Shore Power Price Competition Between Ports

Jingwen Qi[1[0000-0003-1838-9061]], Shuaian Wang[2[0000-0001-9247-4403]] and Xiaobo Qu[3[0000-0003-0973-3756]]

[1] The Hong Kong Polytechnic University, Hung Hom Kowloon Hong Kong, 999077, China,
jingwen.qi@connect.polyu.hk

[1] The Hong Kong Polytechnic University, Hung Hom Kowloon Hong Kong, 999077, China,
hans.wang@connect.polyu.hk

[2] Department of Architecture and Civil Engineering, Chalmers University of Technology, Gothenburg, Sweden,
xiaobo@chalmers.se

Abstract. Air pollution and climate change arouse consistent attention of international community. Shipping industry, being one of the most important transport methods, carries more than 80% of the total international trade and has been recognized as a potential source of air pollutant mitigation. In order to reduce emissions of marine traffic especially in the area of coastal waters, regulations about the quality of marine fuel have been carried out, and the maximum sulphur content allowed for marine fuel becomes increasingly stringent as time goes by. In order to comply with the regulations, shipping has to take various measures, including adopting electric power from shore while berthing. Shore side electricity, also called cold ironing, refers to the use of electricity from shore side while berthing at the port instead of auxiliary engine. In recent years, shore power has been adopted in an increasing number of ports, in China most ports are able to provide shore power for ships while berthing. For ships with shore power facilities, the price of shore-side electricity is an element that can influence their choice of port to visit. It is an incentive for ports to lower the power price. This paper tends to investigate what is the best price to maximize the port's total benefit in the competition with other ports in the same group. In order to describe the competition among ports, game theory is applied, and the Bertrand model is adopted.

Keywords: Shore Power Price, Bertrand Model, Game Theory.

1 Introduction

The problem of air pollution and climate change arouse consistent attention of international community. Series of conventions and agreements have been signed among countries and regions such as the Kyoto Protocol and the Delhi Declaration (Qu et al., 2020). Shipping industry, being one of the most important transport methods, carries more than 80% of the total international trade (Qu and Meng, 2012; UNCTAD 2017; Wang et al., 2019). Recently, shipping sector has been recognized as a potential source of air pollutant mitigation. Relative researches (IMO, 2014, 2009) show that the NOx emission from marine traffic makes up 15% of global anthropogenic emission, SO_2 emitted by ships constitutes 13% of the total anthropogenic sources, as for CO_2 marine traffic accounts for approximately 2.7% of the annual emissions. Although the proportions are relatively low, 70% of the marine traffic exhausted emissions are emitted in the area within 400km of coastline, and have bad influence for air quality, ecological environment and public health of coastal cities. For instance, in Shanghai 11% of NOx, 12.4% of SO2 and 5.6% of PM are emitted at the area of the port of Shanghai (Chen et al., 2019). At the same time, over 95% of ship currently in use adopt diesel engines for propulsion, and for the cost reason these engines always burn low-quality fuel oil with high sulphur content. According to the comments to the NSW Environment Protection Authority (2015), the fuels used in marine traffic are on average 2,700 times dirtier than those used by land vehicles.

In order to reduce emissions of marine traffic especially in the area of coastal waters, regulations about the quality of marine fuel have been carried out, and the maximum sulphur content allowed for marine fuel becomes increasingly stringent as time goes by. After 1 January 2020, as required by IMO, all the ships should use fuel oil with sulphur content no higher than 0.5%, for ships sailing in the designated emission control areas 0.1% would be the upper limit of sulphur content.

