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Enhance MARINER Tool for Commercial Marine Emission Inventories

Final Report

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Final Report

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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 HIS Markit's Sea-web Ships database
IMO	International Maritime Organization
kn	knot
kW	Kilowatt
MARINER	MARINe Emissions Resolver
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 expanded the usability of MARINER by adding new reporting options and improving processing efficiency. We also improved accuracy by updating "gap-filling" methods, which are needed when individual data cannot be found for a particular vessel, to make them more representative of vessels found within Texas waters.

The CMV EI includes two major types of marine sources: 1) Ocean-Going Vessels (OGV) and 2) harbor craft. We used an activity-weighting scheme to update the gap-filling defaults for OGV with activity characterized using carbon dioxide (CO_2) emissions estimated from fuel consumed by vessels within the Texas domain. For the harbor craft, Ramboll performed a literature review to find Texas-specific information that could be used to update defaults from the Environmental Protection Agency (EPA), but only found data for the fishing fleet. After updating the gap-filling defaults for both OGV and harbor craft, a 2019 Texas EI was generated and compared with an existing EI using previous defaults. Comparing the two EIs showed that the fishing fleet had the greatest emission changes because a large fraction of fishing vessels require gap-filling.

Ramboll added new reporting options that allow MARINER to generate additional activity and emission summary reports as well as temporal profiles that are useful in formatting CMV emissions for air quality modeling. The new options are as follows:

- Emission Inventory Report. This option generates an emission inventory summary that aggregates the highly resolved temporal AIS data.
- Temporal Profiles. This option generates temporal profiles that are useful for processing emissions with the Emission Processor System Version 3 (EPS3).
- Vessel Activity Report. This option generates summaries of vessel activity by vessel type that include total hours and nautical miles traveled aggregated over the computational domain or geopolitical regions defined by Federal Information Processing System (FIPS) codes.

MARINER runtime improvements were achieved by focusing on the emissions calculation step, which is the most time-consuming step, and runtime was reduced by about 75%. Quality assurance steps confirmed that improved efficiency has not compromised EI quality. To reduce MARINER memory requirements, Ramboll removed code related to a large emission file that is not being used in any subsequent step. To resolve a memory issue associated with vessel type 31 (Towboat/Pushboat), Ramboll considered several options but determined that implementation would require more resources than were available in this project and so further work on this issue is recommended.

1.0 INTRODUCTION

The MARINER tool automates the generation of emissions datasets from highly resolved CMV information. To generate these emissions datasets, MARINER combines the identity, location, and operation of vessels from the Automatic Identification System (AIS) with the vessel characteristics from the IHS Markit (IHS) database. Ramboll initially developed the tool to produce detailed CMV EI for use in photochemical modeling and to implement applicable EPA guidance for CMV sources. MARINER was further updated to follow the EPA's revised guidance and to generate 2019 and 2020 CMV EI that can be imported to the air emissions reporting interfaces used by both the EPA and TCEQ.

The purpose of this project is to enhance the usability of MARINER by adding new processing options as well as improving runtime and memory usage. Improvements to MARINER were performed in two phases. The first phase, described in Chapter 2, updated "gap-filling" methods, when individual data cannot be found for a particular vessel, to make them more representative of vessels found within Texas waters. The second phase, described in Chapter 3, added new options that allow MARINER to generate additional activity and emission summary reports and temporal profiles. The code was also modified to improve MARINER runtime and memory usage.

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 guide. The user's guide will not be discussed any further in this report. Finally, at the end of Chapter 3, we discuss recommendations for future improvements to MARINER.

2.0 ALTERNATIVE VESSEL CHARACTERISTICS

This chapter describes the methodology used to update the defaults for vessel characteristics so that they are more representative of vessels within Texas waters. The IHS global vessel characteristics database provides information that is essential for the development of emission estimates. Relevant data provided by the IHS database include the engine attributes (e.g., age, stroke, total installed power), the design characteristics (e.g., service speed, maximum draft), and the vessel use information (e.g., ship type detail). Although the IHS data is expansive and is updated periodically, data gaps in the dataset require MARINER to fill this information using IHS global averages as a function of IHS ship type.

The CMV EI includes two major types of marine sources: 1) Ocean-Going vessels (OGV) and 2) harbor craft. OGV typically have Category 3 (C3) propulsion engines, which have a per-cylinder displacement of 30 liters or more; however, some OGV have smaller Category 1 (C1) or Category 2 (C2) engines. The harbor craft source sector covers all commercial marine vessels that are not considered in the OGV sector, such as tugboats and work boats. Unlike OGV, harbor craft typically spend most of their operating time in or near a single port or region and are typically equipped with C1 or C2 engines.

