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Port Operational Strategies: Virtual Vessel Arrival

This fact sheet is one of a series of documents produced by the EPA Ports Initiative to inform port stakeholders about potential emission reduction strategies.[1] Each fact sheet contains basic information about the strategy, emission impacts, cost components, and example programs. While each strategy can achieve benefits on its own, implementing them together could create synergies.[2]

Strategy Summary

Description: Ocean-going vessels can experience significant delays entering their destination ports, resulting in increased fuel consumption and emissions while they idle at anchorage. It is common practice for vessel operators to travel full speed to their destinations and then wait for berths, sometimes for several days. Virtual vessel arrival systems inform vessel operators of expected delays at their destination ports, helping them align arrival times with berth availability. This adjustment reduces or eliminates wait times and corresponding offshore anchorage emissions and fuel consumption. In addition, these systems can inform optimal voyage speeds, resulting in further potential fuel savings.

Virtual vessel arrival is a low-cost strategy that has several basic requirements including enhanced vessel traffic planning and communication systems, and program monitoring improvements. This strategy is relatively new and has only been demonstrated for a few vessels worldwide, but is a promising approach for increasing vessel operational efficiency and reducing emissions. Figure 1 summarizes the virtual vessel arrival process.[3]

Advantages: Delays are common for ocean-going vessels, as illustrated in Figure 2 (showing dozens of tankers awaiting entry into the Port of Houston) and Figure 3 (showing the large variability in on-time arrivals for container ships, globally and for two tradelanes).[4] While delayed, vessels wait offshore at nearby anchorages, using their auxiliary engines and potentially dragging their anchors and suffering collisions. They may also use their main engines, depending on weather.

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1 The emissions evaluated in these fact sheets include nitrogen oxides (NO_x), particulate matter (PM), hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), and sulfur dioxide (SO_2).

2 See the Ports Initiative's fact sheets on vessel speed reduction (https://www.epa.gov/ports-initiative/marine-vessel-speed-reduction-reduces-air-emissions-and-fuel-usage), port management information systems (https://www.epa.gov/ports-initiative/management-information-systems-improve-operational-efficiencies-and-air-quality), and gate management (https://www.epa.gov/ports-initiative/port-gate-management-strategies-improve-air-quality-and-efficiency-ports).

3 Adapted from Intertanko and OCIMF. 2011. Virtual Arrival: Optimising Voyage Management and Reducing Vessel Emissions—an Emissions Management Framework. https://www.ocimf.org/media/115960/Virtual-Arrival.pdf. Accessed 3-5-2021.

