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Updating the Marine Emissions Resolver

Final Report

RAMBØLL

Updating the Marine Emissions Resolver

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LIST OF ACRONYMS AND ABBREVIATIONS

AIS	Automatic Identification System
C1C2	Category 1 and 2 engines
C3	category 3 engines
CMV	Commercial Marine Vessels
CO_2	carbon dioxide
EI	Emission Inventory
EPA	United States Environmental Protection Agency
GIS	geographic information systems
IHS	The IHS Markit's Sea-web Ships database
IMO	International Maritime Organization
kn	knot
kW	Kilowatt
MARINER	MARINe Emissions Resolver
MMSI	Maritime Mobile Service Identity
MS Excel	Microsoft Excel
NOx	nitrogen oxides
OGV	Ocean Going Vessel
PM	particulate matter
QA	Quality Assurance
SCC	Source Classification Code
SIP	State Implementation Plan
TCEQ	Texas Commission on Environmental Quality
TPD	tons per day
TPY	tons per year
US	United States
VOC	volatile organic compounds

EXECUTIVE SUMMARY

The TCEQ uses the MARINe Emissions Resolver (MARINER) tool to create detailed commercial marine vessel (CMV) emission inventories (EIs). Ramboll updated MARINER to be consistent with the April 2022 EPA Port Emissions Inventory Guidance and expanded the program's usability by adding new reporting options and adding an option to estimate future year emissions that account for fleet turnover and age distribution. Ramboll also conducted a search for publicly available vessel characteristics that could be used to cross-reference data in the MARINER tool, with the goal of decreasing the tool's reliance on default values.

MARINER was updated for consistency with the April 2022 EPA Port Emissions Inventory Guidance with the following changes:

1. NOx emission factors update for C3 vessels' auxiliary engines operating with marine gas oil or marine diesel oil fuel types.

2. Ocean-going vessel transit mode is now defined when speeds are greater than 1 knot (instead of 3 knots).

3. NOx emissions factors update for ocean-going vessels with Tier III propulsion engines operating at low loads.

After MARINER was updated, Ramboll generated a 2019 Texas EI and compared it with an existing EI. Consistent with the updates to items 1 and 3 above, an increase in NOx emissions was observed for ocean-going vessels (OGV) and C3 vessels. The implementation of item 2 leads to emissions differences between maneuvering and transit operating modes for OGV. Carbon monoxide (CO) and other pollutants show very small emission changes overall, usually less than 0.4%.

Ramboll added new reporting options that allow MARINER to generate additional information and emission summary reports. The new options are:

- An option to provide emissions information at hourly intervals.

- An option to provide output emissions at a finer spatial resolution of 1.33 km.

- An option to estimate future year emissions that account for fleet turnover and age distribution following the EPA's port EI 2022 guidance. Activity growth rates are not applied in MARINER.

- An option to generate vessel activity reports by individual vessels that include total hours and nautical miles traveled, aggregated over the computational domain or geopolitical regions defined by FIPS codes.

Ramboll explored several approaches to develop a program ("web crawler") that could automate finding International Maritime Organization (IMO) records and other vessel characteristics based on existing Maritime Mobile Service Identity (MMSI) codes. Although the goal was partly achieved during implementation, a functional program was not developed because many websites, including Google, block this type of automated process or ask for human verification. As a result, Ramboll does not recommend further development of a web crawler, and instead suggests updating and using the most recent versions of the databases MARINER uses, particularly the IHS dataset.

1.0 INTRODUCTION

The MARINe Emissions Resolver (MARINER) tool automates the generation of highly resolved commercial marine vessel (CMV) emissions from Automatic Identification System (AIS) data and vessel characteristics from the IHS Markit (IHS) database. The Texas Commission on Environmental Quality (TCEQ) has used this tool to generate CMV emissions for ozone State Implementation Plans (SIP) attainment demonstrations. Ramboll developed the tool to generate detailed CMV emission inventories (EI) for use in photochemical modeling (TCEQ WO 582-20-12636-017). The tool was later updated to follow the United State Environmental Protection Agency (EPA) September 2020 guidance on the generation of CMV EI that can be easily imported into the air emissions reporting interfaces used by the EPA and TCEQ (TCEQ WO 582-21-11294-001). Finally, new processing options were added, and runtime and memory usage were improved to increase the tool's usability (TCEQ WO 582-22-31220-030).

This report summarizes the changes Ramboll made to MARINER to expand its usability and ensure its consistency with the EPA Port Emissions Inventory Guidance published in April 2022[1]. Chapter 2.0 describes this update and the implementation of these new options: higher spatial and temporal resolution emissions information, ability to estimate future year emissions within the tool and new vessel activity reports by individual vessels. Chapter 3.0 summarizes our findings after conducting a search for publicly available vessel characteristics that could be used to cross-reference data in the MARINER tool. One objective of this task was to decrease the number of mismatched vessel identifiers due to changes in vessel ownership, thus reducing the need to rely on default values.

