

Inspection Policy of a Port State Control Authority

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Abstract

A port State control authority (PSCA) undertakes inspections to enforce that ships visiting its ports meet the required standards. By doing so, the PSCA wants to reduce the frequency of shipping accidents and to minimize expected social loss in its territorial water. Due to resources constraints, port States control authorities realize it impractical to inspect all the ships. The general approach taken by them is to set overall inspection rates to ensure that a certain number of ships are inspected, and use targeting factors to focus resources on those ships most likely to be substandard. In this paper, we use a Stackelberg game to model a PSCA's problem of setting an overall inspection rate. Then, based on mechanism design theory, we propose an inspection scheme which can help the PSCA to differentiate between good and substandard ships. Our results can help port States control authorities to design inspection policies at their waters under various circumstances.

1. Introduction

Detrimental environmental and social impacts caused by shipping accidents threaten the interest of port States. Examples of accidents are easy to recollect; the grounding of the *Exxon Valdez*, the capsizing of the *Herald of Free Enterprise*, and the *Estonia* passenger ferry are some of the most widely publicized accidents in maritime transportation. Inspection of ship safety is an administrative measure to reduce the occurrence of shipping accidents (Viladrich-Grau, 2003; Li and Zheng, 2007). So port States control authorities, under the guide of the Port State Control (PSC) programmes, conduct port inspections to prevent shipping accidents from occurring in their waters.

Port State authorities recognise that inspecting all ships would be both impractical due to the resources constraints, and unnecessary since not all ships are substandard. The general approach taken by regional port States control authorities is to set overall inspection rates, and to use targeting factors to focus on those ships most likely to be substandard. In this paper, we first investigate how to set an optimal overall inspection rate for a port State control authority. Then, based on a mechanism design model, we show that the port State authority can use an inspection scheme to let a shipowner truthfully reveal the information about his ship's status. In the scheme, the shipowner is required to select an inspection rate according to its own status. The scheme, if appropriately designed, can ensure that the substandard ship would select a higher inspection rate, and a well-run ship would select a lower inspection rate. This mechanism, together with the targeting factors method, can help authorities to focus inspection resources on those substandard ships. Thus, those shipowners of substandard ships would like to make enough efforts to meet the requirements of the authorities.

The paper proceeds as follows. In Section 2, we first briefly summarize the history of port inspection policies during the development of the PSC programmes, and then review the literature. In section 3, we use a Stackelberg game to obtain an overall inspection rate for a port State control authority. In section 4 we use a mechanism design model to design an inspection scheme under which a shipowner would truthfully reveal his

ship's status. Section 5 concludes this paper.

2. Literature Review

Before the 1980s, decisions concerning port inspections were not regarded as a potential means of making shipping safer. Originally, there were no conventions to guarantee the enforcement of the PSC programmes, which refers to a state's jurisdiction over ships in its ports. Traditionally, a ship is legally regarded as a floating island of the flag State's territory and hence the ship must be subject to the exclusive jurisdiction of its flag State. 'Flag State' refers to the state whose flag a ship flies and whose nationality a ship bears. Flag State jurisdiction was restricted by the enforcement of the PSC programmes and hence legal conflict could arise between them. It took a long time to deal with such issues and to determine the content of port State jurisdiction. The final text of the provisions on "Enforcement by Port States" was completed and included in Art.218 of the United Nations Convention on the Law of the Sea 1982 (UNCLOS 1982).

Although the concept of port state control is quite new, there is a flourishing development of the PSC programmes. Based on the provisions of UNCLOS 1982, regional PSC organizations appeared, such as the Paris MOU based on the Paris Memorandum of Understanding on Port State Control 1982, and the Tokyo MOU based on the Memorandum of Understanding on Port State Control in the Asia-Pacific Region 1993. These organizations conduct port inspections and determine the target inspection rates in different regions. For example, the target inspection rate of the Paris MOU is 25%. The target annual inspection rate of the Tokyo MOU is 75%, increasing from the original target of 50% since it was achieved in 1996. To maintain the effect of port inspections, it is therefore common in port States to further increase the frequency of port inspections and hence to force the shipowners to increase effort levels to keep their ships at higher safe levels.