As one of the most important parties in shipping industry, shipping companies can contribute to the reduction of marine traffic emissions. Shore side electricity, also called cold ironing, refers to the use of electricity from shore side while berthing at the port instead of auxiliary engine. To make use of shore side electricity system, both the port and the ship need to install some extra equipment. To supply shore side electricity port needs to expand the capacity of its substation and install extra socket box and cable operator. Ships also need to be equipped with some special devices to use shore power. Both the port and the shipping company have to make essential extra investment before take advantage of shore power. However, using shore side electricity can reduce SO_2, NOx and other PM emissions by up to 90% (the comments to the NSW Environment Protection Authority, 2015), therefore produce environmental benefit, enhance the local and regional air quality, and contribute to public health. So, the government will provide subsidies to promote the use of shore power. And with reasonable price, port could even earn some profit from selling the power to ships. In recent years, shore power has been adopted in an increasing number of ports, in China most ports are able to provide shore power for ships while berthing (Chen et al., 2019). For shipping companies, since the installation of shore power system is a one-time investment but can bring long-term revenue in the future it is worthwhile to equip the ships. As increasing number of ports adopt shore power system and the regulation of fuel oil sulphur content becomes more stringent, the earnings of equipping ships with shore power facilities will be more remarkable. The proportion of ships adopt shore side power will grow in the future.

A port group consists of several ports that are approximate in geographic location. Therefore, these ports have similar transportation network and partly overlapping economic hinterland. With the development of port capacity and the collection and distribution efficiency, internal competition of port group becomes fiercer. For ships with shore power facilities, the price of shore-side electricity is an element that can influence their choice of port to visit. The ships attracted by preferential power price bring the same port charge revenue and the cargo handling fee in the long term, at the same time cause much less air pollution than traditional ships. It is an incentive for ports to lower the power price. This paper tends to investigate what is the best price to maximize the port's total benefit in the competition with other ports in the same group. In order to describe the competition among ports, game theory is applied.

2 Literature Review

Shore power system, also referred to as cold ironing, is a promising method to reduce the ship emissions while berthing. According to IMO (2012), shore side power is "a measure to improve air quality in ports and port cities, to reduce emissions of air pollutants and noise and, to a lesser extent, to reduce carbon dioxide through ships at berth replacing onboard generated power from diesel auxiliary engines with electricity supplied by the shore". Through the use of shore power, the reliance on auxiliary engines to power ships on berthing can be eliminated. The environmental and social benefits are hot topics in research of shore power system, an essential number of existing studies focus on them. Generally speaking, relative studies come up to similar conclusion that the application of shore power system can reduce the air pollutants and mitigate the environmental burden. Various investigations have been conducted to examine the effect of shore power system at different areas and ports. Vaishnav et al. (2016) compared the economic costs of shore power system and the benefit it can bring at US ports. Result shows that when quarter to two-third ships call at US ports use shore power instead of auxiliary engines while berthing, the environmental benefits will exceed the economic loss of shipping companies for retrofitting their ships, and have a surplus in the region of \$70–150 million. Winkel et al. (2016) investigated situations in European ports, and found that through applying shore power system, 800,000 tons' carbon emissions would be reduced by the year 2020, and generate about €2.94 billion public health benefits. According to Ballini and Bozzo (2015), with 60% ships using shore power the system will bring €2.97 million external health savings for the port of Copenhagen. For the port of Aberdeen, the environmental benefits are evaluated to be around £1.3 million (Innes and Monios 2018).

Game theory is a new branch of modern mathematics and an important part of operational research. There is no precise and uniform definition for game theory, but according to John C. Harsanyi, the winner of the 1994's Nobel Prize in Economics, game theory is a theory of strategic interaction. Born in 1928 when Von Neumann proved the basic principle of game theory, game theory becomes one of the most extensively used analytical tools in economics, and has been applied in many disciplines.