Each chapter in this report discusses the accomplishments and limitations of the work completed. An updated MARINER User's Guide along with the updated MARINER code were provided to TCEQ as separate deliverables. Any reader interested in more details on hardware and software requirements as well as the general configuration of the tool should consult this user's guide which will not be discussed any further in this report. Finally, Ramboll discusses recommendations for future improvements to MARINER.

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[1] Ports Emissions Inventory Guidance: Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emissions, April 2022, EPA-420-B-22-011, available at https://www.epa.gov/state-and-local-transportation/port-emissions-inventory-guidance

2.0 MARINER MODIFICATIONS

This chapter summarizes the changes made to expand the usability of MARINER and to ensure its consistency with the EPA Port Emissions Inventory Guidance. Ramboll ensured that EI quality is unaffected by these changes by comparing test results with previously generated emissions.

Ramboll implemented the following functionalities as new options to MARINER:

1) An option to provide emissions information at higher temporal resolution. MARINER now can provide emissions output at hourly intervals in addition to the default daily emission outputs

2) An option to provide emissions at a finer spatial resolution of 1.33 km. This allows emissions to be gridded into coarser model grid resolutions when processed through the Emissions Processing System version 3 (EPS3)

3) An option that allows the program to estimate future year emissions that account for fleet turnover and age distribution following the EPA's port EI 2022 guidance. Activity growth rates are not applied in MARINER

4) An option that allows the program to generate vessel activity reports by individual vessels that include total operating hours and travelled nautical miles, aggregated over the computational domain or geopolitical regions defined by FIPS codes

2.1 Updates for Consistency with EPA Port Guidance

MARINER was updated for consistency with the April 2022 EPA Port Emissions Inventory Guidance with the following changes:

1. Updates to NOx emission factors for C3 vessels' auxiliary engines operating with marine gas oil or marine diesel oil fuel types. This corrects EPA's September 2020 guidance that inadvertently reversed the medium-speed and high-speed diesel engine type numbers. In MARINER the input file with emission factors for C3 vessels was updated to reflect this change. For additional details refer to Table 3.5 in the April 2022 EPA Ports Emissions Inventory Guidance.

2. Ocean-going vessel transit mode is now defined when speeds are greater than 1 knot (instead of 3 knots). This change was implemented directly in MARINER's python code. For additional details refer to Table 3.11 in the April 2022 EPA Ports Emissions Inventory Guidance.

3. Updates made to NOx emissions factors for ocean-going vessels with Tier III propulsion engines operating at low loads. Specifically, EPA considers that Tier III propulsion engines operating below 25% load should be assigned the corresponding Tier II emission factor because the exhaust temperature would be too low for the emissions control technologies to work as intended. This change was implemented directly in MARINER's python code. For additional details refer to Table 3.5 in the April 2022 EPA Ports Emissions Inventory Guidance.

Item 1 would cause an increase in C3 vessel NOx emissions because the auxiliary engine NOx emission factors for medium-speed diesel (MSD) engine are supposed to be higher than high-speed diesel (HSD) engine, which were inadvertently reversed in the September 2020 EPA Ports Emissions Inventory Guidance. As MARINER assumes MSD engine type for C3 auxiliary engines, this update fixes the issue and as a result increases auxiliary engine NOx emissions.

Item 2 would result in emissions differences across all pollutants between maneuvering and transit operating modes for ocean-going vessels.

Item 3 would increase NOx emissions for ocean-going vessels with Tier III propulsion engines because Tier II emission factors are higher than Tier III and thus under low loads, switching to Tier II emission factors would increase emissions.

After MARINER was updated, Ramboll generated Texas marine emissions for year 2019 and compared them with an existing inventory from a previous project (TCEQ WO 582-22-31220-030). The existing EI followed the September 2020 EPA Ports Emissions Inventory Guidance. This comparison shows how the emissions change as a result of implementing the updates described above. Table 2-1 summarizes the emissions comparison by ship type. This table confirms that all OGVs—for example, Chemical Tanker and Oil Tanker— experienced increases in NOx emissions. Overall, CO emissions decreased by 0.4%; NOx emissions increased by 6.9%; and PM_{10}, $PM_{2.5}$, SO_2, and VOC decreased by less than 0.1%. Table 2-2 compares OGV's emissions by operating mode. The change in emissions due to the updates in speed of transit mode is not significant in our comparison with the 2019 marine emissions inventory other than NOx, which is also affected by the update in items 1 and 3.The increase over 20% in NOx hoteling emissions is mainly driven by the item 1 update mentioned above.

Table 2-1. Comparison of 2019 annual domain-wide emissions (tons) by vessel type.

