Pilot Green Transport Fund

Final Report On
Trial of Diesel-Electric Propulsion System for Ferry
(The "Star" Ferry Company, Limited)

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(Trial Period: 1 December 2016 – 31 December 2017)

Executive Summary

1. Introduction

1.1 The Pilot Green Transport Fund (the Fund) is set up to encourage transport operators to try out green innovative transport technologies, contributing to better air quality and public health for Hong Kong. The "Star" Ferry Company, Limited (Star Ferry) was approved under the Fund for trial of one diesel-electric propulsion (DEP) system by retrofitting it to an existing ferry (World Star). The DEP system replaced the ferry's original diesel engine and diesel generators. The DEP system was expected to lower the fuel consumption and air pollutants emissions of the ferry. Through the tendering procedure stipulated in the Subsidy Agreement, Star Ferry appointed Leung Wan Kee Shipyard to retrofit the DEP system on World Star for trial. This renovated ferry is referred to as DEP ferry in this report.

1.2 The original ferry was retrofitted into the DEP ferry. Since there was no other ferry running the same route as DEP ferry, the historical data of the DEP ferry before retrofit would be used in this report to compare with data collected from the DEP ferry during the trial.

1.3 PolyU Technology and Consultancy Company Limited (PolyU) has been engaged by the Environmental Protection Department (EPD) as an independent third party assessor to monitor the trial and evaluate the performance of the green innovative technology under trial as compared with its conventional counterpart.

1.4 This report summarizes the performance of the DEP ferry in the twelve months of the trial and compares it with the performance of the original ferry (hereafter called conventional ferry).

2. Trial Product and Ferry

2.1 The DEP system includes two 465 bkW (425 ekW) Caterpillar diesel generators, a 118 ekW Caterpillar diesel generator, two 500 kW electric motors and the associated control equipment. The two 465 bkW generators meet International Maritime Organization (IMO) Tier II and United States Environmental Protection Agency (USEPA) Tier 3 emission standards. A 465 bkW generator is to power the electric motors to propel the ferry and the 118 ekW generator is to provide electricity for on-board installation's use. Another 465 bkW generator is for stand-by purpose as required by

Marine Department for safety reason. The DEP system replaced the ferry's original 540 kW pre-1990 diesel engine as well as two 40 kW diesel generators. Besides, a seawater scrubber system (ie, trial product under PGTF) was also installed in the DEP system to reduce air pollutants such as sulphur dioxide (SO_2) and smoke in the exhaust gas.

2.2 Key features of the DEP system, DEP ferry and the conventional ferry are in Appendix 1 and photos of the DEP system and the ferry are in Appendix 2. The DEP ferry provides round trip service from Tsim Sha Tsui Pier to Disneyland Resort Pier twice a day, a trip to Tsing Ma Bridge and a harbor cruise once per day. Daily operating hours for providing such service is about 11 hours for the DEP ferry.

3. Trial Information

3.1 The trial started on 1 December 2016 and lasted for 12 months. However, the trial was considered to be in a preliminary trial stage for the months of December 2016 to March 2017 as Star Ferry was familiarizing/testing the performance and characteristics of the engine and the ferry though it started providing services. More representative trial under normal daily operation was thus considered to start in April 2017. Star Ferry provided data from December 2016 to December 2017 for analysis.

3.2 Star Ferry was required to collect and provide trial information including the DEP ferry operation data and maintenance records. DEP ferry operation data include passenger carried, operating hours, amount and cost of diesel fuel consumed. Maintenance records include cost and downtime associated with scheduled and unscheduled maintenance of the DEP ferry related to the performance of the DEP system. Similar data are also required from the conventional ferry. In addition to the cost information, reports on maintenance work, operational difficulties and opinions of the captains of the DEP ferry and passengers were collected to reflect any problems of the DEP ferry.

4. Findings of Trial

4.1 Operating Costs

4.1.1 The following table summarizes the statistical data of the DEP ferry and the conventional ferry. The fuel consumption of DEP ferry was 0.6 litre per hour (1%) slightly higher than that of the conventional ferry. There is uncertainty in the data analysis, therefore, there is statistically no difference between the fuel consumption of the DEP ferry and the conventional ferry.

Table 1: Key operation statistics of each ferry (December 2016 – December 2017)

	DEP Ferry [1]	**Conventional Ferry (historical data)**
Total time travelled (hr)	2,276	-
Average fuel consumption (litre per hour)	63.2	62.6 [2]
Average fuel cost (HK$/hr) [3]	1,055	1,045 [4]
Total operating cost per hr (HK$/hr)	1,080	1,189
Downtime (no. of working day) [5]	24	16.9 [6]

[1] As December 2016 – March 2017 were in preliminary trial stage and the data collected are not representative, therefore, the evaluation was taken from April 2017 to December 2017.

