Study of inland ship water pollution control policy strategy based on Game theory

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Abstract. Sanitary sewage, oily wastewater, toxicant containing wastewater, and domestic solid wastes are major pollutants from ships threatening inland water bodies. These pollutants are in significant volumes and wide ranges. Therefore, great efforts have been invested in inland ship water pollution control policy and regulations. A local ship pollution control decision evolution Game model based on bounded rationality is established to obtain the key factors affecting decision-making by ships in water pollution control include cost for pollution control, subsidies and credits, administrative supervision and punishment, while key factors affecting decision-making by authorities include cost for administrative supervision and pressures from supervisors caused by not taking supervisions, thus providing recommendations on policy and measures for inland ship pollution. This study provides references for establishment of inland ship pollution control system.

1. Introduction

The inland water transportation refers to the cargo/passenger transportation using ships travelling in inland water bodies (e.g., rivers, lakes, canals) and it exhibits large transportation capacity, low energy consumption, and limited land occupation. Currently, China has developed an inland water transportation system consisting of the Yangtze River, the Pearl River, the Huai River, the Heilongjiang River, and the Songhuajiang-Liaohe River system, and the Yangtze River, the Huai River, the Taihu Lake, and the Qiantang River are connected by the Beijing-Hangzhou Canal. In Jan 2011, the State Council issued ‘Opinions on Accelerating Developments of Inland Water Transportation in the Yangtze River and Other Rivers’, indicating that inland water transportation has become a national strategy. Owing to advantages of inland water transportation, the inland water transportation volume has increased drastically. In 2017, China has 132, 300 inland ships, which achieves cargo transportation volume of 3.705 billion tons and cargo transportation of 149.49 billion ton km \[1\]. Owing to increasing quantity of cargo ships and developments of entertaining passenger ships, discharges of sanitary sewage, oily wastewater, toxicant containing wastewater, and domestic solid wastes from inland ships have placed a severe threat to inland water resources and ecological environment protection, thus been an urgent issue.

2. Current situation of inland ship water pollution control

2.1. Main pollutants
2.1.1. Sanitary sewage. The sanitary sewage refers to wastewater produced by daily life of persons on board, including discharges from toilets, discharges from infirmary, discharges from live animals on board, and other wastewaters containing the mentioned discharges.

2.1.2. Oily wastewater. The oily wastewater refers to wastewater containing crude oil, fuel oil, lubricating oil, and other petroleum products/residues. These wastewaters are produced in navigation, repair, and maintenance of ships and can be categorized as those from machines and those containing cargo oil residues.

2.1.3. Toxicant containing wastewater. The toxicant containing wastewater refers to wastewaters produced by activities such as tank washing (before docking maintenance, before changing merchandise, and after each voyage), especially ships transporting hazardous chemicals.

2.1.4. Domestic solid wastes. The domestic solid wastes refer to wastes produced from ships during service, including plastics, domestic wastes, operation wastes, and cargo residues.

2.2. Calculation of pollutant volumes
Owing to rapidly increasing quantity and capacity of ships, water pollutions from ships have increased drastically. In 2017, China has 132,300 inland ships, which achieves passenger transportation volume of 59 million [1]. Assume that each passenger stays on board for 1 d and sanitary sewage and wastes are 130 L/capita∙d and 1.2 kg/capita∙d, respectively, while average staff per ship is five and average service period is 300 per annual, the pollutants produced from inland ships can be calculated as follows:

2.2.1. Volume of sanitary sewage. The total flow on board is 257.45 million capita∙d p.a. (59 million capita∙d + 13.23×5×3 million capita∙d) and the sanitary sewage produced is 33.47 million t p.a. (25.745 million capita∙d × 0.13 t/capita∙d), while the sanitary sewage produced by pontoons is 10 million t p.a.. Hence, the overall sanitary sewage produced by inland ships is 43.47 million t p.a..

2.2.2. Volume of oily wastewaters. Assume that the average oily wastewater produced is 0.5 t per 1000 kWh host power and each ship travels for 8 h per day, the overall power of inland ship was 33.27 million kW in 2016 and the oily wastewater produced was 48.57 million t p.a (0.5÷1000 t/kWh × 33.27 million kW × 8 h/d × 365).

2.2.3. Volume of toxicant containing wastewaters. Despite its small volume (1-4 % of the maximum ship loads), the tank washing wastewater is usually toxic. In 2016, the overall chemical throughput by inland ports is 112 million t and the actual load is usually 70% of the maximum load, the toxicant containing wastewater produced is 0.8 million t p.a (112÷200 million t p.a. ÷ 70% × 1%).

