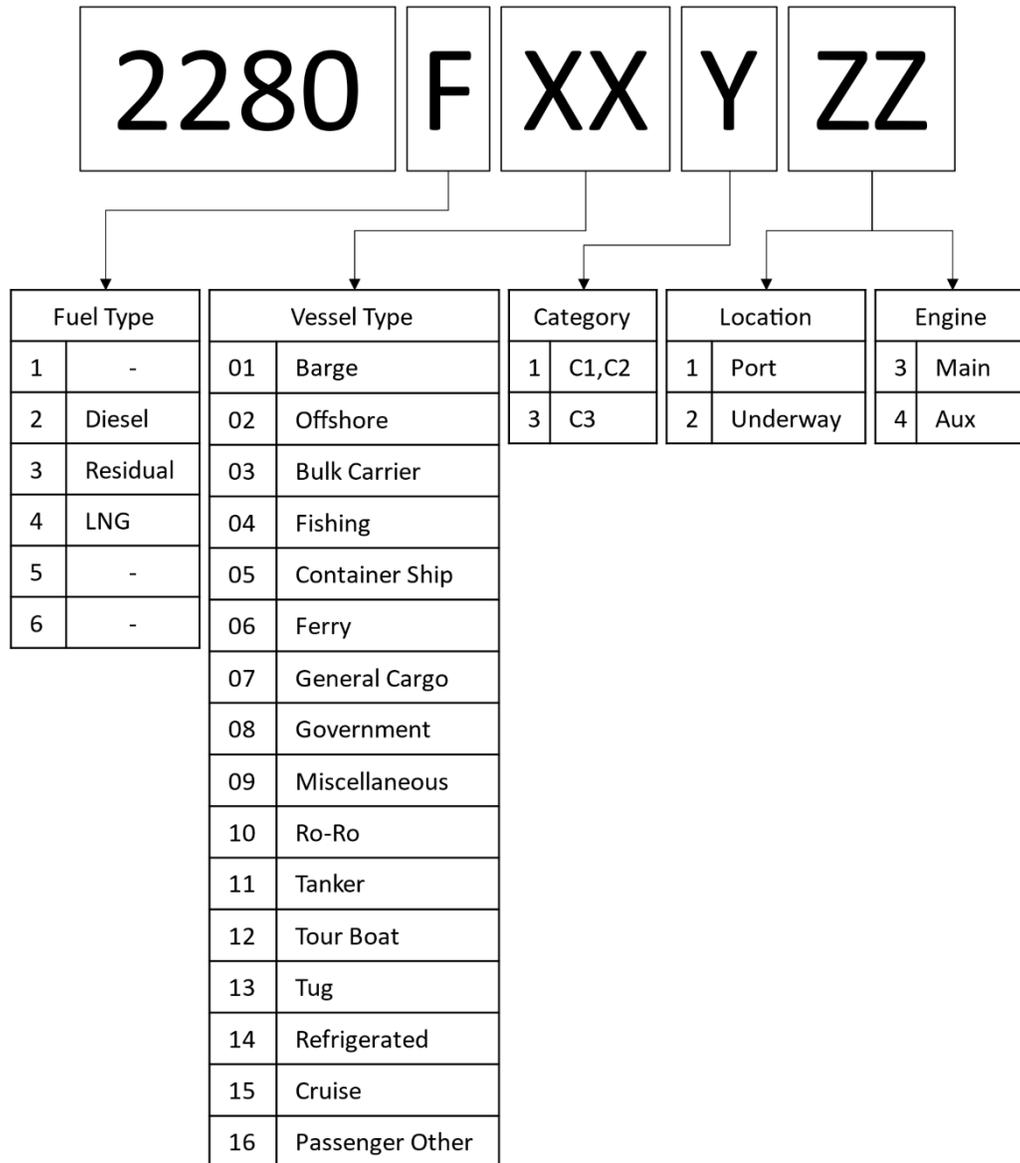
B.2.14 Mechanical Propulsion and Service Speed Surrogate Values for Work Boat