MARINER treats OGV differently from harbor craft because there is more specific information for OGV. For instance, OGV engine load estimates use a combination of AIS supplied data on instantaneous speed, vessel draft, and location, while harbor craft engine load is calculated with default load factors regardless of vessel speed. OGV estimates of engine load also require the rated power for propulsion and auxiliary engines, engine type, model year (Emission Tier level), rated vessel speed (at 100% load or load a design speed), and vessel design draft (when fully loaded). In contrast, current estimates of engine load for harbor craft only require the vessel type and engine characteristics.

2.1 Methodology

This section describes the methodology used to develop gap-filling data by vessel type that are more representative of sources in Texas. This is an improvement from how MARINER filled the input data gaps for all vessel types using IHS global averages and US EPA national defaults.

The gap-filling methodology described in Ramboll (2021) states that:

- For vessels that have a match in the IHS data set, IHS vessel characteristics are merged with the unique list of vessels from the Texas domain, and missing fields are first gap-filled with IHS global averages per IHS ship type. IHS ship type is then mapped to EPA ship type to gap-fill any remaining missing fields with EPA's best practice information.
- For unmatched vessels, the AIS vessel type (from the AIS data set) is mapped to one of the EPA ship types described in the EPA guidance (Table 2-1). For instance, Miscellaneous (C1/C2) is the default EPA ship type for AIS vessel type zero[1]. Any remaining missing fields are gap-filled with EPA's best practices information for OGV and harbor craft respectively.

[1]AIS Vessel Type 0 ("Not available or no ship, default") includes all ships not classified by other categories

Table 2-1. Filling Gaps in vessel classification according to the EPA guidance.

Parameters	EPA Guidance (EPA, 2020)
Propulsion engine power, engine type, service speed, max draft	Table C.4. Average OGV Engine Category, Engine Type, Installed Power, Maximum Speed, and Maximum Draft by Ship Type
Propulsion engine power, auxiliary engine power	Table G.1. Default Harbor Craft Engine Sizes and Annual Activity

Ramboll considered two possible averaging schemes for aggregating known data: population-weighted and activity-weighted averaging. We decided that the activity-weighting scheme represents the Texas fleet better than population-weighting because it explicitly considers the frequency of each ship's operations in Texas. Activity can be characterized using carbon dioxide (CO_2) emissions obtained from fuel consumed by vessels within the Texas domain. The following equation indicates how the activity-weighted average was computed:

$$\text{Activity-Weighted Average} = \frac{\sum(\text{CO}_2\ \text{Emissions} \times \text{Vessel Characteristics})}{\sum \text{CO}_2\ \text{Emissions}}$$

Eq 1.1

The following inputs for OGVs (C3) were reviewed and computed to reflect Texas-specific averages:

- Vessel Type (Freight design type)
- Vessels Characteristics
  - Design Speed
  - Design Maximum Draft
- Engine Characteristics (propulsion engines)
  - Rated power
  - Engine types (slow or medium diesel primarily or diesel-electric)
  - Model year (Emission Tier level)

And similarly for harbor craft (C1/C2):

- Vessel Type (Use and Design)
- Engine Characteristics (propulsion and auxiliary engines)
  - Rated power
  - Displacement
  - Engine tier and category (c1 or c2)
  - Model year (Emission Tier level)

Gap filling using CO_2 emisions as a proxy for fuel consumed could introduce a potential bias for NOx emissions because the latter does not necessarily scale linearly with the fuel burned or the engine output. However, we concluded that any such bias is minor because the gap filling defaults are used only in few vessels. Emissions factors for NOx are determined by the model year, with significantly lower values for vessels newer than 2015 (Tier III). We think the approach used to determine the model year (from the weighted average described above) will not bias the NO_x emissions because: (1) the gap-filling defaults are only used in

10% of the total records for OGVs (C3) and (2) only a handful records exist in the 2020 database for the more stringent Tier III.

Ramboll performed a literature review seeking useful data on the Texas harbor craft (C1/C2) fleet that could be used to update or replace the EPA defaults currently used in MARINER. However, with the exception of fishing fleet data in ERG (2015), no other relevant information was found for C1/C2 vessels. In the following section we provide the changes in the Texas-specific defaults for both OGV (C3) and harbor craft (C1/C2) vessels after we implement the methodology described in this section.

2.2 Emissions Changes due to Texas-Specific Defaults

2.2.1 Ocean Going Vessels

Activity-weighted averages for OGVs were calculated using Equation 1.1 considering all vessel activity in 2019 and 2020. Only the vessels that can be identified in the IHS dataset were included in the calculation, while vessels in need of any gap-filling were excluded. Table 2-2 summarizes the new Texas-specific gap-filling defaults per IHS ship type that are proposed to replace the existing IHS global averages. The table also includes the EPA's default averages for comparison with the new gap-filling defaults.