2.2.4. Volume of solid wastes. Reference to urban per capita production, solid waste production is 1.2 kg/capita∙d (equivalent to that of domestic wastes) [2], the overall volume of solid wastes by inland ships is 310,000 t (257.45 million capita∙d × 1.2 kg/capita∙d).

In summary, wastewater produced by inland ships is 92.84 million t p.a., which consists of 43.47 million t sanitary sewage, 48.57 million t oily wastewater, 0.8 million t toxicant containing wastewater, and 0.31 million t solid waste.

2.3. Relevant regulations

2.3.1. Environmental protection regulations and standards. The environmental protection regulations and standards related to inland ship water pollution control are the Water Pollution Control Law and the Control Standards for Water Pollutants from Ships.

Issued in 1984 and revised in 1996, 2008, and 2017, the Water Pollution Control Law is the
fundamental law for control of water pollution by inland ships. This law clarifies anti-pollution measures that should be taken by inland ships, including allocation of anti-pollution equipment, possession of relevant permits/licenses, and strict compliance with the operating procedures and the truthful records during pollutant discharging. On the other hand, this law requires ports, wharfs, loading/unloading stations, and shipyards be equipped with sufficient receiving facilities for pollutants and wastes from inland ships. Additionally, units engaged in receiving pollutants and wastes from inland ships or tank washing for oil/hazardous goods carrying ships should have corresponding receiving and processing capacity. Meanwhile, this law requires ships engaged in receiving oil residue, oily wastewater, hazardous good residues, tank washing for oil/hazardous goods carrying ships, lighting of liquid hazardous goods in bulk, and other at sea or underwater operations to apply for permits/licenses by local authorities.

The Control Standards for Pollutants from Ships (GB 3552-83) is the first national standards and acts in China that standardizes discharge behaviors of ships and plays a key role in improving environment quality. It is revised in 2018 and renamed as the Control Standards for Water Pollutants from Ships (GB 3552-2018). This revision involves control standards for discharges of toxicant containing wastewater by ships and clarifies the schemes of applicable water bodies and ships. In terms of discharge control for sanitary sewage, pH value, CODCr, overall chlorine (overall residue chlorine), overall nitrogen, ammonia nitrogen, and overall phosphorus have been involved, the upper limits of BOD5, suspended matters, and thermal resistance E. Coli colonies, classification schemes and control requirements for ship wastes have been adjusted, and the standardized monitoring methods of oily wastewater and sanitary sewage in machinery spaces have been clearly defined, and the provision that prohibits discharges of sanitary sewage into drinking water source protection areas and requires recording of control measures has been included.

2.3.2. Regulations standards for supervision by the transportation department. The traffic and transportation regulation regulations standards related to inland ship water pollution control are mainly the Environmental Management Regulations for Prevention and Control of Pollution from Ships in Inland Waters and the Inland Ship Legal Technical Inspection Rules.

Issued in 2005 and revised in 2015, the Environmental Management Regulations for Prevention and Control of Pollution from Ships in Inland Waters is based on principles of prevention first, combination of prevention and processing, timely disposal and comprehensive processing. The 2015 revision involves prohibition of oil spill dispersant in inland waters to avoid secondary pollution, reduction of requirements for processing equipment on board to encourage on shore processing, standardization of damage liability insurances for ship carrying hazardous chemicals to improve the compensation ability for accident damages, clarification of responsibility of the main body, removal of administrative reporting of fencing plans and the alternative measures.

The Inland Ship Legal Technical Inspection Rules 2011 include detailed regulations for ship structures and equipment for preventions of oil pollution, toxicant containing wastewater pollution, sanitary sewage pollution, garbage pollution.

2.4. Key control measures and policies

2.4.1. Specific control measures. The control of ship pollution shall be designed according to the pollutant category. For sanitary sewage, individual collection/discharge systems are required for black water and ash water, except for specific equipment certificated by authorities; water saving devices such as vacuum stool are encouraged. For oily wastewaters, individual collection/discharge systems are required for oily wastewater in machinery spaces and oily wastewater containing cargo oil residues; closed drain system drip trays should be set up at A plate joints of loading/unloading pipelines for fuel oil and lubricants; The fuel tanks and lubricant tanks should be equipped with high level alarm devices to prevent overflows. For toxicant containing wastewaters, ports shall be equipped with specialized tank washing stations and toxicant containing wastewaters, ballast water/tank washing water
containing such toxicants, and other mixtures should be processed on the shore. The washing water or other mixtures should be processed on shore. For ship garbage, it should be classified before collection and storage and detergents/additives used for washing of cargo tanks, A plate, and ship body should be free of substances that are hazardous to marine environments. Additionally, old ships should be abandoned gradually. In other words, old ships with short remaining life that cannot be equipped with wastewater collection and processing systems owing to limited space and high transformation cost shall be abandoned.

