NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Energy and Emission Performance of Singapore Harbour Craft

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Overview of Singapore Harbour Craft

Prefix	Description	Breakdown
SP	In-port limit carriage of passengers	passenger launch, ferry boat
SC	In-port limit carriage of dry or packaged cargoes	Mainly supply vessel and barge
SB	In-port limit carriage in bulk of petroleum, liquefied gases, liquid chemicals or vegetable/animal oils	Mainly bunker tanker and product tanker
ST	In-port limit for towing, pushing or pulling other vessels.	Mainly tug, some supply vessel and workboat for tug
SR	In-port limit for any other purposes	Barge, Cabin Cruiser, Jack-up Barge, Junk, Landing Craft, Motor Sampan, Passenger Hover Craft, Piling Barge, Research / Survey Vessel, Sludge / Slop Barge, Speed Boat


SP, Launch Craft ≤ 12 pax


SP, Passenger Ferry > 12 pax


SC, Ro-Ro Vessel

SC, Cargo Launch


SB, Bunker Tanker


ST, Harbour Tugboat


SR, Research Vessel

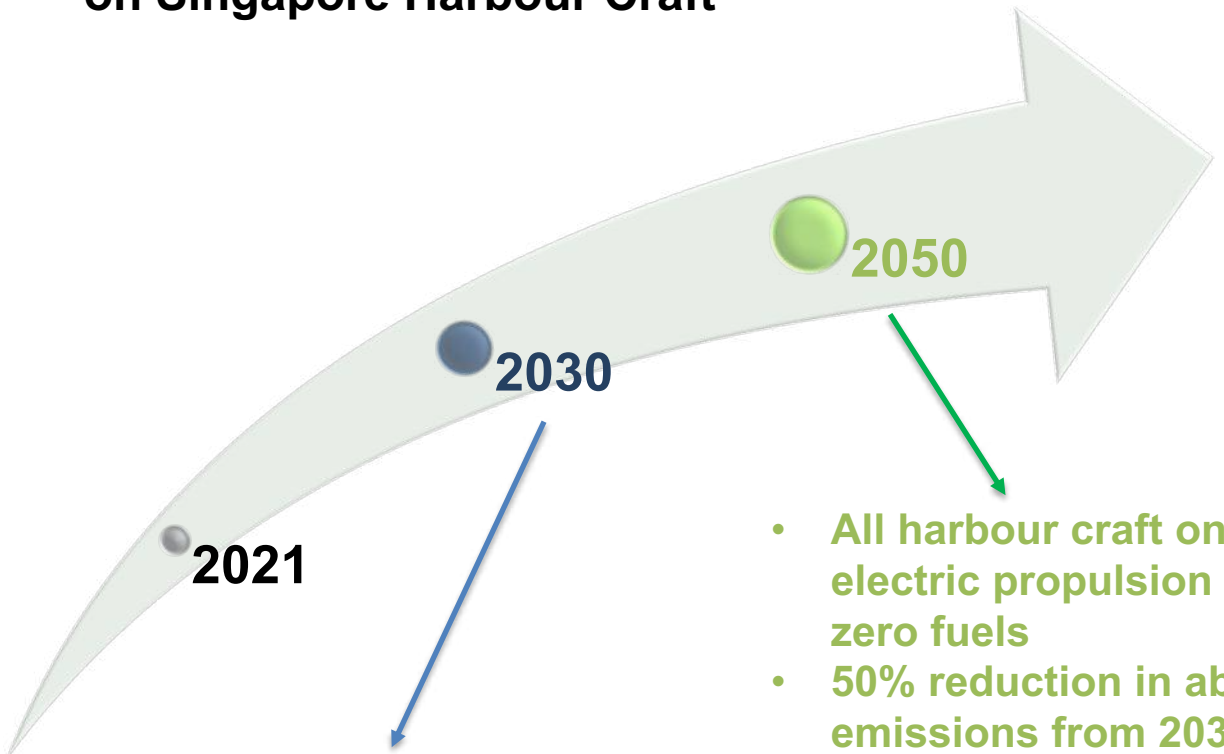
SR, Environmental Craft

In total, around 2,300 harbour craft (1,600 with engines) are operating within Singapore water: 11% tanker, 29% supply vessels, 7% passenger, 16% tug boat, 37% others

Source: MESD (2020), "A Study on the Future Energy Options of Singapore Harbour Craft".