Pollutant	CO		NOx		PM$_{10}$		PM$_{2.5}$		SO$_2$		VOC	
Vessel Type	New	Old	New	Old	New	Old	New	Old	New	Old	New	Old
Bulk Carrier (C3)	316	316	3,329	3,020	52	52	47	48	115	115	137	137
Chemical Tanker (C3)	1,659	1,660	17,602	15,451	290	290	266	267	658	659	698	699
Container Ship (C3)	580	582	5,714	5,441	80	80	74	74	183	184	276	277
Crew and Supply	134	134	788	788	16	16	16	16	0.6	0.6	24	24
Cruise (C3)	283	283	3,161	2,885	49	49	45	45	107	107	124	124
Dredge	81	81	461	461	8	8	8	8	0.3	0.3	10	10
Fishing	364	364	2,115	2,115	36	36	35	35	1.1	1.1	43	43
General Cargo (C3)	346	346	3,751	3,270	59	59	54	55	133	133	145	145
Government	0.9	0.9	5	5	0.1	0.1	0.1	0.1	0.004	0.004	0.1	0.1
Harbor Ferry	69	69	356	356	7	7	7	7	0.2	0.2	5	5
Liquified Gas Tanker (C3)	376	376	3,889	3,693	111	111	102	102	289	289	173	173
Miscellaneous (partially C3)	657	681	3,773	3,755	80	80	77	77	10	10	112	112
Offshore Support/Drillship (C3)	7	7	58	48	1.1	1.1	1.0	1.0	3	3	3	3
Oil Tanker (C3)	1,729	1,730	17,977	16,132	471	471	433	433	1,206	1,206	766	766
Other Tanker (C3)	149	149	1,628	1,530	32	32	30	30	78	78	66	66
Pilot	35	50	154	154	4	4	4	4	0.1	0.1	5	5
Reefer (C3)	15	15	173	162	2	2	2	2	5	5	7	7
RORO (C3)	165	165	1,836	1,616	28	28	25	25	62	62	71	71
Towboat/Pushboat	3,601	3,602	19,835	19,837	328	328	318	318	10	10	250	250
Tug Boat	952	957	4,532	4,532	96	96	94	94	4	4	96	96
Work Boat	36	37	212	212	4	4	4	4	0.1	0.1	5	5
Total	**11,555**	**11,605**	**91,347**	**85,461**	**1,754**	**1,755**	**1,643**	**1,643**	**2,865**	**2,866**	**3,015**	**3,018**
Percent Change[a]	**-0.4%**		**6.9%**		**-0.04%**		**-0.04%**		**-0.05%**		**-0.08%**	

[a] Percentage change is calculated as: 100 x (new emissions – old emissions)/old emissions

Table 2-2. **Comparison of 2019 annual domain-wide emissions (tons) by operating mode for OGVs.**

Operating Mode	Hoteling			Maneuvering			Transit		
Pollutant	New	Old	Percent Change[a]	New	Old	Percent Change[a]	New	Old	Percent Change[a]
CO	2,370	2,370	0%	817	817	0%	2,438	2,443	-0.2%
NOx	24,775	20,145	23.0%	6,992	6,205	12.7%	27,351	26,897	1.7%
PM$_{10}$	709	709	0%	121	121	0%	345	345	-0.2%
PM$_{2.5}$	652	652	0%	111	111	0%	317	318	-0.2%
SO$_2$	1,834	1,834	0%	300	300	0%	706	707	-0.2%
VOC	959	959	0%	413	413	0%	1,094	1,096	-0.2%

[a] Percentage change is calculated as: 100 x (new emissions – old emissions)/old emissions

2.2 Emissions at Hourly Intervals

This new option generates emissions at hourly intervals. This is an addition to the default daily average-day emissions. When this option is turned on, MARINER will output both daily and hourly emissions. Emissions are aggregated at hourly intervals in the spatial processing step and are written as EPS3 PRESHP input files. Figure 2-1 shows an example hourly output file, with the red box highlighting the period type (S = Special Interval; left column) and the start (middle column) and end (right column) hour (yymmddhh format) for each emissions record (per row). To invoke this option in the configuration file, the user must set the following variable to True:

```
HOUR_EMIS = True
```

```
85003      228000CRTH  OilTanker  S 20070100 20070101   54.000  -1390.0   0.001    54.000  -1390.0   0.001  0 42603 0.02278311
85003      228000CRTH  OilTanker  S 20070101 20070102   54.000  -1390.0   0.001    54.000  -1390.0   0.001  0 42603 0.02813291
85003      228000CRTH  OilTanker  S 20070102 20070103   54.000  -1390.0   0.001    54.000  -1390.0   0.001  0 42603 0.02678616
85003      228000CRTH  OilTanker  S 20070103 20070104   54.000  -1390.0   0.001    54.000  -1390.0   0.001  0 42603 0.02675639
85003      228000CRTH  OilTanker  S 20070104 20070105   54.000  -1390.0   0.001    54.000  -1390.0   0.001  0 42603 0.02678616
85003      228000CRTH  OilTanker  S 20070105 20070106   54.000  -1390.0   0.001    54.000  -1390.0   0.001  0 42603 0.02680104
85003      228000CRTH  OilTanker  S 20070106 20070107   54.000  -1390.0   0.001    54.000  -1390.0   0.001  0 42603 0.02678616
85003      228000CRTH  OilTanker  S 20070107 20070108   54.000  -1390.0   0.001    54.000  -1390.0   0.001  0 42603 0.02677872
85003      228000CRTH  OilTanker  S 20070108 20070109   54.000  -1390.0   0.001    54.000  -1390.0   0.001  0 42603 0.02680104
85003      228000CRTH  OilTanker  S 20070109 20070110   54.000  -1390.0   0.001    54.000  -1390.0   0.001  0 42603 0.02678616
.
.
```

Figure 2-1. **Example EPS3 PRESHP input file with emissions at hourly intervals. Red box highlights the new format for hourly intervals.**

Table 2-3 compares the default daily average to hourly emissions—both aggregated for the month of August 2019—for NOx and VOC by FIPS. As expected, the emissions are identical in practice, with statewide differences of less than 1×10^{-5} tons aggregated over a month.