4 Ibid.

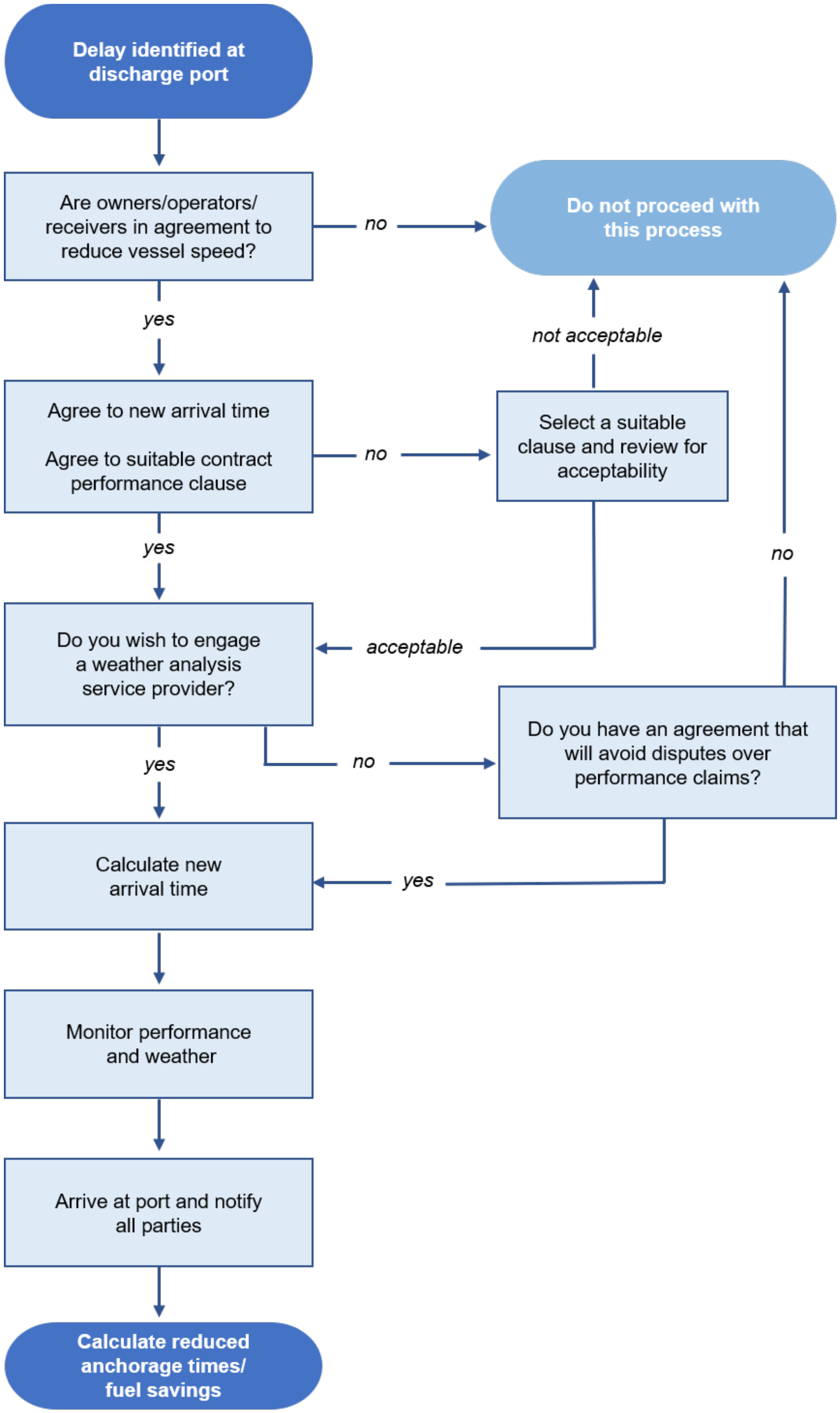

Figure 1. Virtual Vessel Arrival Process

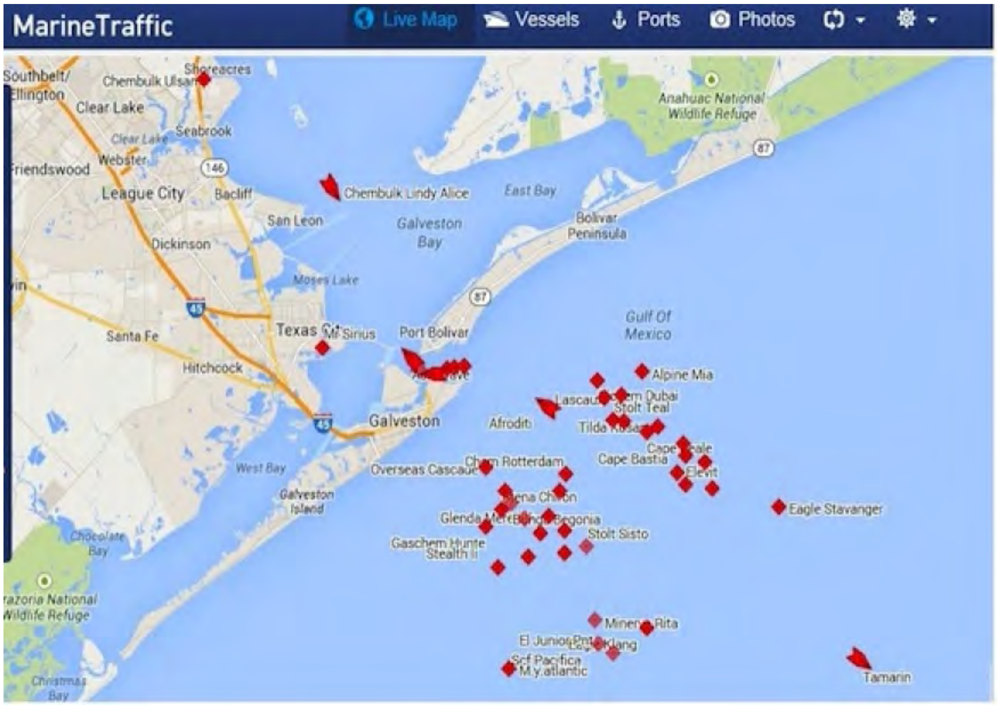

Figure 2. Tankers Waiting to Enter the Ports of Houston, Texas City and Galveston [5]

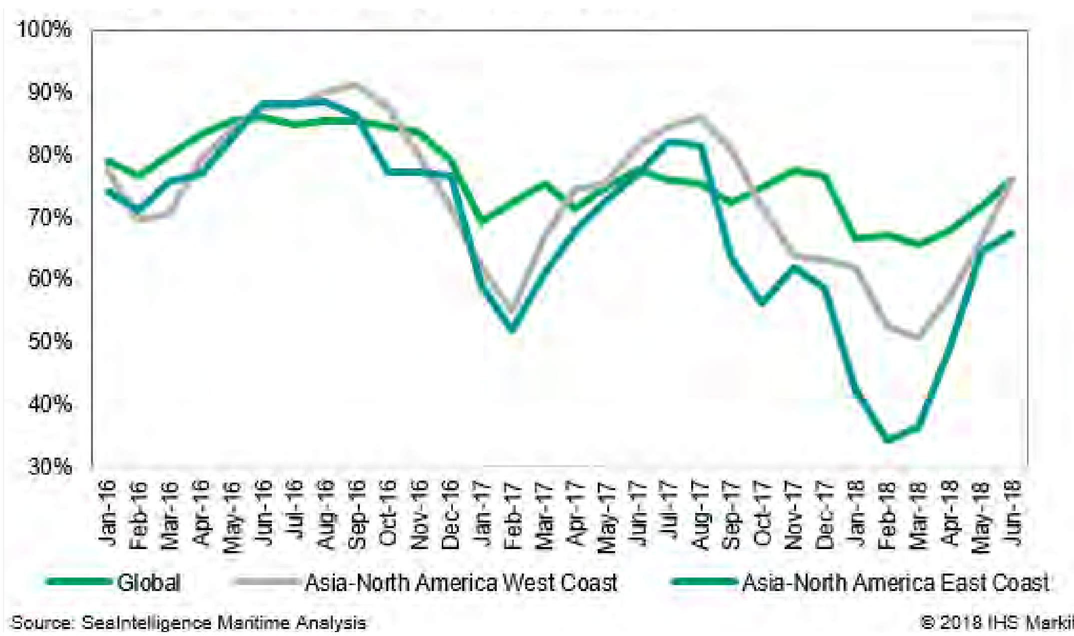

Figure 3. Percentage of Container Ship Sailings with On-time Arrivals[6]

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5 Parker, B. 2014. Busy Days at Galveston as Tankers Crowd the Anchorage. Seatrade Maritime News. https://www.seatrade-maritime.com/americas/busy-days-galveston-tankers-crowd-anchorages. MarineTraffic holds the original rights to the graphic. Accessed 3-5-2021.

6 Mongelluzzo, B. 2018. New APL Service to Test Expedited Demand on Trans-Pacific. Journal of Commerce. https://www.joc.com/maritime-news/trade-lanes/trans-pacific/new-apl-service-test-expedited-demand-trans-pacific_20180717.html. Accessed 3-5-2021.

Virtual vessel arrival reduces or eliminates the emissions generated while waiting at anchorage, improving air quality and the health of port workers and nearby communities.[7] These emissions can be a significant part of total marine vessel port emissions. For example, emissions at anchorage contributed about 7 percent of $PM_{2.5}$, 5 percent of NO_x, 8 percent of SO_x, and 7 percent of CO_{2e} emissions from ocean-going vessels at the Port of Los Angeles in 2016.[8] In addition, advance information regarding port delays allows a vessel to reduce its speed, using less fuel and generating fewer emissions en route.