Emission Targets for Singapore Harbour Craft

MPA's Maritime Singapore Decarbonisation Blueprint on Singapore Harbour Craft



- All harbour craft on low-carbon energy solutions
- 15% reduction in absolute emissions from 2021 levels

- All harbour craft on full electric propulsion and net zero fuels
- 50% reduction in absolute emissions from 2030 levels

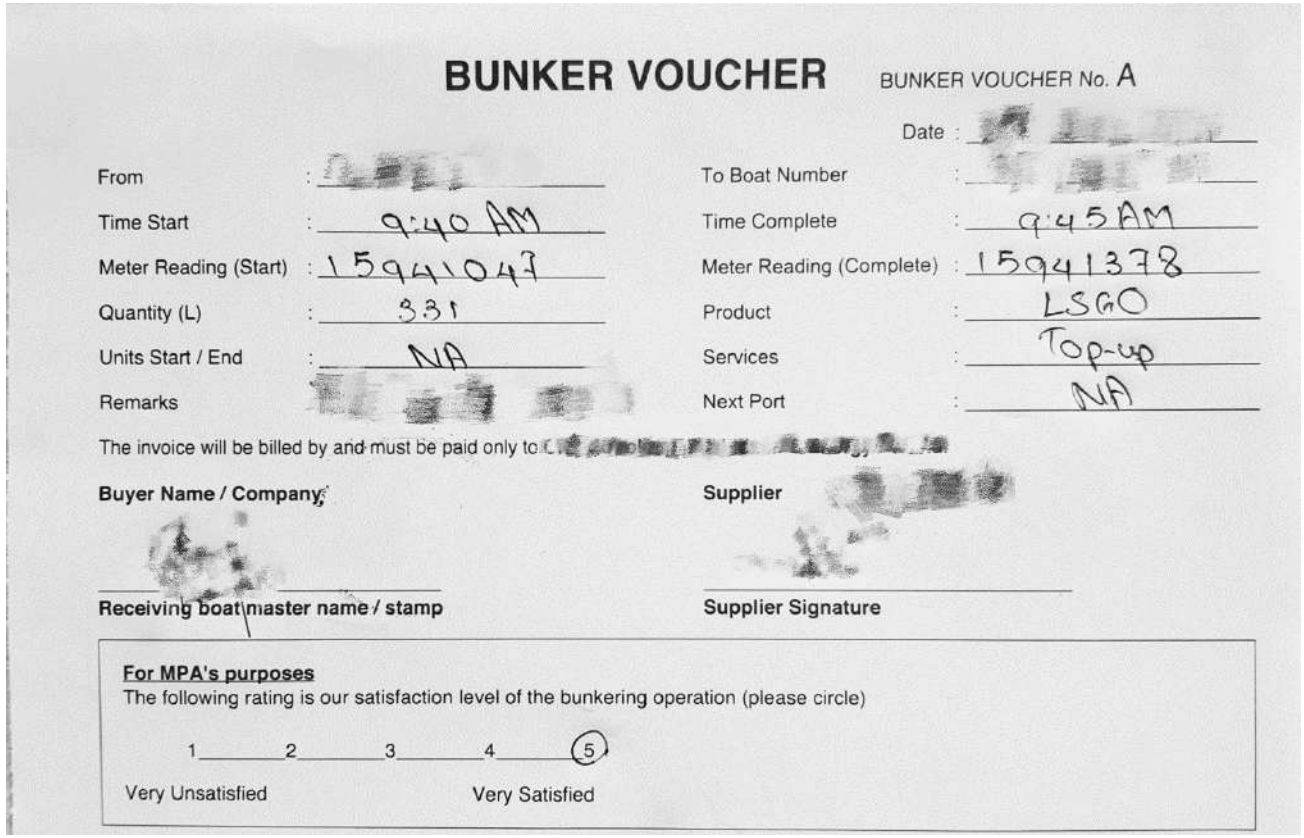
Questions to ponder for shipowners and operators:

- What is the current operational profile of my harbour craft?
- What is my baseline emissions?
- How are the baseline emissions correlated to the operational profile of my vessel?
- How should I know that an emission abatement solution works as expected for my harbour craft?
- To what extent will the emission abatement solution work?

