Eco-Piloting Best Practices will Reduce Emissions of Nitrogen Oxides from Passenger Ferry Operations

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ABSTRACT
Air pollution negatively impacts climate change and human health. MARPOL Annex VI regulations for the prevention of harmful emissions from ships dictate engine performance standards and fuel composition. On-land transportation in the US has a long history of regulation and has developed best practices to minimize harmful emissions. Best practices have not been developed for merchant vessels which present a missed opportunity for emission reduction, particularly for high profile inland operations such as passenger ferries. Content analysis of five eco-driving sources was conducted to identify comprehensive eco-driving best practices for adaptation to eco-piloting best practices. Quantitative analysis of engine specifications and vessel maneuvering characteristics was conducted to support the best practices and prove the emission reduction of oxides of nitrogen (NOx). Eco-piloting best practices are a source of emission reduction that will complement existing engine and fuel requirements and allow ferries to better compete with other transportation sectors.

1. INTRODUCTION

Air pollution is an environmental health risk with an annual global financial impact of over 5.1 trillion USD, and an annual human health impact of over 3.2 million premature deaths [1]. Shipping contributes between two and six percent of global air pollution, depending on the pollutant, and the levels of pollution are disproportionately high in port cities [2; 3].

MARPOL Annex VI establishes progressive reductions on the levels of NOx, PM, and SOx in the exhaust gas from ocean-going ships. Vessels which operate exclusively in the inland waters of the US and transit no further than 24 miles off the coast, such as passenger ferries, are regulated under amendments to the federal Clean Air Act (CAA) [2; 3]. Engine tier standards in the CAA are similar to those in MARPOL, regulating emissions of PM and NOx, with slight variations. For the purpose of this paper, the US CAA standards are referenced.

A complimentary strategy for NOx emission reduction is operational modification. Speed changes are often conducted for operational goals, but Corbett, Wang, & Winebrake [4] demonstrate that speed reductions can reduce emissions from ships by 70%. The ports of Los Angeles and Long Beach reduced shipping emissions by 43-49% between 2008 and 2013 through a Voluntary Speed Reduction (VSR) program [5].

The regulatory compliance framework for on- and off-road vehicles in the US is similar to that of vessel compliance, combining engine specifications and fuel composition. After mechanical emissions management and fuel composition standards for on- and off-road vehicles were implemented, companies turned to operational management strategies for additional emission reduction potential.

Eco-driving is an operational management modification which promotes fuel-efficient operations through reduced engine idling, light braking, coasting or using the engine to decelerate, anticipating the flow of traffic, maintaining steady speeds, using cruise control, and following the speed limit [6; 7]. Eco-driving programs achieve seven to ten percent reduction in immediate fuel consumption and between four and seven percent in the long-term [6; 8].

This study addresses the following research questions: What is a comprehensive set of eco-driving best practices? How would the eco-driving best practices be adapted for passenger ferry operations? Could NOx emissions be reduced through the application of eco-piloting best practices? The hypothesis for this study was that passenger ferry operations can reduce NOx emissions by adopting eco-piloting best practices.

2. METHODS

This study was conducted using a mixed methods approach with content analysis of five sources of eco-driving best practices for on- and off-road transportation. To identify a comprehensive set of eco-driving best practices, peer-reviewed articles on eco-driving programs for on- and off-road transportation sectors were reviewed. Three articles were selected based on recency and the detail of reporting the specific best practices. Multiple eco-driving training videos were reviewed, and two eco-driving training videos were selected for their recency, detail, and legitimacy. Online availability was a factor in the video selection.

The eco-driving best practices were adapted to eco-piloting best practices for passenger ferries with consideration for engine propulsion and operational demands. NOx emitted from passenger vessels far exceeds levels emitted from on-road vehicles per passenger mile so it is a pollutant of particular concern for ships and was therefore selected for this study [9].

For the scope of this study, due to time, funding, and data availability, quantitative analysis of emission reduction from the application of the eco-driving best practices was demonstrated for only two of the five best practices. Three passenger ferries with a variety of engine type, propulsion type, in-service date, and run in the San Francisco Bay were chosen due to their high-profile activity, dependence on public funding, and engine types similar to off-road vehicles.