Li and Cullinane (2003) analyse the various methods by which shipowners might reduce their maritime liability risk, and derive a conceptual approach to the application of cost-benefit analysis in maritime safety regulation. They advocate the adoption of the approach as a means of ensuring that safety regulation sets optimum targets such that the level of compliance yields maximum economic benefit.

Ships that visit a port are assigned targeting factors according to a scoring system designed by the port. The Paris MOU, for example, assigns an overall targeting factor to ships, whereas United States Coast Guard has developed a boarding priority matrix for the purpose of calculating a targeting factor. Li (1999) and Xu et al. (2007) attempt to improve these scoring systems, and help port States control authorities identify risky ships. Other attempts focus on the introduction of new technical or management measures. An optimal monitoring technique by combining the satellite information was investigated by Florens and Foucher (1999). Gawande and Bohara (2005) analysed an optimal contract which mixes penalties based on the amount of pollution ex post with penalties based on the extent of noncompliance ex ante. An integrated inspection support system was investigated by Hamada, Fujimoto and Shintaku (2002).

3. Setting the Overall Port Inspection Rate

In this section, we study the problem of a port State control authority that sets an overall port inspection rate. We first formulate this problem, and then solve the problem.

3.1. Introduction and the formulation of the game

We consider a port State control authority and ships calling at the port. Let $\theta, \theta \in [a, b]$, denote the status of a ship in terms of its likelihood to pass the inspection. Note that the likelihood depends on factors such as owner/operator, flag, history, ship type and age, maintenance, etc. A ship of smaller θ is more likely to be substandard. Those ships are differentiated only by θ , which we refer to as a ship's type. The port authority and the shipowners share common beliefs regarding the probability distribution of types, $G(\theta)$; with $G(\theta) = g(\theta)d\theta$. The leader in the game is the PSCA, and the followers are shipowners. The sequence of events is as follows: the port State control authority selects its inspection rate first, then a shipowner decides his effort level to pass the inspection under the given inspection rate. For expositional convenience, we

assume that one ship has a shipowner and each shipowner is an independent decision unit. When no confusion is caused, we interchangeably use a ship and a shipowner.

When a ship is inspected, a cost is incurred, which includes penalty cost due to delay of delivery, extra salaries paid to seafarers, operational expenses during the inspection period, fine imposed by the port State authority, loss of future business for not passing inspection, etc. Let r denote the inspection rate, e_θ denote type θ shipowner's effort level, $M_\theta(e_\theta)$ denote the expected accident cost for the ship given an effort level e_θ , and $Q_\theta(e_\theta, r)$ denote the expected cost caused by inspection, $\theta \in [a, b]$. For a given inspection rate r , the θ type shipowner's cost function $F_\theta(e_\theta, r)$ can be expressed as

$$M_\theta(e_\theta) + Q_\theta(e_\theta, r) + e_\theta$$

The shipowner would choose an effort level to minimize $F_\theta(e_\theta, r)$. Let $e_\theta^*(r)$ denote type θ shipowner's optimal effort level when the inspection rate is r , $\theta \in [a, b]$.

The objective of a port State authority is to minimize expected social loss. Let $D_\theta(e_\theta)$ denote the expected damage and recovery cost caused by the type θ ship when the shipowner's effort level is e_θ , $\theta \in [a, b]$. Let $C_\theta(r)$ denote the expected social loss when inspection level is r and the ship's type is e_θ , $\theta \in [a, b]$. The social loss includes cost of resources used for inspection, operational costs, the opportunity cost of the ship, etc. When the inspection rate is r , type θ shipowner would choose an effort level $e_\theta(r)$, and the port State authority's objective function can be expressed as

$$D_\theta(e_\theta(r)) + C_\theta(r).$$

For type θ ship, the port State authority's problem can be formulated as

$$\begin{aligned} & \min_r D_\theta(e_\theta(r)) + C_\theta(r) \\ & \text{subject to} \\ & e_\theta^*(r) = \arg \min_{e_\theta} F_\theta(e_\theta, r). \end{aligned}$$

Let r_θ^* denote the optimal inspection rate for type θ ship, $\theta \in [a, b]$. Then the overall inspection rate for the PSCA is

$$\int_a^b r_\theta^* dG(\theta). \quad (1)$$

3.2. Solving the Game

3.2.1. Assumptions

We assume that type θ ship's accident cost $M_\theta(e_\theta)$ is a decreasing function in the shipowner's effort level e_θ , thus $dM_\theta/de_\theta < 0$. Further, we assume that the effort level e_θ follows the law of diminishing returns, which means that with increasing effort level, the effect to lower accidents cost decreases. Thus, we have $d^2M_\theta/de_\theta^2 > 0$.