Table 2-3.   Comparison of NOx and VOC emissions (tons) for average daily output and hourly output, aggregated in both cases for August 2019.

State	FIPS	County Name	NOx Daily	NOx Hourly	VOC Daily	VOC Hourly
TX	48007	Aransas	55	55	2	2
TX	48039	Brazoria	172	172	7	7
TX	48057	Calhoun	81	81	3	3
TX	48061	Cameron	24	24	1	1
TX	48071	Chambers	200	200	11	11
TX	48167	Galveston	721	721	40	40
TX	48201	Harris	823	823	50	50
TX	48245	Jefferson	392	392	22	22
TX	48261	Kenedy	13	13	0.3	0.3
TX	48273	Kleberg	6	6	0.1	0.1
TX	48321	Matagorda	134	134	4	4
TX	48355	Nueces	242	242	16	16
TX	48361	Orange	135	135	7	7
TX	48409	San Patricio	28	28	2	2
TX	48469	Victoria	2	2	0.1	0.1
TX	48489	Willacy	6	6	0.1	0.1
TX	n/a	Others[2]	0.02	0.02	0.001	0.001
TX	n/a	**Statewide Total Emissions**	**3,035**	**3,035**	**166**	**166**
TX	n/a	**Difference in Emissions**	**2×10^{-6}**		**9×10^{-6}**	
Outside TX	85000	US Water	3,740	3,740	302	302
Outside TX	n/a	Others[3]	591	591	26	26
All	**n/a**	**Total Emissions**	**7,366**	**7,366**	**495**	**495**

2.3   Emissions at a Finer Spatial Resolution

MARINER uses a polygon shapefile to define the horizontal resolution for the emissions output. Before the updates in this project, the shapefile represented a 4 km resolution modeling grid. A new shapefile with a 1.33 km modeling grid was created to represent emissions at a finer spatial resolution. The finer emissions can also be aggregated into coarser modeling grid resolutions when processed through EPS3.

[2] Other Texas counties had less than 1 ton of NOx and VOC emissions during August 2019.

[3] Includes Alabama, Louisiana, Oklahoma, Mexico, and International Water

The user can change the modeling grid by specifying the GRIDFILE parameter in the configuration file. An example of the path to the shapefile is shown in Figure 2-2.

```
# specify path to shapefiles (spatial gridding and sea margin)
GRIDFILE = '/disk8/TCEQ_Mariner/devel/GIS/srcmap/fishnet_1333m_FIPS_clean.shp'
```

Figure 2-2. Example of the grid shapefile path within the configuration file.

Ramboll conducted two sets of MARINER runs for the year 2019 to test the runtime and emissions differences between the 1.33 and 4 km modeling grids. Table 2-4 compares for both grids, the runtime to execute the spatial gridding step in MARINER. The table shows that using the 1.33 km modeling grid increased the runtime in four out of the six bi-monthly test runs, while the January – February test run experienced a decrease in runtime. The runtime for the September – October run is almost the same for both grids.

Table 2-4. Comparison of runtime between the 1.33 km and the 4 km modeling grid for the spatial gridding step.

MARINER 2019 Run	1.33 km Case Runtime (minutes)	4 km Case Runtime (minutes)	Runtime Ratio[a]
January - February	68.9	87.7	0.8
March - April	110.5	56.5	2.0
May – June	102.4	67.0	1.5
July - August	105.8	86.2	1.2
September - October	75.5	77.6	1.0
November – December	126.8	61.6	2.1

[a] Runtime Ratio is defined as the ratio of the runtime of 1.33 km case to that of the 4 km case

FIPS codes were assigned to each grid cell based on the location of the center of the grid cell. This may cause some grid cells along the county boundary to have different FIPS codes between the 4 km and 1.33 km modeling grids. Table 2-5 compares the NOx and VOC emissions by FIPS from the 2019 annual run with 1.33 km and 4 km modeling grids. For NOx emissions, the most noticeable difference is in San Patricio County, followed by Orange County and Chambers County. San Patricio County, close to the Port of Corpus Christi, borders US water. Similarly, Orange County has Sabine Lake and borders with Louisiana; Chambers County is close to the Port of Galveston and borders with US waters. All these counties have relatively higher vessel activities compared to inland counties, and thus different FIPS assignments can lead to more evident discrepancies in emissions. VOC emissions have a similar trend. Overall, the difference in total state-wide emissions is very small.