Instead of using EPA defaults, the Texas-specific averages were used to gap-fill missing vessel characteristics as summarized in Table 2-3. For unmatched vessels, the AIS vessel type is mapped to one of the EPA ship types described in the EPA guidance. General Cargo is chosen as the default EPA ship type for AIS vessel type 70-79 and Chemical Tanker is chosen as the default EPA ship type for AIS vessel type 80-89.

Table 2-2. Activity-weighted averages per ship type for the Texas fleet.

EPA Ship Type	IHS Ship Type	Number					
Bulk Carrier	EPA default	n/a	SSD	8,800	15.3	11.8	n/a
	Bulk Carrier	1336	SSD	8,401	15.3	12.3	2010
	Bulk Carrier, Self-discharging	12	SSD	11,371	15.3	13.2	1998
	Bulk/Caustic Soda Carrier (CABU)	4	SSD	9,860	15.4	13.9	2001
	Cement Carrier	3	SSD	7,235	15.6	8.3	1981
Chemical Tanker	EPA default	n/a	SSD	8,200	15.5	11.5	n/a
	Chemical Tanker	6	SSD	10,050	15.8	10.5	1980
	Chemical/Products Tanker	1381	SSD	8,603	15.4	11.8	2009
	Molten Sulphur Tanker	1	MSD	7,441	16.0	10.1	1992
Container Ship	EPA default	n/a	SSD	35,300	23.7	11.8	n/a
	Container Ship (Fully Cellular)	375	SSD	46,296	25.0	13.2	2005
Cruise	EPA default	n/a	SSD	34,800	22.9	8.0	n/a
	Passenger/Cruise	9	MSD	71,069	22.6	8.3	2004
General Cargo	EPA default	n/a	SSD	4,800	14.1	5.5	n/a
	Deck Cargo Ship	4	MSD	13,627	14.9	6.5	2015
	General Cargo Ship	483	MSD	7,346	16.5	9.1	2007
	Livestock Carrier	1	MSD	4,102	17.0	6.0	1997
	Open Hatch Cargo Ship	146	SSD	8,878	15.7	11.7	2006
Liquified Gas Tanker	EPA default	n/a	SSD	12,000	17.6	10.5	n/a
	Combination Gas Tanker (LNG/LPG)	10	MSD	7,097	15.0	9.4	2014
	LNG Tanker	206	MSD	35,958	19.8	12.3	2013
	LPG Tanker	425	SSD	10,729	17.1	11.1	2011
	LPG/Chemical Tanker	1	SSD	9,611	16.8	10.1	1998
Miscellaneous (C3)	EPA default	n/a	SSD	5,800	15.5	6.7	n/a

EPA Ship Type	IHS Ship Type	Number					
	Crane Vessel	1	MSD	27,374	14.9	14.5	2008
	Gas Processing Vessel	11	MSD	31,317	19.4	12.4	2011
	Heavy Load Carrier	8	MSD	6,713	16.3	8.1	2001
	Heavy Load Carrier, semi submersible	11	MSD	10,639	16.4	7.0	2003
	Logistics Vessel (Naval Ro-Ro Cargo)	8	MSD	51,318	26.4	10.0	1978
	Pipe Burying Vessel	1	MSD	6,339	13.8	6.2	1979
	Pipe Layer	1	MSD	12,776	12.8	7.2	1998
	Pipe Layer Crane Vessel	2	MSD	20,438	13.8	7.6	2006
	Replenishment Tanker	2	SSD	11,498	17.4	11.0	1983
Offshore Support/Drillship	EPA default	n/a	MSD	6,300	15.1	6.1	n/a
	Anchor Handling Tug Supply	2	MSD	12,167	16.5	6.9	2007
	Anchor Handling Vessel	6	MSD	11,969	15.1	7.2	2008
	Offshore Support Vessel	3	MSD	13,626	13.9	7.4	2015
	Platform Supply Ship	3	MSD	7,940	12.8	6.1	2012
Oil Tanker	EPA default	n/a	SSD	10,100	15.6	13.1	n/a
	Asphalt/Bitumen Tanker	13	SSD	3,575	13.7	7.3	2012
	Crude Oil Tanker	648	SSD	14,573	15.8	15.5	2008
	Crude/Oil Products Tanker	251	SSD	13,268	15.7	14.7	2008
Other Tanker	EPA default	n/a	SSD	11,800	14.6	11.9	n/a
	Fruit Juice Carrier, Refrigerated	1	SSD	6,134	14.9	10.5	2014
	Products Tanker	184	SSD	10,908	15.8	13.0	2007
Reefer	EPA default		SSD	9,200	20.0	8.4	n/a
	Refrigerated Cargo Ship	6	SSD	16,040	22.8	9.5	2006
RORO	EPA default	n/a	SSD	16,800	20.3	8.7	n/a
	General Cargo Ship (with Ro-Ro facility)	2	MSD	7,472	17.5	7.5	2009

EPA Ship Type	IHS Ship Type	Number					
	Ro-Ro Cargo Ship	20	SSD	15,756	17.5	8.8	1983
	Vehicles Carrier	193	SSD	14,721	20.1	10.6	1998

Table 2-3. Activity-weighted averages per AIS vessel type for the Texas fleet.