Virtual vessel arrival systems can provide critical information about arrival times, which can then be used to help coordinate services between ports, terminal managers, and charter agencies. Once an arrival time is agreed upon, the weather analysis service provider works with the vessel operator using Automatic Identification System (AIS) data to recompute speed and fuel consumption rates and monitor ocean currents and weather data to determine the optimal route and vessel speed for the revised arrival time. The weather analysis service provider also provides designated stakeholders (such as beneficial cargo owners, terminal operators, and the port) with regular updates on vessel locations and projected arrival times, ensuring that dock and cargo handling equipment are readily available.

Virtual vessel arrival can also save time and money for ship operators and charterers. The ability to direct ships to a terminal with little or no delay, followed by quick freight transfer on arrival, means ports can operate more efficiently and vessels can get back to sea faster. Virtual vessel arrival information can be integrated with other systems such as gate management strategies[9] and port management information systems[10] to help improve scheduling for drayage truck pickups and rail transfers, and may offer additional benefits during extreme weather events such as hurricanes, allowing weather analysis service providers to reroute vessels to other ports more easily.

Ship owners and charterers adopting virtual vessel arrival can reduce fuel costs due to slower underway speeds at sea and less auxiliary engine use at anchor. Charterers may also see savings through reduced penalties paid for early vessel arrival.[11] Because virtual vessel arrival is still new, how potential cost savings will be shared among vessel operators, charterers, and the ports is yet to be determined.

Considerations: A virtual vessel arrival system requires more accurate dockside planning by port officials and terminal operators to project when berth space will be available for arriving vessels. It also requires better communication with port stakeholders, as well as vessel operators and weather analysis service providers, to ensure that cargo handling equipment is readily available when vessels arrive.

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7 Exposure to air pollution associated with emissions from diesel engines can contribute to significant health problems—including premature mortality, increased hospital admissions for heart and lung disease, increased cancer risk, and increased respiratory symptoms—especially for children, the elderly, outdoor workers, and other sensitive populations. (See U.S. Environmental Protection Agency. 2014. Near Roadway Air Pollution and Health: Frequently Asked Questions. https://nepis.epa.gov/Exe/ZyPDF.cgi/P100NFFD.PDF?Dockey=P100NFFD.PDF. Accessed 3-5-2021.

8 Starcrest Consulting Group, LLC. 2017. Port of Los Angeles: Inventory of Air Emissions—2016. https://kentico.portoflosangeles.org/getmedia/644d6f4c-77f7-4eb0-b05b-df4c0fea1295/2016_Air_Emissions_Inventory. Accessed 3-5-2021.

9 U.S. Environmental Protection Agency. 2020. Port Operational Strategies: Gate Management. https://www.epa.gov/ports-initiative/port-gate-management-strategies-improve-air-quality-and-efficiency-ports.

10 U.S. Environmental Protection Agency. 2020. Port Operational Strategies: Port Management Information Systems. https://www.epa.gov/ports-initiative/management-information-systems-improve-operational-efficiencies-and-air-quality.

11 Under certain contracts, if a vessel arrives early and must wait for a berth, the ship operator is entitled to compensation for demurrage fees.

The virtual vessel arrival system can also be beneficial to manage larger container ships to estimate and identify when dockside unloading space is available.

Implementing such a system may also require substantive changes to incentive structures and contracting terms for ship operators, charterers, and cargo owners, for the following reasons:

- Entry at congested ports is generally granted on a first come, first served basis, encouraging vessels to reach the port as quickly as possible.[12]
- Necessary contract modifications will vary depending on the type of charter agreement. Under "time charter" contracts, the charterer pays for the vessel's fuel and can direct the ship operator to reduce speed to conserve fuel. However, the charterer may prioritize timely arrival to the port area over cost. "Voyage charter" contracts typically make the ship operator responsible for fuel charges, providing a direct incentive to reduce speed and conserve fuel, although the operator is still required to comply with the arrival times agreed upon with the charterer.[13]
- Financial incentives for ship operators can be complicated as they relate to demurrage. Demurrage is a fee charged by a carrier, port, or railroad company for the storage of containers that exceed free time offered for loading/unloading. Once free time is expired, the shipper is charged a daily demurrage fee until the cargo is removed from the terminal. If Virtual Vessel Arrival is efficiently paired with truck pickup times for containers via truck appointment systems, demurrage fees can be minimized.