3 Model

According to different criteria, games can be divided into several types. In general, all the games can be identified as cooperative game or non-cooperative game, based on the whether there are binding agreements among parties in the game. From the perspective of behavior time sequence, games are further divided into dynamic game and static game. As the terms suggest, in a static game all the participants make their decisions at the same time or they do not decide simultaneously but the later actor is blind about the action taken by the former actors. In a dynamic game participant move in a time sequence and they are aware of the action of competitors that move before them. Based on the understanding level of participants on their competitors, games are divided into two categories, complete information game and incomplete information game. There are some classical models in game theory, such as Cournot model, Bertrand model, Hotelling model and Stackelberg model. The Bertrand model is used to describe the price competition between two suppliers. In the Bertrand model, competitors decide their prices of homogeneous products, and the price will influence the sales volume and market share, it is consistent with the fact that the shore power provided by different ports are the same. In order to avoid the Bertrand paradox, three methods are adopted: first is to consider capacity constraints, the second is to remove the assumption of product homogeneity, and the third is to introduce dynamic factors into the model. In this model, the shipping company preference for ports is considered in the competition. For ports in the same group, although they are near, but their economic hinterlands, cargo volumes and service content are not identical, so liner shipping routes have their own preferences in port choosing. So in this paper, the Bertrand model with customer preference is adopted to analyze the optimal shore power pricing strategy for ports.

3.1 Assumptions

Before building the mathematical model, some assumptions are made to characterize the problem that is investigated.

i. There are two ports in a port group competing in the price of shore power. Before the providing of shore power, both of them have steady ship customer base.

ii. Ports in a port group provide service to liner shipping companies for the same price. Namely, for ships visiting different ports, the port charge is assumed to be the same.

iii. Adopting shore power can reduce all of the exhaust emissions of berthing ships.

iv. For all the ports, the numbers of ships that are equipped with shore power facility are known before the decision of port side shore power facility installation and pricing.

v. For each port, the number of visiting ships with shore power facilities for each port before the shore power pricing movement is certain and known.

vi. All ships with on-board shore power facility will choose to use it while berthing.

vii. Shipping companies prefer ports that they choose to visit originally. This preference results from advantages of ports such as geographic location and service level. So changing port will bring some loss. In that case, only when the economic profit, namely the cost savings of shifting to another port, is higher than a threshold will the ship route changes it's visiting from port i to port j.

viii. The fuels used by each ship while berthing are identical, at the same time ships consume same amount of fuel oil for each hour berthing at the port. On the one hand, the economic gain for a ship to switching from fuel oil to shore power is proportional to the berthing time. Also, the environment cost for ships to use fuel oil is also proportional to berthing time.

ix. The capacities of ports for traditional ships and ships using shore power are assumed to be adequate. As a result, ships using shore power will not compete with traditional ships for berth.

x. Berthing times of ships visiting both port obey the uniform distribution in the same interval.

3.2 The Bertrand Model

Before the mathematical model, we explain the parameters and sets.

Sets and parameters:

$Port$: The set of ports in the port group.
P: The port charge for both ports (USD/hour).
EnC: The environmental cost of the port area when 1 tonnage fuel oil is consumed by berthing ship (USD/ton).
E: The electricity that is generated by consuming 1 tonnage fuel oil (kwh/ton)
PF: The power fee the port pays to the power company (USD/kwh).
S_i: The number of ships adopting shore power at port i before providing shore power. $i \in 1,2$.
$S_i{}'$: The number of ships adopting shore power at port i after providing shore power. $i \in 1,2$.
T_{ij}: The loss of shipping company to change from port i to port j. $i, j \in 1,2, i \neq j$.
$BT_{min}^{i}/BT_{max}^{i}$: The minimum/maximum berthing time of ships at port i. $i \in 1,2$.
$Bunker$: The bunker price of fuel oil used by ships at berth (USD/ton).
$Fuel$: The mass of fuel oil used by ships at berth for each hour (ton/hour).

Decision variables:

$PowerP_i$: The price of shore power at port i.

Ports in the group make pricing strategy of shore power to maximize its own profit $Pro_i, i = 1,2$. It is assumed that the port should gain some profit by providing shore power to ships. In another word,

$$(PowerP_i - PF) + \frac{EnC}{E} > 0, i = 1,2 \quad (1)$$

Otherwise, the port will not choose to install the shore power infrastructure and provide electricity to ships, and the pricing problem will not exist. Also, we assume that the using shore power at berth can reduce the cost of ships compared with using fuel oil. Namely

$$Bunker > E \times PowerP_i, i = 1,2 \quad (2)$$

Otherwise no ships will choose to using electricity from shore. Equation (1) and (2) determine the upper and lower limit for the power price $PowerP_i \in (\frac{EnC}{E} + PF, \frac{Bunker}{E})$. It is assumed in this paper that $\frac{EnC}{E} + PF < \frac{Bunker}{E}$.