Table 2-5.   Comparison of 2019 annual NOx and VOC emissions (tons) between 1.33 and 4 km grids

State	FIPS	County Name	NOx 1.33 km	NOx 4 km	VOC 1.33 km	VOC 4 km
TX	48007	Aransas	660	634	12	13
TX	48039	Brazoria	2,192	2,194	46	46
TX	48057	Calhoun	1,010	1,000	16	16
TX	48061	Cameron	272	274	7	7
TX	48071	Chambers	2,118	2,335	59	67
TX	48167	Galveston	8,815	8,873	243	242
TX	48201	Harris	11,127	10,913	320	314
TX	48245	Jefferson	5,276	5,003	138	135
TX	48261	Kenedy	164	164	2	2
TX	48273	Kleberg	80	76	1	1
TX	48321	Matagorda	1,509	1,521	22	22
TX	48355	Nueces	3,150	3,000	99	92
TX	48361	Orange	1,614	1,789	44	47
TX	48409	San Patricio	188	381	6	13
TX	48469	Victoria	28	29	0.5	0.5
TX	48489	Willacy	65	70	0.9	0.9
TX	n/a	Others[a]	0.3	0.4	0.01	0.01
TX	n/a	**Statewide Total Emissions**	**38,269**	**38,257**	**1,016**	**1,018**
TX	n/a	**Difference in Emissions**	**11**		**-2**	
TX	n/a	**% Difference in Emissions**	**0.03%**		**-0.2%**	
Outside TX	85003	US Water	46,268	46,219	1,842	1,839
Outside TX	n/a	Others[b]	6,811	6,871	157	158
All	n/a	**Total Emissions**	**91,347**	**91,347**	**3,015**	**3,015**

[a] Other Texas counties with NOx and VOC emissions less than 1 ton/year
[b] Includes Alabama, Louisiana, Oklahoma, Mexico, and International Water

To illustrate the effects of the emissions represented with the higher grid resolution at 1.33 km, Ramboll generated plots to compare the difference between the two modeling grids. Figure 2-3 shows the gridded NOx emissions with the 4 km modeling grid for Galvenston Bay, part of the Houston-Galveston-Brazoria (HGB) ozone nonattainent area. Figure 2-4 is the corresponding plot with the 1.33 km modeling grid. It is evident that the new 1.33 km data is significantly better to resolve the spatial distribution of emissions and that vessel movements are represented more realistically.
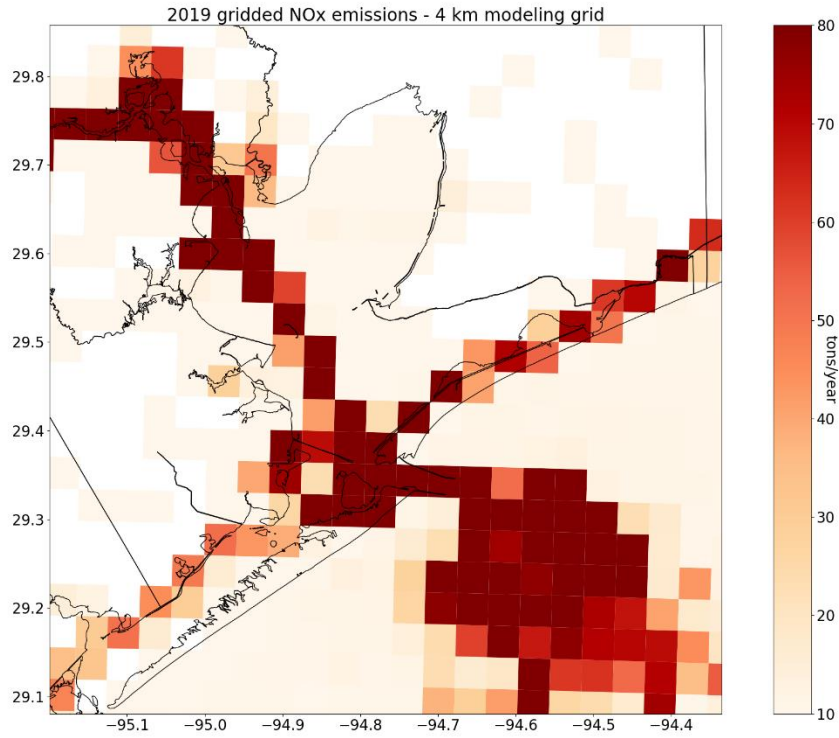
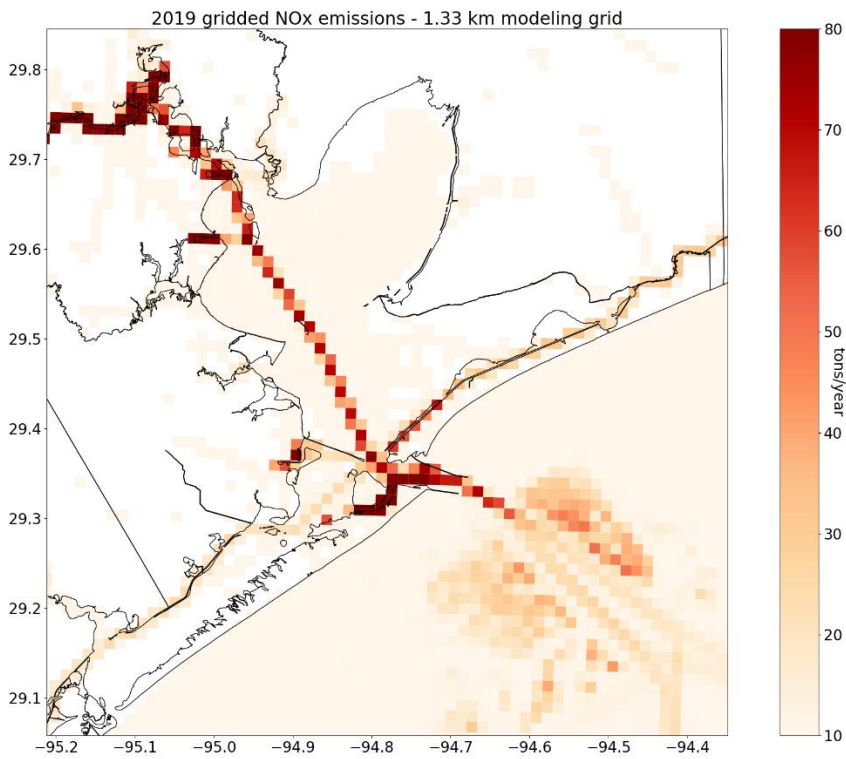**Figure 2-3.   2019 NOx emissions by 4 km modeling grid at Galveston Bay.**