AIS Vessel Code	Ship Type	IHS Ship Type	Number					
70-79 Cargo	General Cargo	EPA default	n/a	SSD	4,800	14.1	5.5	n/a
		General Cargo Ship	483	MSD	7,346	16.5	9.1	2007
80-89 Tanker	Chemical Tanker	EPA default	n/a	SSD	8,200	15.5	11.5	n/a
		Chemical/Products Tanker	1381	SSD	8,603	15.4	11.8	2009

2.2.2 Harbor Craft

For the harbor craft category, only a minority of vessels were found in the IHS database because IHS does not provide information about vessels without assigned IMO numbers. Vessels with assigned IMO numbers are usually engaged in international trade such as articulated tug and barge (ATB) towboats.

MARINER fills information data gaps for all vessels using EPA US national defaults for the 2019 and 2020 emission inventories. One exception to these national defaults is the data available for the Texas fishing fleet (ERG 2015). Table 2-4 summarizes Ramboll's estimate for the average installed propulsion power and the activity weighted averages for the fishing fleet in Texas from ERG (2015). Ramboll recommends a value of 290 kW for the average installed power for the main engine. We derived this value from the total engine work and the total vessel hours as these are reasonable fishing fleet activity parameters.

Table 2-4. Activity-weighted averages for the Texas fishing fleet.

Catch	Vessels	Calls/Yr	Distance	Speed	Installed Power (kW)	Work (kW-hr/Yr[a])	Vessel Hours by Catch
Snapper	84	40	20	7.5	224	2,007,040	8,960
Shrimp	1086	20	20	7.5	522	30,234,240	57,920
Oyster	252	100	40	7.5	224	30,105,600	134,400
Other	195	50	30	7.5	186	7,254,000	39,000
Total	**1617**					**69,600,880**	**240,280**
Average					**290**		

[a] – Using 0.68 load factor

Ramboll recommends using engine work to determine the weighted average installed power for the Texas fishing fleet (ERG 2015, NOAA 2020). However, other activity parameters could have been used for this estimate such as the relative vessel population or the catch in terms of weight or dollar value. Table 2-5 compares the alternative weighting schemes for each type of fishing vessel. This table shows that choosing an activity weighting other than engine work would result in an average installed power that is heavily influenced by the shrimp fishing fleet. We selected weighting by engine work because there is an engineering basis for assuming that engine emissions are related to fuel consumption, i.e., work.

Table 2-5. Comparison of alternative weighting percentages for the Texas fishing fleet.

Fishing Type	Work (kW-hr)	Vessels Population	Catch (tons)	Catch ($)
Snapper[a]	3%	5%	6%	9%
Shrimp	43%	67%	82%	73%
Oyster	43%	16%	7%	16%
Other[b]	10%	12%	5%	3%

[a] – And other fish

[b] – Crab and squid

2.2.3 Implementation of Updated Defaults in MARINER

MARINER was updated with the gap-filling defaults shown in Table 2-2, Table 2-3, and Table 2-4. Ramboll generated a 2019 Texas EI with these new defaults and compared with an existing EI using previous defaults. Table 2-6 summarizes this comparison. Since the only change in the setup is the gap-filling defaults, there is no significant difference in emissions, except for the fishing vessels that have a large portion of their engine power gap-filled. Table 2-6 shows emissions from fishing decreased significantly as the default engine power decreased from 419 kW to 290 kW. Overall, CO emissions decreased by 1.2%; NOx emissions decreased by 1.0%; PM_{10} emissions decreased by 0.7%; $PM_{2.5}$ emissions decreased by 0.8%; SO_2 emissions decreased by 0.002%; and VOC emissions decreased by 0.5%.