2.4.2. Control policy

- **Sanitary sewage**
  From October 2013 to the end of 2017, the Ministry of Transport promoted the national inland river ship type standardization policy during the 12th Five-Year period. The policy encourages the transformations of sanitary sewage systems of current ships, encourages withdraw of old ships from the market before their service life ends, and greatly promotes the capability of inland ships in water pollution control. From October 2013 to December 2015, installations of sanitary sewage collection/processing devices in ships eligible to the "two horizontal one vertical two net eighteen lines" were subsidized. Meanwhile, disassembly of cargo ships with service life from 15 to 30 years (15 to 36 years for ships in Heilongjiang) and passenger ships with service life from 10 to 25 years were subsidized by the government. As a result, sanitary sewage system updates have been applied in approximately 20,000 ships, resulting in an estimated reduction of 137,800 t p.a. direct emission of sanitary sewage.

- **Oily wastewater**
  In terms of oily wastewater control, the Ministry of Transport has not issued any relevant policies yet, while local governments in areas along the Yangtze River have introduced some effective policies to promote oily wastewater recovery. For instance, the government of Jiaxing issued the Implementation Opinions of Further Strengthening the Control of Oily Wastewater and Other Pollutants by Ships. By the end of 2016, "a ship oily wastewater receiving vessel, a ship oily wastewater receiving processing station, a set of related operating scheme" have been achieved for every county of the city. Additionally, water and oil separators, sewage processing plants, and storage containers have been taken to prevent water pollution by ships. Indeed, all 1042 ports in Jiaxing have been equipped with trash cans and oily wastewater receiving buckets, two oily wastewater receiving/processing stations and 30 ship garbage receiving points have been established, and two sewage and oily water receiving ships are in service.

- **Chemicals and tank washing wastewater**
  In August 2017, the Ministry of Transport issued the Guidance for Promotion of Green Shipping in the Yangtze Economic Belt (2017, 114#), which serves as a top-level design for the development of green shipping in the Yangtze River. For the control of inland water pollution by ships, strengthening of the special processing of chemical tank washing operation has been proposed, including planning and construction of chemical tank washing bases, regulating the management of chemical tank washing bases and washing operation, and guiding enterprises to establish relevant industrial funds. Also, special management for control of pollution by ships, including comprehensive investigation of risks of pollution by ships, establishment and optimization of the comprehensive governance mechanism of prevention, processing, compensation for pollution by ships, has been introduced.

  In March 2018, the Layout of the Tank Washing Stations along the Main Stream of the Yangtze River was issued. According to the trend of dangerous chemicals throughput of ports along the Yangtze River, the transformation demands of ships carrying hazardous chemicals in the Yangtze river, and distributions of large petrochemical industrial parks, a total of 13 washing stations with capacity of 7800 ship times will be established by 2020. To date, five tank washing stations, which are distributed in Chongqing, Wuhan and Nanjing port, have been established along on the main stream of the Yangtze River. With an annual capacity of 1250 ship times, these stations completed about 520 ship times in 2016.
3. Game model of discharges by ships and pollution control

As the main body of pollution, the ship owners should be the prior responsibility body for control of water pollution. However, they are naturally chasing maximization of profits by ship management. First, a perfect rational game between two ships has been executed, followed by establishment of an updated imperfect rational model of ship populations based on improved Game to facilitate guidance by the government on decision-making on pollution control by ships.

3.1. General equilibrium analysis

Assuming that Ship A and Ship B are perfect rational and have independent decision-making systems, a cost matrix micro-model is established (see table 1). Herein, $C$ refers to cost and losses caused by pollution control, $R$ refers to compensations/subsidies to contributions in pollution control, $G$ refers to benefits induced by improvements in reputation and management during pollution control processes, $P$ refers to punishment and $I$ refers to losses in reputation and credibility. No ships are involved in $L$, which refers to losses in navigation time, sanitary conditions, and security checks. The cost matrix in Table 1 can lead to various Nash equilibriums (NE) [3]:

- If $R + P + 2I < C$, NE is (do nothing, do nothing), meaning that ships are not desired to participate in pollution control;
- If $R + P + 2I > C$, NE is (control pollution, control pollution), meaning that ships tend to contribute to pollution control;
- If $C < L$, three solutions, including two absolute strategic solutions and one mixed strategic solution, are possible, and Ship A and Ship B make its decision based on that of the other.

| Strategy         | Ship B: control pollution ($x$) | Ship B: do nothing (1-$x$) |
|------------------|---------------------------------|---------------------------|
| Ship A: control pollution ($x$) | $(R+I-2C, R+I-2C)$             | $(R+I-2C, -P-I)$          |
| Ship A: do nothing (1-$x$)      | $(-P-I, R+I-2C)$               | $(-P-I-L, -P-I-L)$        |