Examples of emission abatement solutions:

- Optimising operations
- Use of an alternative fuel
- Battery propulsion
- Technical measures such as changed propeller and changed hull form
- Etc.

Existing Ways of Monitoring Fuel Consumption



BUNKER VOUCHER BUNKER VOUCHER No. A

Date : [redacted]

From	: [redacted]	To Boat Number	: [redacted]
Time Start	: 9:40 AM	Time Complete	: 9:45AM
Meter Reading (Start)	: 15941047	Meter Reading (Complete)	: 15941378
Quantity (L)	: 331	Product	: LSGO
Units Start / End	: NA	Services	: Top-up
Remarks	[redacted]	Next Port	: NA

The invoice will be billed by and must be paid only to [redacted]

Buyer Name / Company

[redacted]

Receiving boat master name / stamp

Supplier

[redacted]

Supplier Signature

For MPA's purposes

The following rating is our satisfaction level of the bunkering operation (please circle)

1 2 3 4 (5)

Very Unsatisfied Very Satisfied

Bunker records and tank sounding:

- The commonly-used and probably only ways for many ships to monitor a harbour vessel's energy performance
- Cost-effective and quite reliable in monitoring fuel consumptions at aggregated level
- However, the usefulness is solely reliant on the bunkering and tank sounding frequency
- The data lacks time resolution, may not be useful for vessel performance optimisation

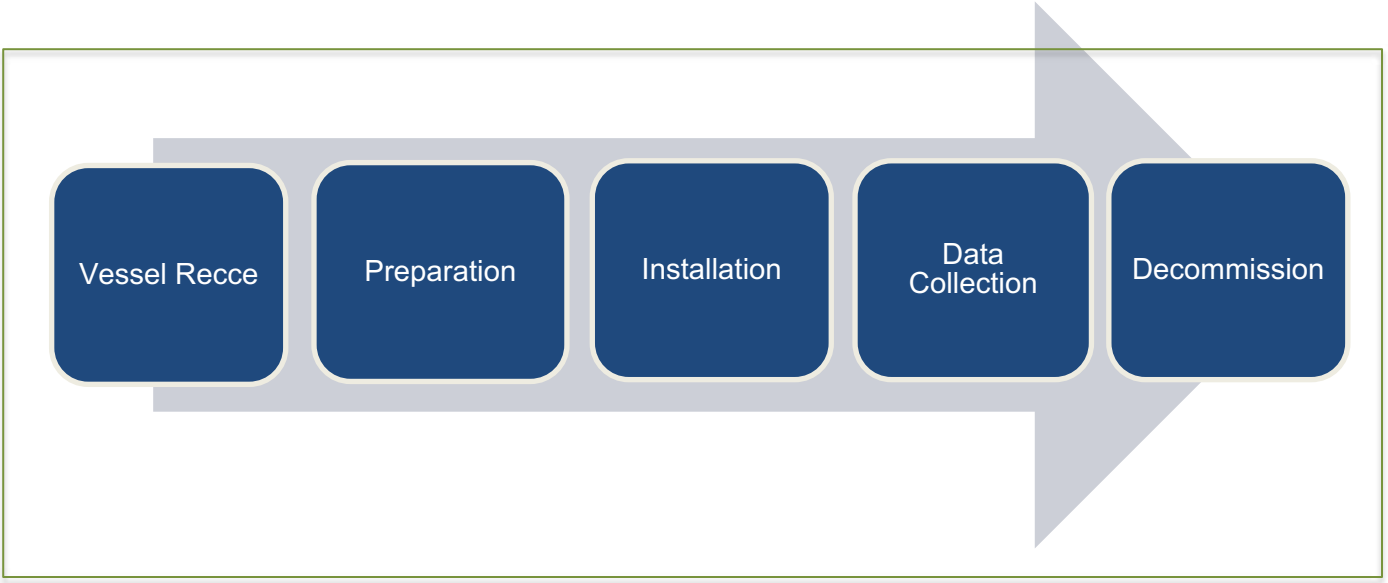
Energy and Emission Performance Measurement (EEPM)