Table 2-6. Comparison of 2019 annual domain-wide emissions (tons) by ship type.[2] [3]

Pollutant	CO			NOx			PM_{10}			PM_{25}			SO_2			VOC		
Ship Type	**New**	**Old**	**% difference**	**New**	**Old**	**% difference**	**New**	**Old**	**% difference**	**New**	**Old**	**% difference**	**New**	**Old**	**% difference**	**New**	**Old**	**% difference**
Bulk Carrier	316	316	-	3,020	3,019	-	52	52	-	48	48	-	115	115	-	267	266	-
Chemical Tanker	1,660	1,658	0.1%	15,451	15,428	0.1%	290	289	0.1%	267	266	0.1%	659	658	0.1%	1,363	1,361	0.1%
Container Ship	582	582	-	5,441	5,445	-	80	80	-	74	74	-	184	184	-	540	540	-
Crew and Supply	134	134	0.3%	788	785	0.4%	16	16	0.4%	16	16	0.4%	1	1	-	46	46	0.3%
Cruise	283	283	-	2,885	2,884	-	49	49	-	45	45	-	107	107	-	242	242	-
Dredge	81	81	-	461	461	-	8	8	-	8	8	-	0	0	-	19	19	-
Fishing	364	511	-28.8%	2,115	2,968	-28.7%	36	50	-28.3%	35	49	-28.3%	1	2	-28.6%	83	116	-28.5%
General Cargo	346	348	-0.4%	3,270	3,354	-2.5%	59	59	0.3%	55	54	0.3%	133	133	0.5%	283	284	-0.2%
Government	1	1	-	5	5	-	0	0	-	0	0	-	0	0	0.2%	0	0	-
Harbor Ferry	69	69	-	356	356	-	7	7	-	7	7	-	0	0	-	9	9	-
Liquified Gas Tanker	376	376	-	3,693	3,690	-	111	111	-	102	102	-	289	289	-	337	337	-
Miscellaneous	681	680	0.2%	3,755	3,746	0.2%	80	79	0.3%	77	77	0.3%	10	10	-	219	219	0.2%
Offshore Support/Drillship	7	7	-	48	48	-	1	1	-	1	1	-	3	3	-	5	5	-
Oil Tanker	1,730	1,731	-	16,132	16,137	-	471	471	-	433	434	-	1,206	1,207	-	1,494	1,494	-
Other Tanker	149	149	-0.2%	1,530	1,534	-0.2%	32	32	-0.3%	30	30	-0.3%	78	79	-0.3%	129	130	-0.2%
Pilot	50	50	-	154	138	11.3%	4	3	39.3%	4	3	39.3%	0	0	-	10	6	65.5%
Reefer	15	15	-	162	162	-	2	2	-	2	2	-	5	5	-	13	13	-
RORO	165	165	-	1,616	1,615	-	28	28	-	25	25	-	62	62	-	138	138	-
Towboat/Pushboat	3,602	3,602	-	19,837	19,837	-	328	328	-	318	318	-	10	10	-	488	488	-
Tug Boat	957	953	0.4%	4,532	4,499	0.7%	96	97	-0.2%	94	94	-0.2%	4	4	-	186	186	0.3%
Work Boat	37	37	0.2%	212	211	0.1%	4	4	0.2%	4	4	0.2%	0	0	0.3%	10	10	0.4%
Total	**11,605**	**11,747**	**-1.2%**	**85,461**	**86,321**	**-1.0%**	**1,755**	**1,768**	**-0.7%**	**1,643**	**1,656**	**-0.8%**	**2,866**	**2,866**	**-**	**5,883**	**5,911**	**-0.5%**

[2] Percentage less than 0.1% is shown as "-".

[3] Percentage difference is calculated as (new emissions – old emissions)/old emissions.

3.0 MARINER MODIFICATIONS

This chapter summarizes the changes in MARINER that expand its usability and improve its runtime and memory usage. MARINER now has the capability to generate additional summary reports and shows a significant improvement in its execution runtime without any compromise in data quality.

Ramboll implemented the following functionalities as new options to the MARINER's configuration setup:

- Emission Inventory Report. This option generates an emission inventory summary that aggregates the highly resolved temporal AIS data.
- Temporal Profiles. This option generates temporal profiles that are useful for processing emissions with the EPS3.
- Vessel Activity Report. This option generates summaries of vessel activity by vessel type that include total hours and nautical miles traveled aggregated over the computational domain or geopolitical regions defined by FIPS codes.

This chapter describes these modifications and provides examples of the type of reports generated by MARINER.

3.1 Emission Inventory Report

This new option in MARINER, allows the code to generate emission inventory summaries. The emissions are summarized by TCEQ custom Source Classification Codes (SCC), pollutant, and by FIPS codes representing counties or areas over water. One benefit of the reports created under this option is that they can serve as a quick way to check the total emissions.

MARINER was modified with a group of functions that read EPS3 input files (PRESHP) and aggregate the data. This option is available and will generate the report described below if the step that converts emissions to EPS3 format is completed. To turn on this option in the configuration file, the user must set this new variable to false:

```
SKIP_INVENTORY_MODE = False
```

Additional details on how to set configuration options can be found in the *MARINER User's Guide*. MARINER will then aggregate the highly temporal AIS data by SCC and FIPS code. For TCEQ's modeling domain, regions outside Texas are assigned the following FIPS:

- Alabama with FIPS of 05000
- Louisiana with FIPS of 22000
- Oklahoma with FIPS of 40000
- Portion of Gulf in U.S. territorial waters coded with 85003
- Portion of Gulf in Mexico territorial waters and land coded with 98MEX
- Portion of Gulf in international waters coded with 98INT

The reports are generated in comma-separated values (csv) format and other programs can read them easily to perform further analysis.