[2] Average fuel consumption for 2001-2010, except for 2007 because the fuel consumption in 2007 was exceptionally low compared with those in the other years

[3] Based on the listed price

[4] Based on the same mean fuel price of the DEP ferry

[5] Downtime refers to the working days the ferry was not in normal operation, which is counted from the first day it stopped normal operation till the day it resumed normal operation.

[6] Average of downtime in 2009 and 2010 for nine months

4.1.2 No change in the fuel consumption by DEP ferry compared with conventional ferry is mainly due to increase of gross tonnage of DEP ferry because of the retrofitted DEP system and an additional weight of seawater scrubber and its fuel consumption. Besides, change of operational mode from operating for short route which involved longer idling time to long trips with very short idling time may also cause increase in fuel consumption. Furthermore, the DEP system has constant speed at 1,800 rpm while the old engine's speed was around 800 rpm during cruising and around 520 rpm during idling, therefore, the DEP system may consume more fuel than the conventional ferry. However, the increase in fuel consumption due to change of operational mode and DEP system could not be quantified due to lacking detailed information for analysis.

4.1.3 During the trial period of December 2016 to December 2017, the DEP ferry had two scheduled maintenances and nine unscheduled maintenances. The DEP ferry had a half-yearly scheduled maintenance in March 2017 which involved cleaning of hull, sea chest gratings and sea trial; however, it is outside the representative trial period (April to December 2017), and therefore, excluded in the assessment. The second half-yearly scheduled maintenance was conducted in September 2017 which involved the running test of the 3 generator sets and a statutory overhaul involving on slip survey (external); propeller, shaft, rudder and gearbox cleaning; ship hull painting; operation trial; and inspection and cleaning of the two seawater scrubber tanks and nozzles. The scheduled maintenance costed HK$57,084 involving 19 days of downtime. Five unscheduled maintenances involved minor repairs of the generator sets and the seawater scrubber system, resulting in 1 day of downtime in total in the representative trial period. As it is under warranty, no maintenance cost was incurred.

4.1.4 The total operating cost is $1,080 per hour for the DEP ferry and $1,189 per hour for the

conventional ferry based on historical data. Compared with the conventional ferry, the total operating cost for the DEP ferry was 9.2% lower. The DEP ferry and conventional ferry had a total of 19 days and 16.9 days downtime, respectively associated with scheduled or unscheduled maintenances required, therefore, the utilization rate was about 93% for the DEP ferry and about 94% for the conventional ferry in the trial period.

4.2 Performance and Reliability

4.2.1 Several captains had operated the DEP ferry. Three captains were interviewed in the trial period and they had different opinions on the operation of the DEP ferry. Two of them had positive responses on the DEP ferry in general but they found the DEP system was noisy and the propulsion system was slow. Another captain had problem in operating the ferry and felt that the performance had deteriorated with time and it was noisy.

4.2.2 The passengers' feedback was in general very positive except some felt that the engine was noisy.

4.2.3 Star Ferry agreed that the green ferry could help improve the air quality and would replace all existing conventional ferries with the green ferry.

4.2.4 During the trial period, the total fuel consumption of the DEP ferry was 140,359 litres of diesel oil, which is 2.4% slightly lower than that of conventional ferry if seawater scrubber and its associated fuel consumption were excluded. Assuming same operating hours with DEP ferry, the conventional ferry consumed 142,478 litres of diesel oil, the saving in fuel consumption during the trial period is thus about 2,119 litres of diesel oil with an equivalent reduction in carbon dioxide equivalent (CO_2e) emission of 5,545 kg.

5. Air Pollutants Emissions

5.1 Apart from obtaining operational data and maintenance record of the DEP system, nitrogen oxides (NO_x), sulphur dioxide (SO_2) and smoke intensity in the exhaust gas were also measured to check the environmental performance of the DEP system compared with the old diesel engine in the conventional ferry.

5.2 All the diesel engines for the DEP system meet EPA Tier III/IMO II emission standards. Based on the measured NO_x concentration, the evaluated $BSNO_x$ values (5.69 to 6.39 g/kWh with an average of 6.09 g/kWh) are lower than the IMO II NO_x limit for the engine (7.85 g/kWh at 1,800 RPM).

5.3 With reference to the Feasibility Study of using Water Scrubber for Ferry (ie, Day Star), The Hong Kong University conducted in September 2008 (hereafter called HKU Study 2008), the estimated NO_x emission of the ferry using old diesel engine similar to DEP ferry was 19.4 g/kWh, which is about three folds of the evaluated average NO_x emission of the DEP ferry (ie, 6.09 g/kWh)

or about 69% reduction in NO_x emission by using DEP engine.

5.4 Black smoke which was emitted during manoeuvring operation of the conventional ferry was not observed from the DEP ferry, indicating that the DEP system significantly reduces the stack emission compared with the conventional ferry. Smoke opacity was measured at the exhaust of DEP system and the average smoke opacity in cruising mode was 1.9 HSU. In the HKU Study 2008, the average measured smoke opacity of Day Star at cruising mode operation was 6.0 HSU. That indicated the smoke opacity was reduced about 68% by using DEP system on ferry.