EEPM Outcome

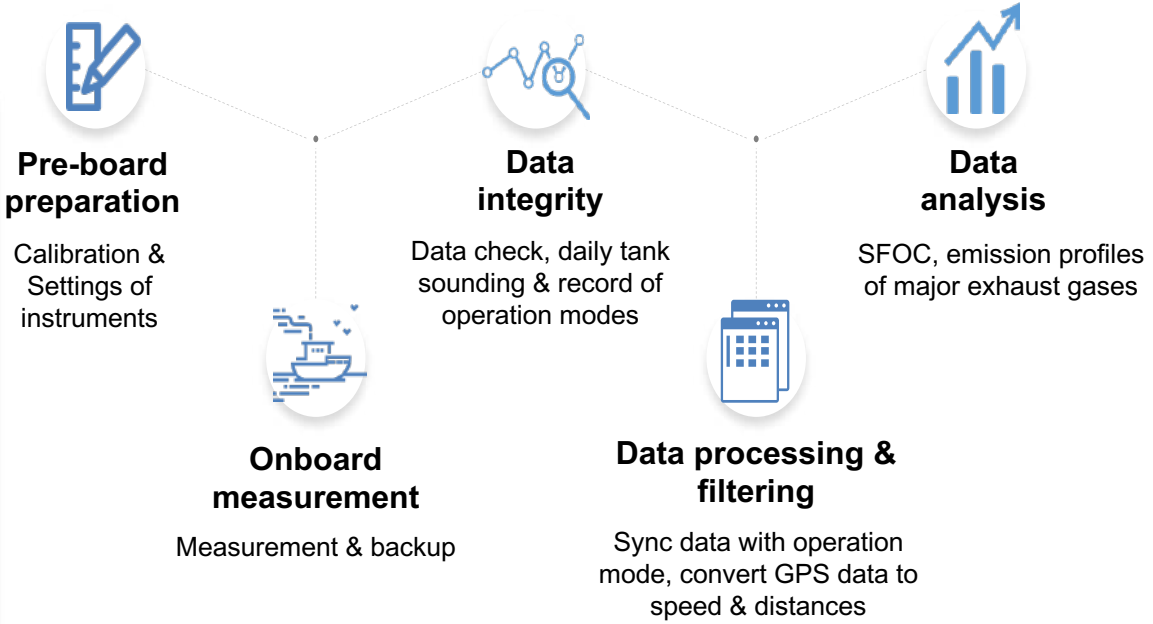
- Operational profile
- Engine performance
- Emission performance

- ✓ MESD's in-house development with a filed patent
- ✓ Provisional Patent name: ***A Method to Obtain Fuel Consumption and Emissions in Marine Propulsion Engines under Actual Operating Conditions***
- ✓ Targeting vessels that do not intend to install permanent sensors
- ✓ A holistic method from onboard data collection to data analysis

Physical Process Workflow



Data Workflow



EEPM: Portable Instrument and Data

Available Instrument

GPS Sensor

Shaft Power Meter

FO Flow Meter

Exhaust Gas Analyzer & Flow Meter

Electric Power Analyzer

RH & Temp Meter

Available instrument for EEPM

Instrument	Parameter	Current Status
FO Flow Meter	Volumetric Flow Mass Flow Flow Velocity	Fuel consumption record manually using sounding method
Shaft Power Meter	Shaft Power Shaft Speed Torque	Not recorded
Exhaust Gas Analyzer & Flow Meter	CO_2 CO SO_2 NOx NO_2 O_2 CH_4 Exhaust Temp Exhaust Flow	Not recorded
Temp & RH Sensor	Temperature Humidity	Can be recorded manually by crew
Electric Power Analyzer	Ampere Voltage Frequency	Not recorded
GPS Sensor	Speed Location Time	Through AIS, but historical records may be only available at a price

List of key parameters that EEPM can measure

EEPM: Onboard Data Collection

- Instruments are installed according to different onboard conditions
- Portable instruments are used to ensure minimum vessel modification

EEPM: Onboard Data Collection

- Vessel can go on business as usual for a period according to vessel owner's expectation
- Onboard instrument maintenance and data collection are carried out periodically to ensure acceptable data quality

EEPM Results Illustration

Operational Profile Analysis

What is the current operational profile of my harbour craft?