We assume that given an effort level e_θ , $Q_\theta(e_\theta, r)$, the cost caused by inspection, increases with inspection level r , since higher inspection level usually results in a longer inspection time, higher probability of detention, more extra salaries paid to seafarers, higher operational expenses, etc. For a given inspection level r , we assume that $Q_\theta(e_\theta, r)$ decreases with effort level e_θ , and follows the law of diminishing returns.

Therefore, we have $\partial Q_\theta(e_\theta, r)/\partial e_\theta < 0$ and $\partial^2 Q_\theta(e_\theta, r)/\partial e_\theta^2 > 0$.

The damage and recovery cost, the main concern of the port State control authority, is the social loss caused by shipping accidents. Since a shipowner's effort level can affect the frequency of shipping accidents, the expected damage and recovery cost decreases in the shipowner's effort. Further, we assume that the law of diminishing returns holds for a shipowner's effort level. Let $D_\theta(e_\theta)$ denote the damage and recovery cost resulted from type θ ship when the shipowner's effort level is e_θ , then we have $dD_\theta(e_\theta)/de_\theta < 0$ and $d^2 D_\theta(e_\theta)/de_\theta^2 > 0$.

The inspection cost of the PSCA include salaries paid to inspectors, purchasing cost of inspection devices, operational costs, etc. We assume that the cost function $C(r)$ is an increasing function of inspection level r . And we assume that $d^2 C(r)/dr^2 < 0$.

3.2.2. Solving the Game

A shipowner observes the port State authority's inspection rate before choosing his effort level. Given an inspection level, type θ shipowner would choose an effort level to minimize his cost function, and the shipowner's problem can be described as

$$\min_{e_\theta} F_\theta(e_\theta, r) = \min_{e_\theta} [M_\theta(e_\theta) + Q_\theta(e_\theta, r) + e_\theta] \quad (2)$$

In the following proposition, we show that there exists an optimal effort level for the type θ shipowner.

Proposition 1. *Suppose that $M_\theta(e_\theta)$ and $Q_\theta(e_\theta, r)$ satisfies the assumptions in Section 3.2.1, then there exists one and only one optimal effort level for type θ shipowner's problem given by (2).*

Proof. According to the assumptions in Section 3.2.1, we can show that $F_\theta(e_\theta, r)$ is concave. Therefore, there exists one and only one optimal effort level for the shipowner of type θ .

Let $e_\theta^*(r)$ denote the optimal effort level of the type θ shipowner when the PSCA's inspection level is r . Thus, type θ shipowner's optimal response function is $e_\theta^*(r)$.

The objective of the port State control authority is to minimize the social loss, and her problem can be describes as

$$\min_{r_\theta} D_\theta(e_\theta(r_\theta)) + C(r_\theta)$$

Since the PSCA can expect that type θ shipowner will choose his optimal effort level $e_\theta^*(r)$, the port State authority's objective function can be simplified to

$$\min_{r_\theta} D_\theta(e_\theta^*(r_\theta)) + C(r_\theta)$$

The port State authority's problem can be described as

$$\begin{aligned} & \min_{r_\theta} D_\theta(e_\theta^*(r_\theta)) + C(r_\theta) \\ & \text{subject to} \\ & e_\theta^*(r_\theta) = \arg \min_{e_\theta} F_\theta(e_\theta, r) \end{aligned}$$

The port State control authority can set the optimal inspection rate r_θ^* for the ship of type θ by solving the

above problem. To set an overall inspection rate, the PSCA can take the expectation of r_θ^* as given in (1).