Appropriate port size and type: Virtual vessel arrival can be applied to any size and type of port, although larger ports with traffic congestion problems will benefit the most from adoption.

Emission Reductions[14]

Primary Pollutants affected: NO_x, PM, HC, CO, CO_2, and SO_2

Anticipated reductions: Reductions will depend on the number of vessels currently delayed, each vessel's auxiliary engine specifications, and the number of hours of delay for each vessel. The calculation methodology below can be used to estimate emission reductions from reduced vessel wait times at port but does not include emission reductions resulting from slower vessel speeds en route.

Calculation methodology: Calculating the emission reductions resulting from adoption of virtual vessel arrival is done on a vessel-specific basis and involves two steps: 1) determining vessel-specific emission rates accounting for the average power rating of the auxiliary engines and boilers used at offshore anchorage;[15]

[12] Price, T. 2011. Shipping Industry Launches "Virtual Arrival" to Save Fuel, Cut Emissions. Renewable Energy Magazine. https://www.renewableenergymagazine.com/energy_saving/shipping-industry-launches-virtual-arrival-to-save. Accessed 3-5-2021.

[13] Lindholm, E. 2014. Efficient Charterparties: Notice of Readiness, Slow Steaming and Virtual Arrival Agreements. https://www.academia.edu/9785488/Efficient_charterparties_-_Notice_of_readiness_slow_steaming_and_virtual_arrival_agreements. Accessed 3-5-2021.

[14] The information in this section is for illustration: although the types of inputs and methods used in this section are generally consistent with EPA established methodologies, it does not constitute official EPA technical guidance for regulatory purposes. Please note that EPA has comprehensive guidance on developing inventories of emissions from ports and port-related goods movement. EPA's *Port Emissions Inventory Guidance*, September 2020, EPA-420-B-20-046, is available at EPA's web site at: www.epa.gov/state-and-local-transportation/port-emissions-inventory-guidance. Accessed 3-5-2021.

[15] Average power ratings account for rated power as well as average load factor. For example, a 100 kW auxiliary engine operated at an average load of 50 percent would be assumed to operate at 50 kW for calculation purposes.

and 2) estimating the decrease in vessel wait times using data from the charterer or weather analysis service provider provided in the trip virtual vessel arrival summary reports. Individual trip calculations can be summed to determine fleet-wide benefits. The inputs required to calculate ship-specific emission reductions, and potential sources of data, are listed below.

- *Average auxiliary power for each vessel* (kW) for anchorage modes from vessel operators, classification societies, or default values provided in Table 1.
- *Average boiler power* (kW) for anchorage modes from vessel operators or default values provided in Table 1.
- *Auxiliary engine emission factors* (g/kW-hr) based on engine type, fuel type, and fuel sulfur concentration provided in Table 2.
- *Boiler emission factors* (g/kW-hr) based on fuel type and fuel sulfur concentration provided in Table 2.
- *Estimated hours the vessel would spend at anchorage* based on anticipated arrival time at full speed and the actual arrival time provided by the charterer or weather analysis service provider

Table 1. Average Auxiliary Engine and Boiler Loads at Anchorage by Ship Type[16]

Ship Type	Subtype	Aux (kW)	Boiler (kW)
Bulk carrier	Small	190	50
	Handysize	190	50
	Handymax	260	100
	Panamax	420	200
	Capesize	420	200
	Capesize largest	420	200
Chemical tanker	Smallest	80	125
	Small	230	250
	Handysize	230	250
	Handymax	550	250
Container ship	1,000 TEU	300	120
	2,000 TEU	820	290
	3,000 TEU	1,230	350
	5,000 TEU	1,390	450
	8,000 TEU	1,420	450
	12,000 TEU	1,630	520
	14,500 TEU	1,960	630
	Largest	2,160	700
Cruise	2,000 ton	450	250
	10,000 ton	450	250
	60,000 ton	3,500	1,000
	100,000 ton	11,480	500
	Largest	11,480	500
Ferry/passenger (C3)	2,000 ton	186	0
	Largest	524	0
Ferry/roll-on/ passenger (C3)	2,000 ton	105	0
	Largest	710	0
Fishing (C3)	All C3 fishing	200	0