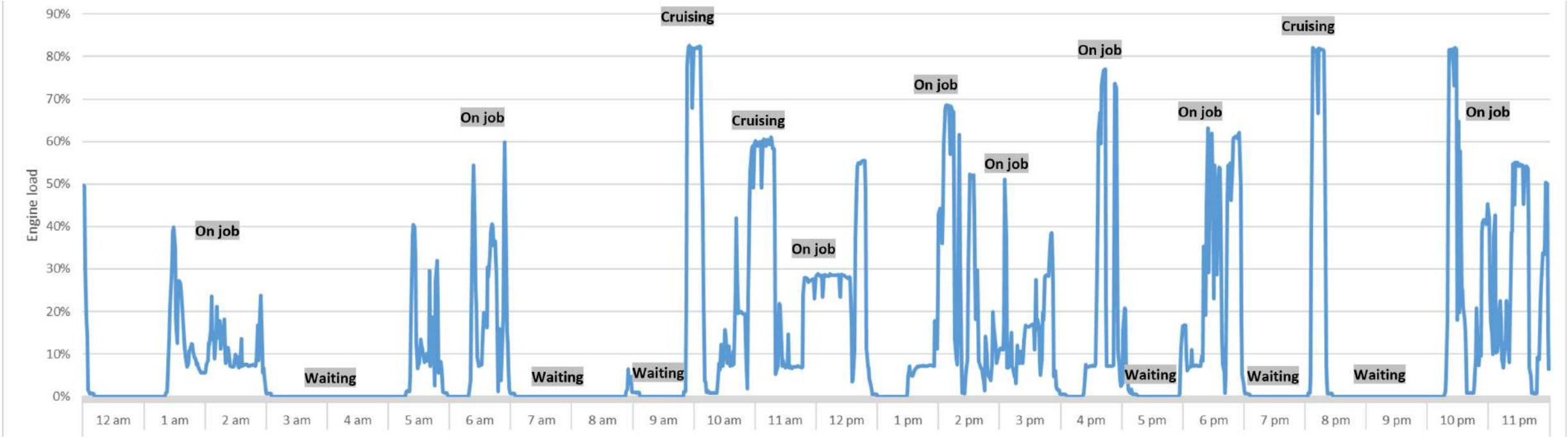
Emission Analysis

What is my baseline emissions?
How are the baseline emissions correlated to the operational profile?

Engine Performance Analysis

How should I know that an emission abatement solution works?
To what extent will the emission abatement solution work?

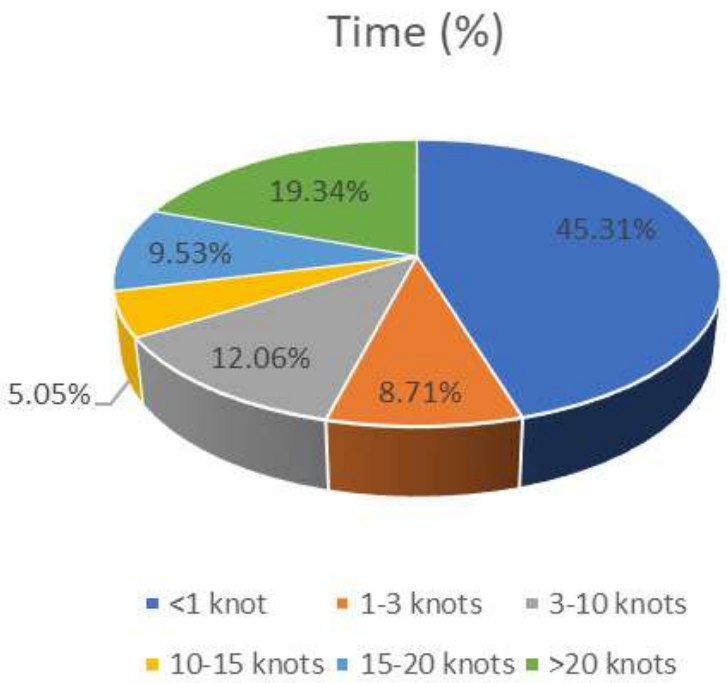
What is My Current Operational Profile?