Figure 2-4.   2019 NOx emissions by 1.33 km modeling grid at Galveston Bay.

2.4 Future Year Emissions

This new option generates future year emissions that account for fleet turnover to newer and cleaner engines. MARINER does this by getting a new set of vessel keel-laid dates for the future year inventory. The vessel keel-laid dates are adjusted by adding the difference between the future and base years to each keel-laid date used in the base year inventory. For example, if the base year inventory represents 2020 and the projected inventory represents 2030, the difference of 10 years is added to each keel-laid year. Then, emission factors are reassigned to all vessels using the adjusted keel-laid dates. The activity data is the same as the base year AIS data. Activity growth rates will be applied in the EPS3 emissions processing to account for future year activity outside of MARINER.

To turn on this option in the configuration file, the user must set the following variable to a future year, for example:

```
FutureYear = 2032
```

To turn off this option, the user must set `FutureYear` to False. Ramboll generated a 2032 January to February Texas EI and compared it with the 2019 EI mentioned in Section 2.1. Table 2-6 compares emissions by vessel category (between OGV and Harbor Craft). Most of the emissions changes are associated with reassigned emission factors. For OGVs, NOx emissions decrease by 57% while other pollutants' emissions are unchanged. This is reasonable because, among the emissions factors, only NOx emission factors are associated with engine year or tiers. For harbor craft, almost all pollutants' emission factors are associated with engine tiers except SO_2. Therefore, the emissions are lowered for all pollutants except SO_2.

Table 2-6.   Comparison of 2019 and 2032 January to February emissions (tons) by vessel category.[4]

Operating Mode	OGV			Harbor Craft		
Pollutant	2019	2032	Percent Change[a]	2019	2032	Percent Change[a]
CO	876	876	0%	887	826	-6.8%
NOx	9,241	3,963	-57.1%	4,843	3,445	-28.9%
PM_{10}	184	184	0%	86	73	-15.8%
$PM_{2.5}$	169	169	0%	84	70	-15.8%
SO_2	444	444	0%	3	3	0%
VOC	384	384	0%	79	62	-21.6%

[a] Percentage change is calculated as 100 x (2032 emissions – 2019 emissions)/2019 emissions

2.5 Vessel-Specific Activity Report

MARINER already generated vessel activity reports that aggregate vessel activity by domain and by FIPS. This functionality was expanded to also generate activity by individual vessels. The vessel-specific activity information is useful because it allows a more in-depth inspection of the vessel activity levels.

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[4] Percentage difference is calculated as (2032 emissions – 2019 emissions)/2019 emissions.

MARINER was modified with a group of new functions that first read the activity feather[5] files and then extract relevant vessel identification information used in the report such as MMSI, IMO, and vessel name. When the vessel activity by FIPS is needed, an additional step is required to intersect the AIS activity data with a shapefile to add the FIPS information. This shapefile is the same as the one used for spatial gridding in the spatial processing step. In the final step, the data is aggregated to the level described below.