Figure 3-1 below shows an emissions inventory report example. All the variables in this report are described and are consistent with EPS3 conventions. Metadata such as the time selected to run the report and the average period of the emissions is provided in the first six lines of the file. Summary data is provided starting on line seven. The report contains the following six columns:

INFIPS	FIPS state/county code
INSCC	TCEQ custom Source Classification Code
INVESL	EPA Ship Type
INPOL	Pollutant code
EMISSHIP	Emissions of specified pollutant in tons/day

```
# Inputs = EPS3 preshp files generated from 07_eps3 step.,,,,
# IBEGDT = 19030100,,,,
# IENDDT = 19053123,,,,
# IPERO = AD (Average Day),,,,
# INZONE = UTM zone,,,,
# Inventory mode emissions summary by FIPS,  SCC and pollutants,,,,
INFIPS,INSCC,INVESL,INPOL,EMISSHIP
22000,228000BLKT,BulkCarri,42101,1.83E-05
22000,228000BLKT,BulkCarri,42102,0.00793576
22000,228000BLKT,BulkCarri,42401,4.84E-06
22000,228000BLKT,BulkCarri,42603,0.00019509
22000,228000BLKT,BulkCarri,42604,4.00E-08
22000,228000BLKT,BulkCarri,42605,3.90E-07
.
.
```

Figure 3-1. Example emissions inventory report.

3.2 Temporal Profiles

This new MARINER option generates temporal profiles that are useful for processing emissions with EPS3. The temporal profiles will be generated if the emissions calculation step is completed. To turn on this option in the configuration file, the user must set this new variable to false:

```
SKIP_TEMP_PROFILE = False
```

The user needs to set two additional parameters: the averaging period (AvePeriod) and the number of hours that shift data to local time (TIMESHIFT). The only two types of temporal averages that can be selected are either seasonal or monthly. The time shift variable must be an integer with the offset (in hours) from the time in Coordinated Universal Time (UTC) to the corresponding local timezone. The integer must be negative for time zones west of UTC. Texas is in Central Standard Time (CST) and therefore TIMESHIFT should be set to ‑6. The following is an example showing how these parameters can be set:

```
AvePeriod = 'Month' # Options: ‘Month’ or 'Season'
TIMESHIFT = -6      # CST = 6 hours behind UTC
```

The symbol # appears before comments that MARINER will ignore. Seasons are defined internally as the following months:

- Spring: March, April, May
- Summer: June, July, August
- Fall: September, October, November
- Winter: December, January, February

MARINER can generate three different types of temporal profiles: weekly, weekday, and weekend profiles. The profiles are generated in plain text format for EPS3 although other programs can read them easily to perform further analysis.

Prior to any estimates, MARINER first shifts the data timestamps from the internal UTC to the corresponding local time zone (CST for Texas). Once the data is set to local time, averaging and other calculations reflect the temporal patterns for daily activities and emissions in Texas, which ensures results are consistent and easy to interpret. The following sections describe each of the temporal profiles that can be generated.

3.2.1 Weekly Profiles

Figure 3-2 shows an example of the weekly temporal profiles that MARINER can now generate by season or by month. The format of this profile follows EPS3 conventions. Namely the first field is the temporal profile code (weekly) and the data inside the packet represent weight factors for the day of the week for each pollutant, activity and vessel type.

```
/WEEKLY/
 100  100  100  100  100  100  100  100  700 No Variation by Day of Week
 101  106  106  106  106  106   84   84  700 2019-Jan-NOx-Hotelling-Crew and Supply
 102  100  100  100  100  100  100  100  700 2019-Jan-NOx-Hotelling-Fishing (C1/C2)
 103   82   82   82   82   82  153  153  700 2019-Jan-NOx-Maneuvering-Crew and Supply
 104   94   94   94   94   94  116  116  700 2019-Jan-NOx-Maneuvering-Fishing (C1/C2)
 105   91   91   91   91   91  127  127  700 2019-Jan-NOx-Transit-Crew and Supply
 106   92   92   92   92   92  123  123  700 2019-Jan-NOx-Transit-Fishing (C1/C2)
 107  106  106  106  106  106   84   84  700 2019-Jan-VOC-Hotelling-Crew and Supply
 108  100  100  100  100  100  100  100  700 2019-Jan-VOC-Hotelling-Fishing (C1/C2)
.
.
/END/
```

Figure 3-2.   Example weekly temporal profile.