Engine load profile of a ST vessel on a day

- Engine load at different vessel activities is shown in the figure
- This ST vessel tends to use about 60-80% engine load during cruising
- Fluctuating engine load during a job, ranging from 10% to 80%

What is My Current Operational Profile?



Speed Category	% of Time	Average Vessel Speed (knot)	Fuel Consumption per distance travelled (kg/NM)	Average Starboard Engine RPM	Average Port Engine RPM
<1 knot	45.3%	0.13	12.26	18.38	22.02
1-3 knots	8.7%	1.74	1.94	185.05	221.03
3-10 knots	12.1%	6.34	2.30	577.89	641.14
10-15 knots	5.0%	12.34	3.51	1,054.93	1,090.13
15-20 knots	9.5%	18.01	4.36	1,421.72	1,437.63
>20 knots	19.3%	22.86	5.29	1,661.48	1,684.97
All category	100.0%	7.73	4.63	604.18	624.43

Recorded time (%) spent and respective fuel consumption in each vessel speed category for a SP (<12 Pax) vessel

- This slide shows the use of raw operational data to generate detailed operational profile analysis
- This SP vessel spends most of the time (45%) with a speed less than 1 knot (engine off or idling)
- During cruising, this vessel tends to travel fast (>20 knots)
- Generally, a slower vessel is associated with a lower fuel consumption per distance

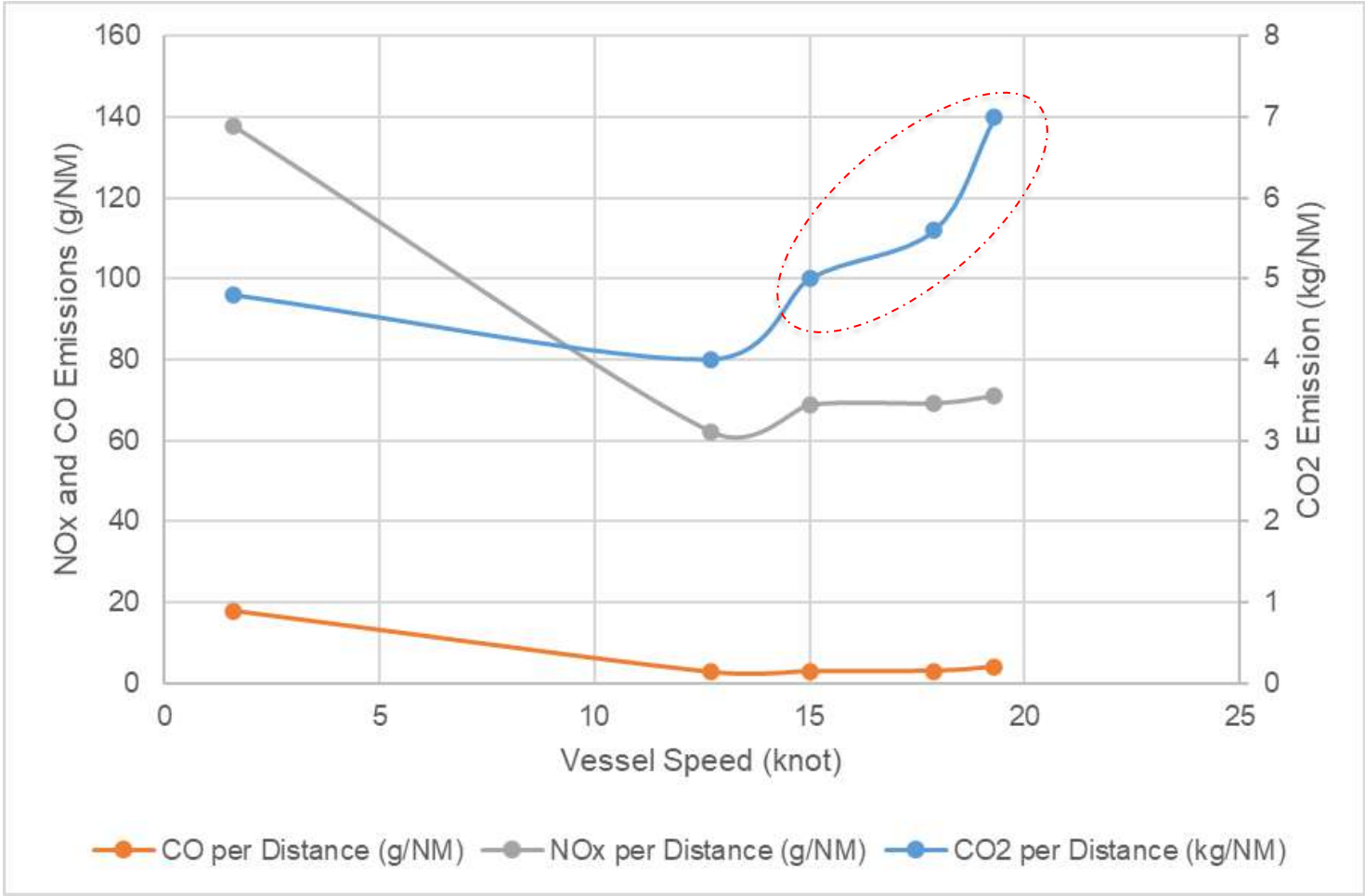
What is My Baseline Emissions?