5.5 The average SO_2 emission from the exhaust of DEP system was 6.0 ppm in cruising mode. The HKU Study 2008 shows an average SO_2 emission of 34.3 ppm in the exhaust of the old diesel engine. The results indicate that there is a significant reduction in SO_2 emission (about 83%) in the DEP ferry's exhaust gas. According to Star Ferry, the sulphur content of diesel used in 2008 was about 0.33%. Since 2014, the fuel sulphur content is tightened from 0.5% to 0.05% and the significant reduction of SO_2 emission in exhaust is therefore mainly due to the tightening of statutory fuel sulphur content in recent years rather than improvement in engine technology.

6. Summary

6.1 The trial showed that under local operating conditions, the DEP system could meet the user's operational requirements. Moreover, the DEP system did not cause any problems to the ferry operator during the trial period and was able to cope with required tasks. The captains of DEP ferry found no problem in operating the ferry in general but found the DEP system was noisy. The ferry was able to cope with its assigned duties. Its operation was smooth while the DEP ferry and the conventional ferry for comparison had similar level of utilization rates.

6.2 The analysis shows that there is statistically no difference between the fuel consumption of the DEP ferry and the conventional ferry and it is considered mainly due to (1) increase in weight of DEP ferry after retrofit; (2) an additional weight of seawater scrubber and its fuel consumption; (3) change of operation mode; and (4) higher engine speed of DEP system. If the extra weight of seawater scrubber and its fuel consumption were excluded, the DEP ferry could save about 2.4% of fuel with an equivalent reduction in CO_2 equivalent emission of 5,545 kg. There was no indication that the fuel consumption rate had deteriorated in the trial period.

6.3 Besides, NO_x, SO_2 and smoke intensity in the exhaust gas of the DEP engine were also measured to check the environmental performance of the DEP system compared with the old diesel engine in the conventional ferry. The measured NO_x results show that the DEP system complies with IMO Tier II and USEPA Tier III emission standards, and reduces NO_x emission and smoke intensity by about 69% and 68%, respectively compared with the old diesel engine. Compared with the old diesel engine which consumed fuel of 0.33% sulphur content in the past, the average SO_2 emission level from exhaust of DEP system (before seawater scrubber) was reduced by about 83% due to tightening of statutory fuel sulphur content to 0.05% in recent years rather than improvement in engine technology.

Appendix 1: Key Features of the Trial Product and Ferries Involved in the Trial

1. Diesel-electric propulsion (DEP) system for ferry

Main Generator Set

No. of generator set:	2
Maker:	Caterpillar
Model:	C18 Marine Generator Set
Rating:	425 kW (531 KVA) @1800 rpm, 60 Hz
Engine:	6-cylinder in line diesel engine
Emission standard:	EPA Tier 3/IMO II

Auxiliary Generator Set

No. of generator set:	1
Maker:	Caterpillar
Model:	C7.1 Marine Generator Set
Rating:	118 kW (148 KVA) @1800 rpm, 60 Hz
Engine:	6-cylinder in line diesel engine
Emission standard:	EPA Tier 3/IMO II

Propulsion Motor

No. of motor:	2
Maker:	Dezhou Hengli
Model:	YVF2-4503-8-H
Rating:	500 kW, 440 V, 60 Hz

2. Ferry with DEP

Name of vessel:	World Star
Type:	Class I Ferry Vessel
Port of Registry	Hong Kong
Length overall:	46.00 meter
Extreme breadth:	9.3 meter
Light Ship Displacement:	337,880 kg
Gross Tonnage:	364,000 kg
Net Tonnage:	109,000 kg
Passenger capacity:	408 people
Year of manufacture:	1989; retrofitted with DEP in 2016

3. Ferry with Conventional Diesel Propulsion System

Name of vessel:	World Star
Type:	Class I Ferry Vessel
Length overall:	46.00 meters
Extreme breadth:	9.3 m
Light Ship Displacement:	323.39 tonnes
Gross Tonnage:	352 tonnes
Net Tonnage:	186 tonnes
Passenger capacity:	755 people
Year of manufacture:	1989
Main engine:	MAN 6L 20/27; 900 rpm, 540 kW
Generator set:	2 nos.of Cummins 6B5.9; 1500 rpm, 40 kW [total 80 kW]

Appendix 2: Photos of Ferry and Diesel Electric Propulsion System

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<tr><td>Front view of Ferry</td><td>Side view of Ferry</td></tr>
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<tr><td>#1 main diesel generator (for propulsion)</td><td>#2 main diesel generator (for propulsion)</td></tr>
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<tr><td>Auxiliary diesel generator</td><td>Propulsion motor</td></tr>
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