3.3 Profit Function

$\boldsymbol{PowerP_1 > PowerP_2}$**.** For the situation that $PowerP_1 > PowerP_2$, all the shore power ships visiting port 2 will keep their choice of port. For ships using shore power and visiting port 1, they may change their choice for the economic profit from lower shore power price in port 2. From simple deduction we know that with the same shore power prices of both ports $PowerP_1, PowerP_2$ ship with longer berthing time will get more cost saving in shore power. So first we calculate the price with which the utility of the ship with the longest berthing time to switch from port 1 to port 2 equals to 0.

$$(PowerP_1 - PowerP_2) \times BT^1_{max} - T_{12} = 0 \tag{3}$$

From equation (3) we deduct the value of $PowerP_1 = \frac{T_{12}}{BT^1_{max}} + PowerP_2$. Then we calculate the price with which the utility of the ship with the shortest berthing time to switch from port 1 to port 2 equals to 0.

$$(PowerP_1 - PowerP_2) \times BT^1_{min} - T_{12} = 0 \tag{4}$$

From equation (4) we deduct the value of $PowerP_1 = \frac{T_{12}}{BT^1_{min}} + PowerP_2$.

When $PowerP_1 \leq \frac{T_{12}}{BT^1_{max}} + PowerP_2$, no ship will change the visiting port so the ship number visiting each port remain the same, ${S_1}' = S_1, {S_2}' = S_2$. The profit of two ports are

$$Pro_i = [(PowerP_i - PF)E + EnC] \times Fuel \times \frac{S_i}{BT^i_{max} - BT^i_{min}} \int_{BT^i_{min}}^{BT^i_{max}} x\, dx\, , i = 1,2. \tag{5}$$

The total profit consists of the profit of selling electricity to ships and the reduced environmental cost.

When $\frac{T_{12}}{BT^1_{max}} + PowerP_2 < PowerP_1 \leq \frac{T_{12}}{BT^1_{min}} + PowerP_2$, assume the ship with berthing time BT' satisfies the following equation

$$(PowerP_1 - PowerP_2) \times BT' - T_{12} = 0\ . \tag{6}$$

We can calculate the value of $BT' = \frac{T_{12}}{PowerP_1 - PowerP_2}$. Ships that berth at port 1 longer than BT' will change their choice and visit port 2. So we have

$$\begin{cases} {S_1}' = S_1 - S_1 \times \frac{BT^1_{max} - BT'}{BT^1_{max} - BT^1_{min}} \\ {S_2}' = S_2 + S_1 \times \frac{BT^1_{max} - BT'}{BT^1_{max} - BT^1_{min}}. \end{cases} \tag{7}$$

The profit of two ports are like the following equation:

$$\begin{cases} Pro_1 = [(PowerP_1 - PF) \times E + EnC] \times Fuel \times \frac{S_1}{BT^1_{max} - BT^1_{min}} \int_{BT^1_{min}}^{BT'} x\, dx - \\ \qquad [P - EnC \times Fuel] \frac{S_1}{BT^1_{max} - BT^1_{min}} \int_{BT'}^{BT^1_{max}} x\, dx \\ Pro_2 = [(PowerP_2 - PF) \times E + EnC] \times Fuel \times \frac{S_2}{BT^2_{max} - BT^2_{min}} \int_{BT^2_{min}}^{BT^2_{max}} x\, dx + \\ \qquad [(PowerP_1 - PF) \times E \times Fuel + P] \frac{S_1}{BT^1_{max} - BT^1_{min}} \int_{BT'}^{BT^1_{max}} x\, dx \end{cases} \tag{8}$$

Port 1 loses the revenue result from the ships that switch from port 1 to port 2 but gain the electricity selling profit and environmental cost savings for ships that choose to stay. The profit of port 2 consists of two parts, the saved environmental cost and profit of selling the shore power to ships that originally visit port 2 and the revenue bring by the ships that are attracted form port 1.