Date	Gas Analyzer Measured time (min)	PT CO_2 Emission (kg)	STBD CO_2 Emission (kg)	PT NOx Emission (kg)	STBD NOx Emission (kg)	PT CO Emission (kg)	STBD CO Emission (kg)	PT Average RPM	STBD Average RPM	Distance Travelled (NM)
Day 1	122.0	66.9	67.0	1.07	1.01	0.057	0.055	1,089.3	1,076.1	16.6
Day 2	164.0	113.7	119.0	1.69	1.65	0.080	0.090	1,168.2	1,160.1	24.4
Day 3	57.0	38.2	40.3	0.56	0.61	0.034	0.036	1,112.7	1,111.6	7.9
Day 4	217.0	87.5	89.4	1.53	1.42	0.126	0.108	919.2	910.1	17.2
Day 5	90.0	11.1	10.4	0.35	0.32	0.064	0.052	686.0	666.5	0.0
All Days	650.0	317.3	326.1	5.20	5.00	0.36	0.34	998.6	988.1	66.2

Five-Day Emission Measurement for a SC Vessel

- This slide shows the results of a five-day emission measurement for both port (PT) and starboard (STBD) main engines of a SC vessel
- The emission amount is derived by using our onboard data and following the method in ISO 8178, Part 4
- Daily CO_2, NOx, and CO emissions are included in the table