This option is available and will generate reports if the steps to calculate activity and determine vessel classes are completed. It also outputs the aggregated activity report by vessel type. To turn on this option in the configuration file, the user must set the following variable to false:

SKIP_ACTIVITY_REPORT = False

The reports are generated in CSV format and can be easily imported into other programs for further reporting or analysis. The period is indicated in the file name. Figure 2-5 shows an example report for the vessel activity by domain. The information by domain summarizes the vessel activity over the spatial domain defined by the user to run MARINER. The file contains the following seven columns:

VesselType   Vessel type identification code
MMSI   Maritime Mobile Service Identity value
IMO   International Maritime Organization Vessel number (if available)
VesselName   Name as shown on the station radio license
Speedbin   Speed bin. Vessel speeds are classified as:
        1 if speed is less than or equal to 1 knot
        2 if speed is larger than 1 knot or less than or equal to 3 knots
        3 if speed is larger than 3 knots
Hour   Total number of hours in the run period
NauticalMile   Total number of nautical miles in the run period

```
VesselType,MMSI,IMO,VesselName,SpeedBin,Hour,NauticalMile
30,368135990,0,CAPTAIN SCOTT,1,0.581111111111111,0.3999389070518997
30,368135990,0,CAPTAIN SCOTT,2,16.554722222222253,51.52717503177525
30,368135990,0,CAPTAIN SCOTT,3,6.83666666666669,23.891181309225026
30,368139450,0,GULF WHALE,1,2.3938888888888887,1.9869979004441831
30,368139450,0,GULF WHALE,2,14.158888888888905,42.84406790359813
30,368139450,0,GULF WHALE,3,7.40944444444445,40.76132384413669
30,368149610,0,LUCKY T & H,1,11.499722222222228,0.24310789553001644
82,219151000,9422665,NORDIC ANN,2,0.14805555555555555,0.4105990634521286
82,219151000,9422665,NORDIC ANN,3,16.58277777777779,251.25263842319828
51,368926011,0,S3008,1,0.09972222222222223,0.0006890907641258891
.
.
```

Figure 2-5.   Example domain-wide vessel-specific activity report.

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[5] Feather is a portable file format for storing data frames that utilizes the Arrow IPC format internally. For additional information refer to https://arrow.apache.org/docs/python/feather.html

Figure 2-6 shows an example report for vessel activity by FIPS. The information is very similar to the report by domain except that an additional column (FIPS) defines the applicable geopolitical region for each data record.

```
VesselType,MMSI,IMO,VesselName,SpeedBin,SCFIPS,Hour,NauticalMile
30,368135990,0,CAPTAIN SCOTT,2,85003,16.55472222222224,51.52717503177533
30,368135990,0,CAPTAIN SCOTT,3,85003,6.836666666666691,23.891181309225036
30,368139450,0,GULF WHALE,1,85003,2.3938888888888883,1.9869979004441827
30,368139450,0,GULF WHALE,2,85003,14.158888888888903,42.84406790359813
30,368139450,0,GULF WHALE,3,85003,7.409444444444463,40.76132384413668
30,368149610,0,LUCKY T & H,1,48167,11.499722222222225,0.24310789553001633
82,219151000,9422665,NORDIC ANN,2,85003,0.14805555555555555,0.4105990634521286
82,219151000,9422665,NORDIC ANN,3,85003,15.195833333333367,228.517324733236
82,219151000,9422665,NORDIC ANN,3,98INT,1.3869444444444445,22.735313689962368
51,368926011,0,S3008,1,48167,0.09972222222222223,0.0006890907641258891
.
.
```

Figure 2-6.   Example vessel activity report by FIPS.

3.0 WEB SEARCH RESULTS AND PLAN OF APPLICATION

3.1 Background

MARINER calculates emissions based on vessel characteristics. The tool relies on the AIS database[6] to estimate the engine power of vessels during their instantaneous operations. MARINER estimates engine load and emissions when it matches the Maritime Mobile Service Identity (MMSI) code—which is specific to the transponder installed on a given vessel—with a specific set of vessel characteristics. While there are a few databases with complete information on design characteristics for large and some small commercial vessels, MARINER currently uses a snapshot of the IHS Sea-web dataset circa 2020. IHS uses unique International Maritime Organization (IMO) identification codes[7] to cross-reference with MMSI records, except when there are no IMO records. One objective of this task was to find an efficient process that searches for publicly available information to fill in missing IMO records and necessary vessel characteristic data to supplement the IHS database.

A motivation for this task arose from our prior experience conducting manual internet searches to find missing IMO records for large vessels with Category 3 propulsion engines with known MMSI codes listed in the AIS database. Without this additional information, the vessels would get assigned default characteristics in the emissions calculations, which is less accurate. The MMSI for a vessel can change for multiple reasons, but since the IMO cross-reference remains the same, this makes it valuable to find the IMO records through public reporting of existing vessels or from the builders' and owners' websites, especially for new vessels built after the IHS version currently used in MARINER.

Finding information for smaller commercial vessels with Category 1 and 2 propulsion engines requires a more involved and time-consuming search strategy. While smaller commercial vessels can have IMO codes if the owners need to register the vessel for international activities, they are often used exclusively within US territorial waters and registered only with the US Coast Guard (USCG). For vessels without IMO numbers, MARINER estimates emissions by assigning a default engine power based on vessel type. These vessels serve various purposes such as tug, tow (also known as "push boat"), offshore support, dredge, excursion, ferry, fishing, research, and others identified by AIS data. Online data for these smaller commercial vessels is available if the vessel builders, fleet owners, or other entities publish vessel specifications. However, relying on the vessel name recorded in the AIS data to search for engine power specifications is often unreliable as owners commonly change vessel names to ordinary ones. Furthermore, finding engine power data for smaller vessels through internet searches requires additional effort, as the information is usually reported in non-standard forms or is in links or sub-tabs within a website.