When $PowerP_1 > \frac{T_{12}}{BT_{min}^1} + PowerP_2$, all the ships with shore power facility visiting port 1 will change their decision and choose to visit port 2. So $S_1{}' = 0, S_2{}' = S_2 + S_1$. The profits of two ports are:

$$\begin{cases} Pro_1 = -[P - EnC \times Fuel]\frac{S_1}{BT_{max}^1 - BT_{min}^1}\int_{BT_{min}^1}^{BT_{max}^1} x\,dx \\ Pro_2 = [(PowerP_2 - PF) \times E + EnC] \times Fuel \times \frac{S_2}{BT_{max}^2 - BT_{min}^2}\int_{BT_{min}^2}^{BT_{max}^2} x\,dx + \\ \quad [(PowerP_1 - PF) \times E \times Fuel + P]\frac{S_1}{BT_{max}^1 - BT_{min}^1}\int_{BT_{min}^1}^{BT_{max}^1} x\,dx \end{cases} \quad (9)$$

Port 1 loses the revenue result from all the ships with shore power facility so its profit is negative. The profit of port 2 consists of two parts, the saved environmental cost and profit of selling the shore power to ships that originally visit port 2 and the revenue bring by the ships that are attracted form port 1. Since the profit of port in this situation is negative so it must not be the Nash Equilibrium of the game.

$\boldsymbol{PowerP_1 < PowerP_2}$**.** Following the same logic in the above section, we can deduce the profit function for the two ports when $PowerP_1 < PowerP_2$.

$$Pro_1 = \begin{cases} [(PowerP_1 - PF) \times E + EnC] \times Fuel \times \frac{S_1}{BT_{max}^1 - BT_{min}^1}\int_{BT_{min}^1}^{BT_{max}^1} x\,dx\,, \\ \quad if\ PowerP_2 \le \frac{T_{21}}{BT_{max}^2} + PowerP_1 \\ [(PowerP_1 - PF) \times E + EnC] \times Fuel \times \frac{S_1}{BT_{max}^1 - BT_{min}^1}\int_{BT_{min}^1}^{BT_{max}^1} x\,dx - \\ \quad [(PowerP_2 - PF) \times E \times Fuel + P]\frac{S_2}{BT_{max}^2 - BT_{min}^2}\int_{BT'}^{BT_{max}^2} x\,dx\,, \\ \quad if\ \frac{T_{21}}{BT_{max}^2} + PowerP_1 < PowerP_2 \le \frac{T_{21}}{BT_{min}^2} + PowerP_1 \end{cases} \quad (10)$$

$$Pro_2 = \begin{cases} [(PowerP_2 - PF) \times E + EnC] \times Fuel \times \frac{S_2}{BT_{max}^2 - BT_{min}^2}\int_{BT_{min}^2}^{BT_{max}^2} x\,dx\,, \\ \quad if\ PowerP_2 \le \frac{T_{21}}{BT_{max}^2} + PowerP_1 \\ [(PowerP_2 - PF) \times E + EnC] \times Fuel \times \frac{S_2}{BT_{max}^2 - BT_{min}^2}\int_{BT_{min}^2}^{BT'} x\,dx - \\ \quad [P - EnC \times Fuel]\frac{S_2}{BT_{max}^2 - BT_{min}^2}\int_{BT'}^{BT_{max}^2} x\,dx\,, \\ \quad if\ \frac{T_{21}}{BT_{max}^2} + PowerP_1 < PowerP_2 \le \frac{T_{21}}{BT_{min}^2} + PowerP_1 \end{cases} \quad (11)$$

In which $BT' = \frac{T_{21}}{PowerP_2 - PowerP_1}$.