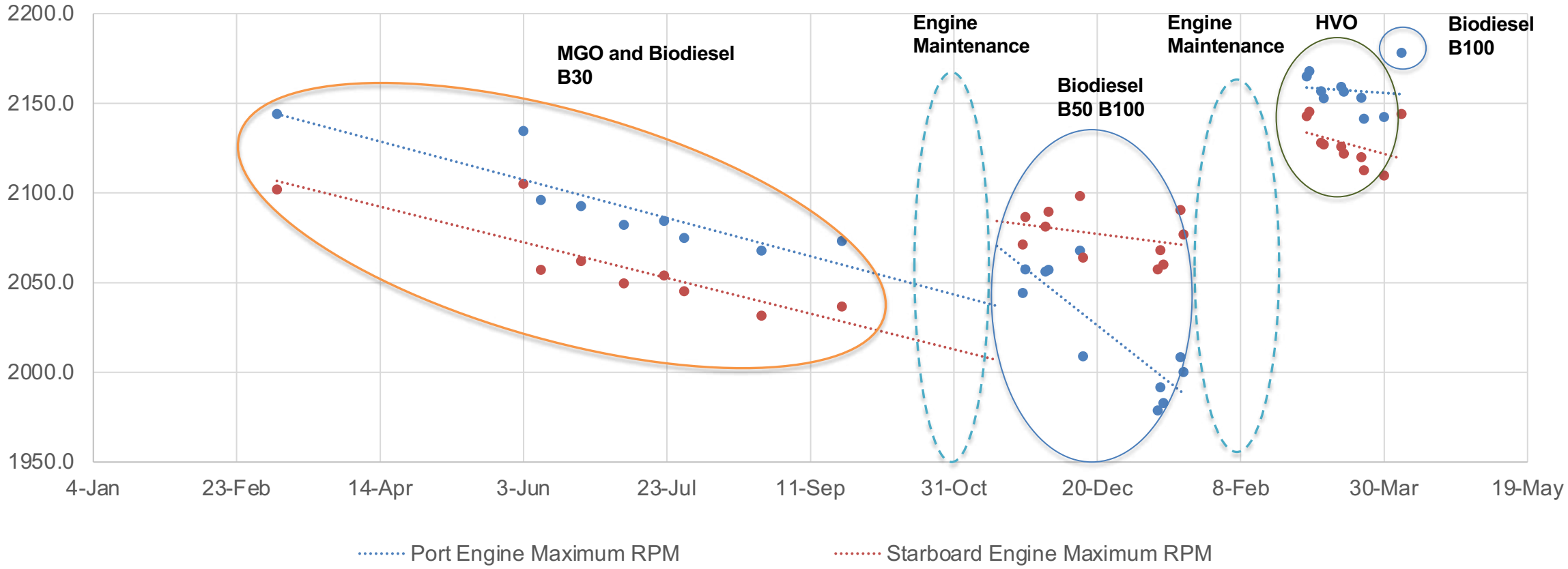
How are the Emissions Correlated to the Operational Profile?



An example of exhaust emissions of a SC vessel at different vessel speed

- This slide shows the exhaust emissions per distance (CO_2, NOx, CO) at different vessel speed for the same SC vessel
- Exhaust emissions per distance tend to be higher at very low speed or very high speed
- The result can help determine optimum engine load at actual operating conditions, i.e. trade-off between speed and emission
- Significant increase of CO_2 emissions happens at very high vessel speed

Whether an Emission Abatement Solution Work? To What Extent?



Maximum engine RPM trend of a SC vessel over a year

- General decreasing trend implying normal engine wear and tear
- Significant improvement in maximum engine RPM after engine maintenance
- The faster-than-expected decreasing trend after 1st maintenance may be due to the use of high-blend biodiesel

Whether an Emission Abatement Solution Work? To What Extent?

Dependent Variable: CO_2 Emissions	Coefficients	Standard Error	T-Stat	P-value
Intercept	-0.351	0.051	-6.877	<0.001
Maintenance effect	-0.377	0.021	-17.584	<0.001
Time to previous maintenance	0.00154	0.00011	13.470	<0.001
Engine RPM	6.44E-10	1.45E-12	444.387	<0.001
Engine room temperature	0.00834	0.00114	7.336	<0.001
Biodiesel blend ratio	0.140	0.014	10.254	<0.001
HVO blend ratio	0.0325	0.0289	1.127	0.260
F-value	36522.90			
Significance F	<0.001			
R-square	0.98309			
Adjusted R-square	0.98306			
Number of samples	3777			

An example of statistical analysis on a SC vessel emission performance

- This slide shows a statistical analysis how CO_2 emissions are affected by various factors
- The purpose is to identify the impact of using an alternative fuel after eliminating the impacts of other environmental and operational factors
- The results show that a higher biodiesel blend is associated with a slightly higher CO_2 emissions (about 3% increase at B100), while the relationship between HVO blend and CO_2 emission is not significant

Recap and Conclusion

- EEPM was developed by MESD to help vessel owners and operators to understand their vessels' energy and emission performance better without the need to install permanent sensors

- EEPM is a holistic method from onboard data collection to data analysis

- EEPM could help ship owners especially harbour craft owners to have a better understanding on:
  - ✓ The operational profile at actual operating conditions
  - ✓ The baseline emission in an actual operating environment
  - ✓ The usefulness of an emission abatement or fuel saving solution

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