2.1 Quantitative Analysis of Best Practice 1: Minimize Engine Idling

The manufacturers engine specifications for each of the three ferries was analyzed to measure NOx emission reduction from elimination of engine idling while alongside the dock. Emissions produced from operating the vessel at minimum engine speed were multiplied by the weekly and annual idling hours of each of the three ferries. Emissions produced were calculated by multiplying the power produced at minimum engine speed by the formula from the manufacturer's engine specifications for calculating NOx emissions in grams per kilowatt-hour. Idling hours were calculated based on time alongside the dock reflected in vessel schedules [10]. It was assumed the engines would be shut down for vessel standby times which exceed 30 min.

Vessel NOx emissions from transiting were calculated to determine the percent of emissions reduction from the application of best practices. Vessel schedules were referenced to determine transit times [10]. Transit times were separated into full ahead operations and wake restricted waters where the vessel must operate at Min AH. The main propulsion power output at FAH and Min AH were multiplied by the times spent at the respective speeds to calculate the annual kWh production. The annual kWhs for transits were then multiplied by the emissions factor for each vessel to calculate the total annual NOx emissions in metric tons (MT). The MT were compared to the emissions reduction from the application of the best practice to calculate the percentage of NOx emissions reduction.

2.2 Quantitative Analysis of Best Practice 4: Reduce Inefficient Revolutions per Minute (RPM) Use

Revolutions per minute (RPM) use may be inefficient during the docking operation called walking the vessel. A vessel with twin propulsion systems may operate the systems with one engine running with its propeller or jet drive in the ahead direction and the other engine with its associated propulsion package in the astern direction, and the rudder controlling lateral motion toward or away from the dock. Time spent walking the vessel on and off the dock is variable; 30 seconds for each docking/undocking was used for this study.

A quantitative analysis was conducted to evaluate the reduction of NOx emissions from walking the vessel with minimal RPMs ahead and astern as opposed to half or full RPMs. The number of dockings were calculated from the vessel schedules [10]. Emissions produced were calculated by multiplying the power produced at the various engine speeds by the emissions factor for NOx in grams per kilowatt-hour. The engine manufacturer, Cummins Inc., provided the emissions factor for the MV Peralta. The emissions factors for the MV Solano and MV Cetus were obtained from California EPA emissions tier level limits [11]. The percentage of NOx emissions reduction was calculated using the same method as was used for Best Practice 1.

3. RESULTS

3.1 Eco-Driving Best Practices

After content analysis of the five sources, the following five eco-driving practices were chosen: 1. Minimize engine idling time; 2. Minimize the use of brakes; coast or use engine to slow; 3. Maintain a steady speed when possible; 4. Use the throttle conservatively; 5. Look ahead [6; 8; 12; 13; 14]. Gear selection was a heavily represented category that belongs in the eco-driving best practices but was intentionally removed from this list due to the lack of application for marine diesel engines.

3.2 Passenger Ferry Eco-Piloting Best Practices

Best Practice 1. Minimize Engine Idling: Turn off the main propulsion engine when alongside the dock, weather permitting.

Best Practice 2. Minimize the use of Astern Propulsion to Reduce Speed: Stop the propulsion when the vessel is at the stopping distance from the dock; minimize astern propulsion for slowing down.

Best Practice 3. Maintain a Steady Speed: Avoid speed changes when possible; favor early course changes for traffic maneuvers.
Best Practice 4. Reduce Inefficient RPM Use: Ensure operations such as walking the vessel on and off the dock utilize minimal RPM necessary for safe operations.
Best Practice 5. Look Ahead: Anticipate traffic, obstructions, and docking operations by practicing anticipatory piloting.

3.3 Emission Reduction from the Application of Eco-Piloting Best Practice 1

The three ferries idle alongside the dock between arrival and departure from 4.2 to 20.4 hours per week, depending on service requirements. The Peralta emits 0.7 MT per year while idling alongside the dock, the Cetus emits 0.1 MT, and the Solano 2.8 MT. Tables used have been omitted due to article length restrictions.

3.4 Emission Reduction from the Application of Eco-Piloting Best Practice 4

There is an evident correlation (r = 1) between RPM and NOx emission; when engine speed is reduced, NOx emissions are reduced for the three vessels. This data was used to create Table 1, which demonstrates potential emission reduction from the application of Best Practice 4 for walking the vessel for docking and undocking operations using less power.