3.4 Nash Equilibrium

For simplicity, we assume that $S_1 = S_2$, $T_{21} = T_{12}$, $BT_{max}^1 = BT_{max}^2$ and $BT_{min}^1 = BT_{min}^2$. So in the following subsection we use S to represent S_1 and S_2, T to represent

T_{21} and T_{12}, BT_{max} to represent BT_{max}^1 and BT_{max}^2, BT_{min} to represent BT_{min}^1 and BT_{min}^2.

After reorganizing we have the profit function for port 1 under different situations:

$$Pro_1 = \begin{cases} [(PowerP_1 - PF) \times E + EnC] \times Fuel \times \frac{S}{BT_{max}-BT_{min}} \int_{BT_{min}}^{BT_{max}} x\,dx, \\ \quad if\ PowerP_2 - \frac{T}{BT_{max}} \le PowerP_1 \le PowerP_2 + \frac{T}{BT_{max}} \\ [(PowerP_1 - PF) \times E + EnC] \times Fuel \times \frac{S}{BT_{max}-BT_{min}} \int_{BT_{min}}^{BT_{max}} x\,dx - \\ \quad [(PowerP_2 - PF) \times E \times Fuel + P] \frac{S}{BT_{max}-BT_{min}} \int_{BT''}^{BT_{max}} x\,dx, \\ \quad if\ PowerP_2 - \frac{T}{BT_{max}} > PowerP_1 \ge PowerP_2 - \frac{T}{BT_{min}} \\ [(PowerP_1 - PF) \times E + EnC] \times Fuel \times \frac{S}{BT_{max}-BT_{min}} \int_{BT_{min}}^{BT'} x\,dx - \\ \quad [P - EnC \times Fuel] \frac{S}{BT_{max}-BT_{min}} \int_{BT'}^{BT_{max}^1} x\,dx, \\ \quad if\ \frac{T}{BT_{max}} + PowerP_2 < PowerP_1 \le \frac{T}{BT_{min}} + PowerP_2 \end{cases} \quad (12)$$

In equation (12) $BT' = \frac{T}{PowerP_1 - PowerP_2}$, $BT'' = \frac{T}{PowerP_2 - PowerP_1}$. And the demand functions of port 1 and port 2 are symmetric. In order to find the Nash equilibrium, we take the partial derivative of the profit function.

$$\frac{\partial Pro_i}{\partial PowerP_i} = 0, i = 1,2 \quad (13)$$

$$\frac{\partial Pro_1}{\partial x} = \begin{cases} \frac{1}{2} E \times Fuel \times a \times \left({BT_{max}}^2 - {BT_{min}}^2\right), if\ y - \frac{T}{BT_{max}} \le x \le y + \frac{T}{BT_{max}} \\ \frac{1}{2} E \times Fuel \times a \times \left({BT_{max}}^2 - {BT_{min}}^2\right) + [(y - PF) \times E \times Fuel + P] \times a \times T^2 \left(\frac{1}{y-x}\right)^3, \\ \quad if\ y - \frac{T}{BT_{max}} > x \ge y - \frac{T}{BT_{min}} \\ \frac{1}{2} Fuel \times a \times \left\{E \times \left[\left(\frac{T}{x-y}\right)^2 - {BT_{min}}^2\right] - 2[(x - PF) \times E + EnC] \times T^2 \left(\frac{1}{x-y}\right)^3\right\} - \\ \quad (P - EnC \times Fuel) \times a \times T^2 \left(\frac{1}{x-y}\right)^3, if\ \frac{T}{BT_{max}} + y < x \le \frac{T}{BT_{min}} + y \end{cases} \quad (14)$$

In equation (14) $x = PowerP_1, y = PowerP_2, a = \frac{S}{BT_{max}-BT_{min}}$.