Ship Type	Subtype	Aux (kW)	Boiler (kW)
General cargo	5,000 DWT	60	0
	10,000 DWT	170	75
	Largest	490	100
Liquified gas tanker	50,000 DWT	240	200
	100,000 DWT	240	300
	200,000 DWT	1,710	600
	Largest	1,710	600
Miscellaneous (C3)	All C3 misc.	190	0
Offshore support/drillship	All offshore support/drillship	320	0
Oil tanker	Smallest	250	100
	Small	375	150
	Handysize	625	250
	Handymax	750	300
	Panamax	750	300
	Aframax	1,000	400
	Suezmax	1,250	500
	VLCC	1,500	600
Other service	All other service	220	0
Other tanker	All other tanker	500	200
Reefer	All reefer	1,170	270
RORO	5,000 ton	600	200
	Largest	950	300
Vehicle carrier	4,000 vehicles	500	268
	Largest	500	268
Yacht	C2/C3[17] yacht	130	0

16 U.S. Environmental Protection Agency. 2020. Port Emissions Inventory Guidance: Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emissions. https://www.epa.gov/ports-initiative/port-and-goods-movement-emission-inventories. Accessed 3-5-2021.

17 C2 = Category 2 propulsion engines; C3 = Category 3 propulsion engines.

Table 2. Default Auxiliary Engine and Boiler Emission Factors (g/kW-hr)[18]

Engine	Fuel/Sulfur %*	Tier	Engine Type	NO_x	PM_{10}	HC	CO	CO_2	SO_2
Auxiliary	MGO/0.1%	1999 and earlier	MSD	10.9	0.188632	0.4	1.1	695.702	0.424248
			HSD	13.8	0.188632	0.4	0.9	695.702	0.424248
		2000–2010 (Tier I)	MSD	9.8	0.188632	0.4	1.1	695.702	0.424248
			HSD	12.2	0.188632	0.4	0.9	695.702	0.424248
		2011–2015 (Tier II)	MSD	7.7	0.188632	0.4	1.1	695.702	0.424248
			HSD	10.5	0.188632	0.4	0.9	695.702	0.424248
		2016 and later (Tier III)	MSD	2.0	0.188632	0.4	1.1	695.702	0.424248
			HSD	2.6	0.188632	0.4	0.9	695.702	0.424248
	RM/HFO/2.7% with scrubber†	1999 and earlier	MSD	14.7	0.077007	0.4	1.1	706.878	0.443799
			HSD	11.6	0.077007	0.4	0.9	706.878	0.443799
		2000–2010 (Tier I)	MSD	13.0	0.077007	0.4	1.1	706.878	0.443799
			HSD	10.4	0.077007	0.4	0.9	706.878	0.443799
		2011–2015 (Tier II)	MSD	11.2	0.077007	0.4	1.1	706.878	0.443799
			HSD	8.2	0.077007	0.4	0.9	706.878	0.443799
		2016 and later (Tier III)	MSD	2.0	0.077007	0.4	1.1	706.878	0.443799
			HSD	2.6	0.077007	0.4	0.9	706.878	0.443799
	LNG	Any	LNG	1.3	0.03	0.0	1.3	456.5	0.0
Boiler	MGO/0.1%	Any	Boiler	2.0	0.201687	0.1	0.2	961.8	0.586518
	RM/HFO/2.7%			2.1	1.871383	0.1	0.2	949.77	16.09992

* MGO—marine gas oil, RM/HFO—residual marine/heavy fuel oil, LNG—liquified natural gas, MSD—medium speed diesel, HSD—high speed diesel

† For control technology using higher-sulfur fuel alternative than ECA-compliant fuel

Use the following equation to calculate the emission reductions associated with virtual vessel arrival:

$$ER_i = \sum_1^Z (AP_z \times DR_z \times AEF_z + VB_z \times DR_z \times BEF_z) \times C$$