4. An Inspection Scheme Based on Mechanism Design Theory

In last section, we obtain the optimal inspection rate r_θ^* that a port State authority should set for type θ ship, $\theta \in [a, b]$. If a ship of type θ is inspected at rate r_θ^* , the social welfare is maximized. Since r_θ^* decreases with θ , a substandard ship is inspected more frequently and a well-run ship is inspected less frequently. By doing so, the resources of the port States authorities can be focused more efficiently on ships most likely to be substandard. To differentiate between good and substandard ships, port States authorities consider weighting ship inspection rate according to the target factor assigned to the ships. They select some criteria such as the ship's flag, age and type, history, which are believed to directly influence how well a ship is likely to be operated, and allocate points to each criterion. Thus, a ship can be assigned a targeting factor according to a scoring system. The Paris MOU, for example, assigns an overall targeting factor to ships, whereas the US Coast Guard (USCG) has developed a boarding priority matrix for the purpose of calculating a targeting factor.

Although a ship's target factor is useful for a PSCA to estimate the ship's likelihood of being substandard, the PSCA does not know exactly if the ship is substandard or not because some privately owned information is still not known to the PSCA. For example, two ships with the same target factor may have different likelihoods to be substandard if the two shipowners make different efforts on maintenance. In this section, we first propose an inspection scheme based on mechanism design theory. Then we simplify the scheme to make it easier to implement. Finally, we propose a procedure to integrate a scoring system with the inspection policy derived from the mechanism model.

Mechanism design is a principal-agent model, and can be used to encourage the agent to reveal his privately owned information. Let the PSCA be the principal and a ship be the agent. The types of the agent is distributed on $[a, b]$, and the port authority and the shipowners share common beliefs regarding the probability distribution of types, $G(\theta)$; with $dG(\theta) = g(\theta)d\theta$. For a ship of type θ , the shipowner's cost is $F_\theta(e_\theta, r)$ when his effort is e and the inspection rate is r . The social loss, which the port authority want to minimize, is $D_\theta(e) + C_\theta(r)$. For an inspection rate r , the authority can evaluate a shipowner's effort which minimizes his total cost, and estimate the social loss. Of all the possible inspection rates, the authority would select an inspection rate which minimize the social loss.

If the PSCA knows the exact type of the ship, the port State authority's problem is a typical Stackelberg game, and has been solved in Section 3. The PSCA's optimal inspection rate for type θ ship is r_θ^* , and type θ shipowner make effort of $e_\theta^*(r)$. In this case, social welfare optimality is achieved, and good (substandard) ships are imposed a low (high) inspection rate. Unfortunately, the PSCA does not know for sure if a ship is in good status or not. In this section, we use a mechanism design model to formulate this problem.

According to mechanism design theory, the PSCA, for the benefit of social welfare, can set an inspection rate for each type of ship, i.e., $r(\theta)$. The inspection rate for a substandard ship is high and the one for a good ship is low. Each shipowner is expected to choose an inspection rate of his type. However, a shipowner has an incentive to choose a low inspection rate to save time and cost. To force the shipowner to truthfully reveal his ship's status, the PSCA impose an appropriate penalty on ships denoted by $t(\theta)$, $\theta \in [a, b]$. Let the mechanism be $\{r(\theta), t(\theta)\}$, $\theta \in [a, b]$, and $p(\theta, e)$ be the detention probability of the ship of type θ when the effort is e . Then the mechanism design problem can be formulated as

$$\begin{aligned} & \min_{\{r(\theta), t(\theta)\}} \int_a^b [D_\theta(e_\theta^*(r)) + C_\theta(r)] dG(\theta) \\ \text{subject to} & \arg \min_e [F_\theta(e, r(\theta)) + t(\theta)r(\theta)p(\theta, e)] \leq \arg \min_e [F_\theta(e, r(\theta')) + t(\theta')r(\theta')p(\theta, e)], \theta' \in [a, b] \quad (3) \end{aligned}$$

where (3) are the incentive compatibility constraints. In (3), $t(\theta)r(\theta)p(\theta, e)$ is the expected penalty cost, and $\arg \min_e [F_\theta(e, r(\theta)) + t(\theta)r(\theta)p(\theta, e)]$ is type θ ship's total cost when the inspection rate is $r(\theta)$. $\arg \min_e [F_\theta(e, r(\theta')) + t(\theta')r(\theta')p(\theta, e)]$ is type θ ship's total cost when the inspection rate chosen by the shipowner is for another type θ' . These constraints ensure that the shipowner of type θ would choose the inspection rate designed for his type, that is, the shipowner would truthfully reveal his type. Note that in this problem, no participation constraint is imposed because a shipowner is forced to participate.