We can see that when $y - \frac{T}{BT_{max}} \le x \le y + \frac{T}{BT_{max}}, \frac{\partial Pro_1}{\partial x} > 0$, so when the difference between x and y are not large enough to make any ship to change their choice of port both the ports tend to set the price just below $\frac{Bunker}{E}$. This is the highest price that the ships will choose to use shore power. The solution of partial derivative functions when $y - \frac{T}{BT_{max}} > x \ge y - \frac{T}{BT_{min}}$ or $\frac{T}{BT_{max}} + y < x \le \frac{T}{BT_{min}} + y$ depends on the real value of the parameters such as $P, EnC, BT_{max}, BT_{min}, PF$. In another word, whether the port will lower its price for shore power depends on the profit that a ship with shore power facility will bring to the port authority. Since the profit function is not straightforward and kind of complex, the Nash equilibrium of the game should be discussed in various situations. Due to the capacity insufficiency, the thorough discussion will remain to be solved later.

4 Conclusion

This paper uses the Bertrand model to describe the price competition between two ports in a port group. The model is established successfully but due to the environmental cost the profit function becomes complicated and make it difficult to find the Nash equilibrium of the game. But the paper is still a start of investigation on the topic of shore power pricing competition. Actually the problem can be generalized to a pricing problem of upgraded product or service. Two companies decide to upgrade their product or service which has a higher marginal profit than the original ones. They try to identify the best price for an upgraded product to gain most profit. Customers have brand loyalty for the brand they originally choose, only when the other supplier provide a much better price will they change their mind. For the companies, a high price will lead to higher marginal profit but may lose some old customers. On the other hand, a lower price may attract customers from competitors but the marginal profit will be low. This problem can be observed in the market that the new generation of product keeps coming up. From personal opinion, this is an interesting topic that can be thoroughly studied.

Acknowledgment

This research is supported by the Research Grants Council of the Hong Kong Special Administrative Region, China [Project number 15201718].

References

1. Ballini F., Bozzo R.: Air pollution from ships in ports: the socioeconomic benefit of cold-ironing technology. Research in Transportation Business and Management 17, 92–98 (2015).
2. Chen J., Zheng T., Garg A., Garg A., Xu L., Li S., Fei Y.: Alternative maritime power application as a green port strategy: barriers in China. Journal of Cleaner Production 213, 825–837 (2019).
3. IMO Onshore power supply. MEPC.1/Circ.794.www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Circ.794.pdf. Accessed 07 Nov 2018(2018).
4. Innes A., Monios J.: Identifying the unique challenges of installing cold ironing at small and medium ports: the case of aberdeen. Transportation Research Part D 62, 298–313 (2018).
5. Qu, X., Meng, Q.: The economic importance of the Straits of Malacca and Singapore: an extreme-scenario analysis. Transportation Research Part E: Logistics and Transportation Review, 48(1), 258-265, (2012).

6. Qu, X., Yu, Y., Zhou, M., Lin, C. T., Wang, X.: Jointly dampening traffic oscillations and improving energy consumption with electric, connected and automated vehicles: A reinforcement learning based approach. Applied Energy, 257, 114030, (2020).
7. Wang, S., Yan, R., Qu, X.: Development of a non-parametric classifier: Effective identification, algorithm, and applications in port state control for maritime transportation. Transportation Research Part B: Methodological, 128, 129-157, (2019).
8. Yu J., Voß S., Tang G.: Strategy development for retrofitting ships for implementing shore side electricity. Transportation Research Part D 74, 201–213 (2019)
9. Transport & Environment comments to NSW EPA consultation regarding stricter sulphur fuel requirement for cruise ships in Sydney harbor, (2015).
10. UNCTAD: Review of maritime transport. United Nations Publication, New York, (2017).
11. Vaishnav P., Fischbeck P.S., Morgan M.G., Corbett J.J.: Shore power for vessels calling at US ports: benefits and costs. Environmental Science & Technology 50(3), 1102–1110 (2016).
12. Winkel R., Weddige U., Johnsen D., Hoen V., Papaefthimiou S.: Shore side electricity in Europe: potential and environmental benefits. Energy Policy 88, 584–593 (2016).