3.2.2 Weekday and Weekend Profiles

Figure 3-3 shows an example of the weekday temporal profiles. These temporal profiles follow EPS3 conventions and the data inside the packet represent weight factors for hour of the weekday for each pollutant, activity, and vessel type. The weekend profile format is identical to the weekday profile shown in this example, except that the identification code WKD would change to WKE.

```
/DIURNAL WEEKDAY/
 500   40   40   40   40   40   40   40   40   40   40   40   40   40   40   40   40   40   40   40   40   40   40   40   40  960 No Variation by Hour of Weekday
 501   60   68   59   64   65   53   53   58   52   58   32   28   29   23   24   23   27   21   11   23   32   36   50   52 1001 2019-Winter-WKD-NOx-Hotelling-Crew and Supply
 502   39   40   40   40   39   39   39   38   41   43   46   47   48   48   48   47   45   40   38   38   39   39   40   41 1002 2019-Winter-WKD-NOx-Hotelling-Fishing (C1/C2)
 503   32   22   22   20   24   32   32   31   29   17   31   45   48   46   54   44   42   54   78   87   65   66   43   35  999 2019-Winter-WKD-NOx-Maneuvering-Crew and Supply
 504   51   49   50   51   51   51   50   48   37   30   27   28   28   27   27   27   28   37   47   51   52   50   50   52  999 2019-Winter-WKD-NOx-Maneuvering-Fishing (C1/C2)
 505   36    2    0    0    0    0    0    0   15   37  137   95   45  121   41   13   59  129   82   47   69    2   25   43  998 2019-Winter-WKD-NOx-Transit-Crew and Supply
 506   34   37   36   33   28   28   28   35   46   56   57   49   44   44   45   49   50   54   50   45   40   39   39   35 1001 2019-Winter-WKD-NOx-Transit-Fishing (C1/C2)
 507   60   68   59   64   65   53   53   58   52   58   32   28   29   23   24   23   27   21   11   23   32   36   50   52 1001 2019-Winter-WKD-VOC-Hotelling-Crew and Supply
 508   39   40   40   40   39   39   39   38   41   43   46   47   48   48   48   47   45   40   38   38   39   39   40   41 1002 2019-Winter-WKD-VOC-Hotelling-Fishing (C1/C2)
 509   32   22   22   20   24   32   32   31   29   17   31   45   48   46   54   44   42   54   78   87   65   66   43   35  999 2019-Winter-WKD-VOC-Maneuvering-Crew and Supply
.
.
/END/
```

Figure 3-3. Example weekday or weekend temporal profile.

3.3 Vessel Activity Report

This option allows MARINER to generate two types of reports: vessel activity by domain and by FIPS. The vessel activity report is useful because it helps to understand the level of vessel activity. MARINER was modified with a group of new functions that first read the activity feather[4] files and extract relevant data. Next, it reads the vessel classes feather file and determines ship types and vessel classes. 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 one being 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. To turn on this option in the configuration file, the user must set this new 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.

Figure 3-4 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 six columns:

VesselType	Vessel type identification code
EPAShipType	EPA ship types described in the EPA guidance
VesselClass	Vessel Class. Either C1C2 or C3
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

[4] 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

```
VesselType,EPAShipType,VesselClass,SpeedBin,Hour,NauticalMile
79.0,Container Ship,C3,3.0,4.949722222222227,71.1728334245489
71.0,Container Ship,C3,1.0,7.639444444444426,0.4502309556215218
71.0,Container Ship,C3,2.0,0.1916666666666667,0.45157066872001383
71.0,Container Ship,C3,3.0,12.455833333333343,218.95793720102546
81.0,Chemical Tanker,C3,1.0,23.89972222222277,2.1709334894944483
52.0,Tug Boat,C1C2,1.0,181.2136111111145,10.88609968487678
52.0,Tug Boat,C1C2,2.0,4.916944444444444,8.578071222206484
52.0,Tug Boat,C1C2,3.0,27.73166666666733,180.22679933546004
.
.
```

Figure 3-4. Example domain-wide vessel activity report.