3.2 Web Crawler Implementation

This section summarizes Ramboll's approach to implementing the search strategies described above for the large Category 3 vessels. Ultimately a program that automates these internet searches was not developed because many websites, including Google,

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[6] AIS Data Fields: MMSI, Date and Time, Latitude, Longitude, Speed over Ground (SOG), Course over Ground (COG), Heading, Vessel Name, IMO, Call Sign, Vessel Type, Status, Length, Width, Draft, Cargo, Transceiver Class

[7] The IMO number's purpose is to assign a permanent number for identification purposes to each company and/or registered owner managing ships of 100 gross tonnage and above engaged on international voyages."
https://www.imo.org/en/ourwork/msas/pages/imo-identification-number-scheme.aspx

prevent this type of automated process or ask for human verification, which defeats the purpose of the program. Since we did not develop a search strategy program for the large vessels, we did not attempt to implement one for smaller vessels.

The search strategy was based on finding IMO records given a set of MMSI codes. The search strategy also included engine power, draft, and other vessel characteristics if the information was available on major ship tracking websites. These are the approaches used to implement the search strategy:

vesseltracking.net

In the first approach, a Python program was coded to get data from a ship and container tracking website: vesseltracking.net. This website provides searching by vessel name, IMO, or MMSI and the website's Uniform Resource Locator (URL) contains the MMSI of interest in its character string. Therefore, the Python program could simply modify the URL with an MMSI missing IMO records and then obtain this and many other vessel characteristics. While this was a successful approach initially, after more than a few attempts searching for information, the website determined our code to be a potentially harmful bot and blocked our internet protocol (IP) address, preventing us from making further requests.

Selenium

In the second approach, a Python module called Selenium[8] was used to avoid IP address being blocked as we performed many consecutive URL requests, which websites identified as coming from a potentially harmful bot. Selenium allows Python code to automate web browser interactions, which in this case was used to control a developmental web browser (Chrome). The objective was to automate the use of a virtual mouse and keyboard to navigate to a web browser search bar, type ship information, and finally press enter to complete the search. Unfortunately, many websites are designed with CAPTCHA[9] tests and are able to distinguish between human and crawler interactions. While the program was never barred from a website, the search results were not adequate and were mostly useless for our purpose.

Google API

The last approach relied on Google's official application programming interface (API) tool.[10] The Google API allows the user to create a custom search tool, that can be accessed remotely by "calling" the API and receiving in return a JavaScript Object Notation (JSON) file. The JSON file has the search results and needs to be parsed to extract the relevant information. While this approach may have provided the needed vessel characteristics, the API has a limit of only 100 searches/records per day. Since the search was expected to look over 1,000 MMSI records, this could have taken several days using the API, and ultimately the approach was impractical. No useful data was obtained from these partial tests because we did not spend any further time trying to parse the JSON file—which would have taken a significant effort—due to the searches limit described above and also because the Google API will likely be phased out soon.

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[8] Selenium: https://pypi.org/project/selenium/

[9] CAPTCHA: https://en.wikipedia.org/wiki/CAPTCHA

[10] Google Search API: https://developers.google.com/custom-search/v1/introduction

3.3   Conclusions

Ramboll explored several approaches to develop a program that could automate finding IMO records and other vessel characteristics based on existing MMSI identification codes. Although Ramboll was able to partly achieve this during our implementation, a functional program could not be developed because many websites, including Google, block this type of automated process or ask for human verification. As a result, Ramboll does not recommend further development of a web crawler, and instead suggests updating and using the most recent versions of the databases MARINER uses, particularly the IHS dataset.

4.0 RECOMMENDATIONS

The following aspects should be considered for future improvements to MARINER:

- Developing a finer spatial resolution shapefile, for instance, 0.44 km, to have an even more detailed representation of vessel emissions for geographically constrained areas such as the Houston Ship Channel.

- Adjusting the distribution of vessel subtypes from the base year to future years to account for expected changes in vessel sizes in the future year inventory.

- Accounting for any planned actions, such as emission reduction strategies or anticipated controls, that could affect future emissions. This could be implemented as a new feature in MARINER.

- Improving memory management to allow MARINER runs for longer periods in the TX domain including all vessels, i.e., more than two months. Currently, memory issues can occur when processing vessel type 31 (Towboat/Pushboat) because this vessel type has the most activity records and thus large memory requirements that make MARINER stop execution occasionally.

- Ramboll does not recommend further development of a web crawler, and instead suggests updating and using the most recent versions of the databases MARINER uses, particularly the IHS dataset.

5.0 REFERENCES

EPA, 2020. "Port Emissions Inventory Guidance: Methodologies for Estimating Port-related and Goods Movement Mobile Source Emissions", U.S. Environmental Protection Agency, Office of Transportation Air Quality, September 2020, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10102U0.pdf . . Accessed on March 16, 2022.

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