A closed-form solution of the above problem is complicated. We only discuss some intuitive insights. To save time and cost, shipowners would like to choose a low inspection rate. To make the owner of a substandard ship to choose a high inspection rate, the port authority can set penalty $t(\theta)$ increasing with θ such that, the penalty on a substandard ship for detention is much higher than the savings from choose a low inspection rate designed for a good ship. In this case, a shipowner would not report a substandard ship as a good one, because the savings in choosing a lower inspection rate may be lower than extra penalty cost he has to pay in case of not passing the inspection.

The inspection scheme represented by $\{r(\theta), t(\theta)\}, \theta \in [a, b]$ is difficult to implement because of high transaction cost incurred due to too many possible inspection rates. We propose an inspection scheme which is much easier to implement. In the scheme, a PSCA sets two different inspection rates, denoted as r_L and r_H and the respective penalties denoted by t_L and t_H . A shipowner chooses r_L (r_H), and pays penalty t_L (t_H) if his ship does not pass the inspection.

If we assume that the ship types has a monotonicity property, then there exists a critical point $\bar{\theta}$ such that a type of θ , $\theta \in [a, \bar{\theta}]$, would choose r_H and a type in $[\bar{\theta}, b]$ would choose r_L . In other words, types distributed on $[a, b]$ are divided into two parts, a type of θ , $\theta \in [a, \bar{\theta}]$ chooses a lower inspection rate, and a type of the other segment chooses a higher inspection rate. If we assume that the ship types has a continuity property, then the type of $\bar{\theta}$ would be indifferent to choosing r_L or r_H . For simplicity and easier implementation, t_L can be normalized to be 0.

Thus we have

$$\min_e F_\theta^-(e, r_L) = \min_e F_\theta^-(e, r_H) + r_H t_H p(\theta, e^*(\theta)).$$

Therefore, the PSCA's problem is

$$\min_{(r_L, r_H, t_L)} \int_a^{\bar{\theta}} [D_\theta(e_\theta^*(r_H)) + C_\theta(r_H)] dG(\theta) + \int_{\bar{\theta}}^b [D_\theta(e_\theta^*(r_L)) + C_\theta(r_L)] dG(\theta)$$

subject to

$$\min_e F_\theta^-(e, r_L) + r_L t_L p(\theta, e^*(\theta)) = \min_e F_\theta^-(e, r_H).$$

The numerical solution of the above problem is not difficult to obtain, although the closed-form solution is complicated. Next, we propose a procedure to set an inspection policy for a port State control authority.

First, we can use the method in Section 3 to obtain an overall inspection rate r_0 for a port State authority. Then, the PSCA can design an inspection rate r_H for ships more likely to be substandard, an inspection rate r_L for ships more likely to be good. Each ship can choose an inspection rate itself and the penalty t_L for detention is imposed on the ship when r_L is chosen. Note that $r_L < r_0 < r_H$, which means inspection rate for ships likely to be substandard (good) is higher (lower) than the overall inspection rate. Finally, the PSCA can use a scoring system to assign a target factor for each ship, and adjust inspection rate for some ships when necessary. For example, if a ship is likely to be substandard according to a scoring system, but chooses a low inspection rate, then the PSCA may inspect the ship with a higher rate.

Compared to a scoring system, the inspection scheme represented by (r_L, r_H, t_L) has two advantages. First, in the case when two ships have the same score, it is possible that one is likely to be substandard for reasons such as poor maintenance and the other is likely to be good for reasons such as good maintenance. Then the scoring system cannot differentiate between the two ships, while the inspection scheme (r_L, r_H, t_L) might be able to do so. Second, under the scheme (r_L, r_H, t_L) , ships reveal their information themselves, which saves the cost to collect and maintain information for scoring a ship.

5. Discussion and Conclusion

In this paper, we first use a Stackelberg game to study the overall inspection rate which should be appropriate for a port State authority, and we show the processes to obtain the optimal inspection level for the PSCA. Our results can help the port State authority to set the overall inspection rate for calling ships. Then we apply mechanism design theory to design an inspection scheme which imposes a higher inspection rate on ships more likely to be substandard. This scheme can improve the ability of port States control authorities to select ships more likely to be substandard. Moreover, the inspection scheme can be integrated with scoring systems used by port States authorities currently.

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