3.2. Evolution Game model

The study mentioned above is based on perfect rational conditions. However, the rationality of ships pursuing maximized benefits is limited, which means the ship owners cannot make decisions in perfect rationality. Meanwhile, water pollution control in a certain area should be studied with all local ships been regarded as a whole so that local optimizations are avoided. Therefore, this study proposes an evolution Game model based on the evolution theory to simulate the law of survival of the fittest in biological evolutions. Specifically, a ship is regarded as a member of a biological group and all individuals will eventually choose a strategy beneficial to its own profit. The ratio of ships adopting the ‘control pollution’ strategy in a certain area is assumed to be $x$, and the ratio of ships adopting the ‘do nothing’ strategy is assumed to be $(1-x)$. The ships that are decision-making bodies with limited rationality are regarded as a dynamic system whose objective is maximization of its benefits. Hence, they tend to adopt the ‘do nothing’ strategy in absence of regulations. In presence of restrictions by laws, subsidies, and public opinions, the ships are encouraged to adopt the ‘control pollution’ strategy. Owing to differences in rationality of individuals, some individuals will be the first to adopt the ‘control pollution’ strategy, while others will evolve to adopt the ‘control pollution’ strategy via learning evolution. Eventually, the strategies adopted by all individuals in this area will be normalized.

If $C - 2L < R + P + 2I < 3C$, the ships will eventually evolve to a stabilized ratio, regardless of the initial ratio. If the initial ratio is stabilized ratio, some individuals will adopt the ‘control pollution’ strategy via learning evolution until the ratio reaches the stabilized ratio; if the initial ratio is greater than stabilized ratio, the ‘do nothing’ strategy will lead to maximized benefits as the authority will reduce checking frequency based on high ratios of legal ships.

If $R + P + 2I \geq 3C$, the cost of the ‘control pollution’ strategy is relatively low, while benefit (e.g., subsidies, credits) is high and punishment to the ‘do nothing’ strategy is high, all ships will eventually...
adopt the ‘control pollution’ strategy, regardless of the initial ratio.

If \( R + P + 2I + L \leq 2C \), most ships in this area will adopt the ‘do nothing’ strategy as the cost of the ‘control pollution’ strategy exceeds its benefit.

In summary, it can be concluded that key factors affecting decision-making by ships in water pollution control include cost for pollution control, subsidies and credits, administrative supervision and punishment, while key factors affecting decision-making by authorities include cost for administrative supervision and pressures from supervisors caused by not taking supervisions.

4. Recommendations on policy and measures

In terms of laws and regulations, pollution control for inland water should be paid more attention. As one of the contracting parties of the United Nations Convention on the Law of the Sea and the International Convention for the Prevention of Pollution from Ships (MARPOL73/78 Convention), China has established completed legislations for marine environment protection [4]. However, water pollution in inland water bodies have not attracted sufficient attention, although both the Water Pollution Control Law and the Control Standards for Water Pollutants from Ships clarifies that standards for pollutant discharge in inland water bodies shall be higher than that in sea [5] as the conditions of inland water bodies have direct and significant effects on our daily life. Instead of the ‘discharge is prohibited’ principle, the removal of pollutants shall be achieved by requirements of forced removal before leaving the port via legislation. Additionally, ship pollutant management systems are required to be established for all ships [6], pollutant receiving capacity of ports shall be evaluated [7], and pollution from ships shall be precisely controlled via legislation.

In terms of administrative supervision, the ship inspection unit shall require installation of storage, separation, and emergency equipment for pollutants, and ensure good conditions of the equipment. The maritime administrative should strengthen the inspection of the processing of sanitary sewage, and especially standardization of the equipment and the operation record, and negotiations with the receiving units and severe punishment on violations are necessary. Additionally, key waters and key vessels (passenger ships, hazardous goods vessels) should be monitored using video surveillance and automatic identification system (AIS) to achieve multi-channel control of pollution from ships. Meanwhile, awareness and social responsibility of sailors can be enhanced through publicity and education.

In terms of pollutant receiving, charges should be standardized and subsidies should be introduced. On one hand, the government should support the receiving units for oily wastewater and sanitary garbage, promotes the “water service area” to provide receiving and processing services for pollutants from ships, and encourage participations by social forces and capital to achieve a large-scale, specialized and integrated receiving system for pollutants from ships. On the other hand, For the of the pollutants from ships, the government should reward/subsidize ships and companies with good performances in water pollution control, reward truthful reports of illegal discharges, establish an effective credit management and evaluation system, and set up a positive example to enhance the awareness of environmental protection responsibility for all the ship owners. Additionally, the pollution processing fee can be included in the fuel tax so that the fee is charged based on its pollutant discharge.

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