Figure 3-5 shows an example report for the 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,EPAShipType,VesselClass,SpeedBin,FIPS,Hour,NauticalMile
79.0,Container Ship,C3,3.0,85003,3.777222222222215,54.36131922853016
71.0,Container Ship,C3,1.0,48201,7.639444444444428,0.45023095562152166
71.0,Container Ship,C3,2.0,48201,0.19166666666666665,0.45157066872001383
71.0,Container Ship,C3,3.0,48071,0.6336111111111112,7.7737004529862785
71.0,Container Ship,C3,3.0,48167,1.9044444444444428,27.837733815861313
71.0,Container Ship,C3,3.0,48201,1.7305555555555538,14.182047256717246
71.0,Container Ship,C3,3.0,85003,7.415555555555575,151.81262092692373
81.0,Chemical Tanker,C3,1.0,85003,23.899722222222287,2.1709334894944488.
.
```

Figure 3-5. Example vessel activity report by FIPS.

3.4 Memory and Runtime Improvements

MARINER now provides the same results with a faster turnaround time. MARINER handles large amounts of data which requires significant memory and computational resources. Ramboll identified certain modules in the code that could be rewritten to improve runtime efficiency. In particular, the emissions calculation step is the most time-consuming step in MARINER. For a one-day test run, Table 3-1 summarizes the runtime in each step of the code. The table shows that about 91% of runtime is devoted to the emissions step.

Table 3-1. One-day test runtime summary by step.

MARINER Step	Runtime (Minutes)	Runtime %
1 subsetting	1.2	0.5%
2 vessel types	0.1	0.0%
3 voyages	0.2	0.1%
4 activity	10.6	4.7%
5 vessel characteristics	1.1	0.5%
6 emissions	203.3	90.9%
7 spatial processing	6.0	2.7%
8 emissions to EPS3	1.2	0.5%
Total	**223.7**	**100%**

Ramboll focused on improving the calculation of C1C2 vessel emissions because this calculation took the most time within the emissions step. C1C2 vessels were processed record by record using a loop structure, similar to how C3 vessels are processed. This loop is necessary for C3 vessels because their propulsion engine operating power changes with speed record by record. However, this flexibility is not needed for C1C2 vessels and the code was modified to remove an unnecessary loop and calculate C1C2 emissions more efficiently. After the code improvement, using the same one-day test run setup, the runtime of the emission calculation step is now 40.9 minutes, a reduction of 80%.

It is important to ensure the integrity of emission calculations and consistency with results previously obtained before any modifications. As a quality assurance procedure, the emissions generated from the modified code were compared to the results from the run with the same setup and unmodified code, and we found no differences in the results. Furthermore, the 2019 EI discussed in Section 2.2.3 was run with the improved version of MARINER and we compared the runtime with the same setup runs conducted in 2021. Table 3-2 summarizes the runtimes in minutes from these runs and shows the corresponding improvements. The reduction percentage varies from 74% to 78%, which is reasonable given the different time period and vessel activity. MARINER will now run in much less time without compromising the data quality of its results.

Table 3-2. MARINER runtime improvements summary for emissions step.

MARINER Run	Original Runtime (Minutes)	Improved Runtime (Minutes)	Runtime Improvement %
One day test	203.3	40.9	80%
January - February	4,359.0	986.2	77%
March - April	4,636.0	1183.1	74%
May – June	5,085.1	1261.5	75%
July - August	5,032.2	1101.0	78%
September - October	5,630.7	1299.9	77%
November – December	5,730.7	1324.1	77%

As part of this task, Ramboll explored several strategies to reduce MARINER memory requirement, but concluded that each would take more time to implement and test than was available in this project. From previous experience, it is clear that memory issues tend to occur during the emissions calculation step since all records need to be stored in memory before they are written to a feather file. MARINER first processes each vessel type individually and writes a feather file per vessel type. Next, MARINER produces a combined ‘emissions.feather’ file with data from all vessel types. To produce this last feather file, MARINER stores all records in a list, and this can consume a lot of memory. MARINER has sometimes failed to write the `emissions.feather’ file when running for long periods with the Texas modeling domain. Since this file is not used in any subsequent step, Ramboll removed all code related to the creation of this file in MARINER. This modification is expected to improve MARINER reliability and reduce memory requirements.

Ramboll identified a separate memory issue that can occur when processing vessel type 31 (Towboat/Pushboat). This vessel type is usually the most active and has the most activity records. To mitigate this memory issue, we considered the following potential code modifications:

- Create several feather files instead of one when vessel type 31 is processed
- Change the main logic in MARINER steps. For instance, processing data by day instead of by vessel type
- Explore the possibility to implement parallel computing in MARINER

Each option represents a significant effort that was beyond the scope of the current project, therefore they were not implemented. However, we recommend these modifications be considered for future improvements to MARINER.

Ramboll also recommends several activities that would improve MARINER capabilities and provide additional insight to CMV EIs developed using MARINER: (1) Find alternatives to the confidential IHS vessel characteristics data that cannot be released to TCEQ and modify MARINER accordingly; (2) conduct a formal uncertainty analysis to determine the primary influences to emissions in MARINER; (3) evaluate one new facility to develop procedures and prototype the application of MARINER to hypothetical emission scenarios; and finally (4) develop tools to maintain vessel cross-referencing within MARINER to minimize uncertainties due to mismatched vessel identifiers.

4.0 REFERENCES

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