C Emissions By SCC

C.1 CMV SCC Definitions

CMV SCC Decoder



C.2 2023 C1C2 Emissions by SCC

SCC	Fuel	Ship Type	Port/Uway	Main/Aux	CO	CO2	NOX	PM10	PM2_5	SO2	VOC
2280201123	Diesel	Barge	Underway	Main	0	3	0	0	0	0	0
2280201124	Diesel	Barge	Underway	Aux	1	215	3	0	0	0	0
2280202113	Diesel	Offshore	Port	Main	6	3,574	103	4	4	0	14
2280202114	Diesel	Offshore	Port	Aux	1,077	582,235	6,602	166	161	5	230
2280202123	Diesel	Offshore	Underway	Main	1,240	672,017	8,426	225	218	6	424
2280202124	Diesel	Offshore	Underway	Aux	3,052	1,504,610	18,982	482	467	14	613
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	374	161,455	2,362	60	58	1	75
2280203124	Diesel	Bulk Carrier	Underway	Aux	22	21,563	149	5	5	0	5
2280204113	Diesel	Fishing	Port	Main	2	650	18	1	1	0	2
2280204114	Diesel	Fishing	Port	Aux	821	351,108	5,227	132	128	3	152
2280204123	Diesel	Fishing	Underway	Main	567	243,079	4,175	116	112	2	197
2280204124	Diesel	Fishing	Underway	Aux	3,765	1,607,196	23,966	604	586	15	695
2280205113	Diesel	Container Ship	Port	Main	0	105	0	0	0	0	0
2280205114	Diesel	Container Ship	Port	Aux	1	2,933	10	1	0	0	0
2280205123	Diesel	Container Ship	Underway	Main	10	5,131	47	1	1	0	2
2280205124	Diesel	Container 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	13	12	0	14
2280207113	Diesel	General Cargo	Port	Main	13	5,963	106	3	3	0	6
2280207114	Diesel	General Cargo	Port	Aux	278	179,167	1,823	53	51	2	56
2280207123	Diesel	General Cargo	Underway	Main	559	239,237	3,796	100	97	2	142
2280207124	Diesel	General Cargo	Underway	Aux	1,523	982,797	9,977	292	280	9	306
2280208113	Diesel	Government	Port	Main	3	1,419	28	1	1	0	2
2280208114	Diesel	Government	Port	Aux	781	342,171	4,860	122	118	3	142

SCC	Fuel	Ship Type	Port/Uway	Main/Aux	CO	CO2	NOX	PM10	PM2_5	SO2	VOC
2280208123	Diesel	Government	Underway	Main	355	162,126	2,316	61	59	1	94
2280208124	Diesel	Government	Underway	Aux	2,252	967,737	14,183	357	346	9	412
2280209113	Diesel	Miscellaneous	Port	Main	3	1,421	37	1	1	0	4
2280209114	Diesel	Miscellaneous	Port	Aux	372	176,532	2,327	58	56	2	73
2280209123	Diesel	Miscellaneous	Underway	Main	424	211,926	3,061	85	82	2	169
2280209124	Diesel	Miscellaneous	Underway	Aux	1,768	936,129	10,850	275	266	9	389
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	640	304,349	4,070	103	99	3	139
2280210124	Diesel	Ro-Ro	Underway	Aux	172	141,188	1,078	34	32	1	37
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	97	43,095	619	16	15	0	19
2280211124	Diesel	Tanker	Underway	Aux	73	68,555	447	13	13	1	14
2280212113	Diesel	Tour Boat	Port	Main	8	3,715	142	5	5	0	17
2280212114	Diesel	Tour Boat	Port	Aux	540	238,688	3,348	84	82	2	100
2280212123	Diesel	Tour Boat	Underway	Main	672	308,514	5,121	149	144	3	302
2280212124	Diesel	Tour Boat	Underway	Aux	3,073	1,369,751	19,012	476	462	13	565
2280213113	Diesel	Tug	Port	Main	103	58,956	859	26	26	1	82
2280213114	Diesel	Tug	Port	Aux	417	244,378	2,423	61	59	2	94
2280213123	Diesel	Tug	Underway	Main	5,063	2,886,995	33,104	894	867	27	1,972
2280213124	Diesel	Tug	Underway	Aux	2,026	1,269,746	11,712	296	287	12	494
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	1,749	12	0	0	0	0
2280214124	Diesel	Refrigerated	Underway	Aux	3	3,107	16	0	0	0	0
Grand Total					32,338	16,413,432	206,585	5,393	5,227	151	8,082