Where:

ER_i = Emission reduction for pollutant *i* (tons)

AP_z = Total auxiliary power for vessel *z* (kW)

DR_z = Anticipated time at anchorage for vessel *z,* based on the difference between the anticipated time of arrival at full speed and the actual time of arrival obtained from the weather analysis service provider or charterer (hours)

AEF_{zi} = Auxiliary engine emission factor for vessel *z* and pollutant *i* (g/kWh)

VB_z = Total boiler power for vessel *z* (kW)

BEF_{zi} = Boiler emission factor for vessel *z* and pollutant *i* (g/kWh)

C = Conversion factor from grams to short tons (1.1023×10^{-6} tons/g)

z = Individual vessel being evaluated

[18] U.S. Environmental Protection Agency. 2020. Port Emissions Inventory Guidance: Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emissions. https://www.epa.gov/ports-initiative/port-and-goods-movement-emission-inventories. Accessed 3-5-2021.

Example calculation: An oil tanker (smallest category) with Tier 1 MSD propulsion engines using marine gas oil (0.1% sulfur) is originally scheduled to arrive at port in 184 hours. While en route, its total trip time is increased to 196 hours to avoid an anticipated wait time of 12 hours at anchorage.

$$ER_{NOx} = (250\text{ kW} \times (196 - 184\text{ hours}) \times 9.8\text{ g NOx/kWh} + 100\text{ kW} \times (196 - 184\text{ hours}) \times 2.0\text{ g NOx /kWh}) \times 1.10231 \times 10^{-6}\text{ tons/g}$$

Where:

ER_{NOx} = 0.0351 tons of NO_x

Repeat this calculation for each pollutant and each vessel using virtual vessel arrival. For smaller ports with fewer vessels at offshore anchorage locations, these calculations can be performed on a simple spreadsheet.

Cost Components[19]

Capital costs: Additional capital investment will likely be limited to:

- Enhancements to existing vessel traffic monitoring and scheduling systems
- Communications system upgrades

Capital costs should be annualized over the expected lifetime of equipment and software to estimate the annual costs of the program.

Operational costs: Operational costs should be limited to:

- Contract agreement development (one-time cost for standard contract template)
- The potential additional staffing needed to administer the program, including training port or charter staff to support enhanced vessel traffic monitoring and scheduling

However, unexpected vessel delays could result in significant additional effort to manage complex scheduling changes.

Cost savings: Costs savings may be realized from multiple sources:

- Vessel fuel savings from reduced voyage speed and engine use at port while waiting for a berth
- Vessel operational cost savings (beyond fuel) from reduced time at port waiting for a berth if the vessel operator chooses later departure rather than slower speed en route to port
- Potential safety improvements with fewer vessels in the port area at the same time potentially reducing the cost of collisions, repairs and legal fees.
- Minimized demurrage fees if Virtual Vessel Arrival is efficiently paired with truck pickup times for containers via truck appointment systems.

[19] The information in this section is for illustration: it does not constitute official EPA technical guidance for regulatory assessments.

Example Program

BP conducted a pilot study that involved 50 successful virtual vessel arrival voyages, including a tanker route from Batumi on the Black Sea to the Isle of Grain in the United Kingdom (see Figure 4). Because the pilot study was conducted for the shipping industry, the analysis focused on the fuel savings and emission benefits associated with slow steaming along the total route rather than the benefits associated with reduced anchorage.[20] Results included reduced fuel consumption by 64.8 tons (27 percent) and reduced emissions of NO_x by 4.9 tons, CO_2 by 202 tons, and SO_2 by 3.9 tons.[21] Impacts associated with the reduction in vessel wait times and safety improvements at the port were acknowledged but not quantified.

Figure 4. Virtual Vessel Arrival Pilot Study Route[22]

[20] At the time of this writing, no studies have been identified specifically quantifying fuel and emissions benefits associated with reduced anchorage time.

[21] Intertanko and Oil Companies International Marine Forum (OCIMF). n.d. Virtual Arrival. https://www.ocimf.org/media/115960/Virtual-Arrival.pdf. Accessed 3-5-2021.

[22] Ibid.