Table 1. Summary of Emission Reduction for Eco-Piloting During Docking and Undocking as Compared to Walking Vessel Using FAH/FAS Engine Orders

	HAH/HAS as Compared to FAH/FAS			
Vessel	**Total Annual Power Reduction**	**Percentage Reduction**	**NOx Emissions**	**NOx Emissions**
	kWh	%	MT	%
Peralta	71,344	46	4.4	58
Cetus	89,245	30	0.1	30
Solano	80,686	27	5.8	27

	Min AH/Min AS as Compared to FAH/FAS			
	kWh	%	MT	%
Peralta	145,721	95	7.2	95
Cetus	210,527	70	0.2	70
Solano	234,780	78	17.0	78

The reduction of emissions from Table 1 are referenced in Table 2 along with the total transiting emissions of NOx.

Table 2. Annual Emissions Reduction for Eco-Piloting Best Practice 4.

Walking at HAH/HAS						
	Annual Emissions Reduction from Walking (HAH/HAS) (NOx)	**Annual Restricted Wake Operating (Min AH)**	**Annual Transit Times**	**Annual Emissions from Transiting (NOx)**	**Annual Emissions from Transiting and Idling and Walking (NOx)**	**Percent Reduction Annually for Reduction of Walking (HAH/HAS)**
	MT	hr	hr	MT	MT	%
Peralta	4.4	0.0	1303.6	164.3	172.7	2.6
Cetus	0.1	1261.9	2466.4	8.1	8.5	1.1
Solano	5.8	969.9	3102.5	1181.2	1205.6	0.5
Walking at Min AH/Min AS						
	Annual Emissions Reduction from Walking (Min AH/Min AS) (NOx)	**Annual Restricted Wake Operating (Min AH)**	**Annual Transit Times**	**Annual Emissions from Transiting (NOx)**	**Annual Emissions from Transiting and Idling and Walking (NOx)**	**Percent Reduction Annually for Reduction of Walking (Min AH/Min AS)**
	MT	hr	hr	MT	MT	%
Peralta	7.2	0.0	1303.6	164.3	172.7	4.2
Cetus	0.2	1261.9	2466.4	8.1	8.5	2.7
Solano	17.0	969.9	3102.5	1181.2	1205.6	1.4

4. DISCUSSION

The results prove that passenger ferry operations can reduce NOx emissions by adopting eco-piloting best practices. Overall operational NOx emission reduction with the application of only two of the five best practices was between 0.7 and 4.6% for each vessel.

4.1 Development of Eco-Driving Best Practices

The principles of eco-driving are similar for passenger vehicles, busses, and construction vehicles. The similarity across transportation sectors strengthens the validity of the list of eco-driving best practices that was developed for this study, particularly for a broader purpose to support the development of best practices for an alternative transportation sector.

4.2 Development of Passenger Ferry Eco-Piloting Best Practices

Three of the five practices were directly transferrable and two required significant language changes to translate to passenger ferry piloting. Brief instructions were developed to accompany each of the eco-piloting best practices to more clearly translate the practical application of eco-driving best practices. Best Practice 4. Reduce Inefficient RPM Use was the most specific for passenger ferry operations and could have much broader application for future studies.

4.3 Application of Best Practice 1. Minimize Engine Idling.

Elimination of engine idling would reduce overall NOx emissions by 0.2 to 0.9%. Tier II vessels achieve higher NOx emission reduction than Tier III vessels. The application of Best Practice 1 will have the most impact if it is practiced on Tier II vessels until their retirement or until they are re-powered or modified to comply with Tier III standards.

4.4 Application of Best Practice 4. Reduce Inefficient RPM Use.

Reducing engine RPMs from FAH/FAS to HAH/HAS during walking operations reduced NOx emissions by 30-60%. The reduction to Min AH/Min AS reduced NOx emissions from walking operations by 70-95%. Application of Best Practice 4 showed 0.4 to 4.2% reduction in total NOx emissions. Maintaining an efficient speed for the transit is an aspect of this best practice that was outside the scope of this study but is recommended for future research.

5. CONCLUSION

This research proves that passenger ferry operations can reduce NOx emissions by adopting eco-piloting best practices. This paper developed five eco-piloting best practices and evaluated two of them. If the data from the application of the two best practices were extrapolated to reflect application of all five eco-piloting best practices, the overall emissions reduction of NOx would be between 1.4 and 7.2%, which is similar to reduction figures in eco-driving studies. A recommendation for future research is to conduct a study of the application of all five eco-piloting best practices, with monitoring and operator feedback.

6. REFERENCES

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