

PORT STATE CONTROL (PSC) TARGETTING SYSTEM WITH DISCRIMINANT ANALYSIS

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SUMMARY/ABSTRACT

Port State Control (PSC) is an effective measure to verify and ensure that the condition and equipment of foreign ships visiting national ports are in compliance with the requirements of international safety and anti-pollution standards. Ships that are found to be in serious violation of standards are detained in port until their deficiencies have been rectified. The objective of PSC is to detect substandard ships and eliminate the threat that they pose to life, property and the marine environment. In order to ensure the effectiveness of PSC, regional port state control organizations are established and agreements on port state control – “Memoranda of Understanding” or MOUs – have been signed covering all of the world’s oceans. For Asia and Pacific region, “Tokyo MOU” is signed by 18 authorities. One of the effective methods that authorities adhere to the MOUs is to develop a common targeting system that determines which ships in port should be inspected.

There are a number of targeting systems proposed and introduced into PSC, however, most of the systems are based on experiential measures or simple comparison of a few attributes of the ships.

In this research we introduce discriminant analysis as a risk assessment method, in order to promote the efficiency of PSC by developing a more accurate and flexible targeting system for ships-in-port classification. Discriminant analysis generates classification functions for a sample of observations from pre-determined categories. A large number of variables can be adapted to the functions. We applied Linear Discriminant Function to historical inspection data. Sixteen attributes recorded in Tokyo MOU database, e.g. ship type, ship age, flag state, and previous inspection results, are utilized as the variables of the function. Coefficients of variables are produced by 32,121 inspection data set collected through the years 2002 and 2003. The developed discriminant function estimates the possibility of detention for each arriving ship. However general solution of the Linear Discriminant Function maximizes the percentage of correct classification, adjustment of constant term enables us to calculate an overall detention rate for a given inspection ability. Among the attributes, flag state, classification society, and the number of detentions during last 4 inspections are the three major factors that influence the estimation. By extending the function, we also developed a function that estimates the required inspection rate to achieve a given rate of detention. Authorities can adopt it as a management measure because it helps to determine the number of inspection officers or other resources for their ports. The functions we proposed can be updated to adjust to the newly obtained data in MOU inspection database. Finally, this paper shows the comparison between the proposed targeting system and the 2003 revised targeting system developed by Tokyo MOU. The comparison result shows that the former provides better capture rates in the range of 10-60% inspection rates.

INTRODUCTION

Ships that deviate from the requirements of international standards are interferences with safety and environmental conservation. Port State Control (PSC) is an effective measure to verify and ensure that the condition and equipment of foreign ships visiting national ports are in compliance with the requirements of international safety and anti-pollution standards. Since its session in 1981, the IMO Assembly has adopted various resolutions and circulars relating to PSC, and more countries around the world have conducted inspection and reinforced the inspection systems. Since ship inspections of PSC take immense effort and expenditure, one hundred percent inspection is difficult. Even to keep inspection rate is not easy at mighty ports where enormous ships come into.

To distribute limited human resources, various criteria called target system are proposed. Target systems include calculation method to estimate the degree of risk with a given ship. However, existing target systems are developed based only on inspectors' experience and technical intuition, and no precise boundary that distinguish ships to be examined is defined.

This paper proposes a new target system that provides criteria based on a statistical method, in order to promote the efficiency of Port State Control. In particular, to improve acquisition rate of ships that should be detained for treatment, we propose an estimation method that utilize past records of inspection.

Firstly, we derive a linear discriminant function that evaluate if an inspection is necessary for a given ship from samples known to belong to either group. Then we develop a method to draw ships to inspect depending on intended inspection rate with the derived discriminant function, and clarify relationship between inspection rates and capture rates. Finally we compare the proposed method with the latest target system called "2003 revised target system" to confirm its efficiency.

Ships that deviate, sometimes substantially or repeatedly, from the requirements of class rules and/or international conventions represent an unacceptable safety hazard.

PSC INSPECTION HISTORY AND TARGET SYSTEM

Inspection History Data

Countries that conduct PSC inspection form regional communities called "MOU (Memorandum of Understanding)" with the aiming of supervise more dangerous ships selectively. For the aim, member countries cooperate in developing inspection manuals and information exchanging.

In Tokyo MOU, a regional cooperation for Asia and the Pacific countries, total calling at port in the year of 2002 was 25,202 and 19,588 (78%) of them are inspected.

As a result, deficiencies are found with 13,760 ships and 1,307 (6.7%) ships had detainable deficiencies (From here we call these ships as "detained ships"). APMIAS (Asia Pacific Maritime Information and Advisory Services) at Vladivostok runs a port state control database called APCIS (Asia Pacific Computerized Information System) to share inspection data among member countries. The following items are recorded in every inspection. Firstly, nine items associated with ship attribute are recorded.

- name of reporting authority
- IMO number
- ship flag state
- ship type
- ship classification society
- year of build
- date of inspection
- place of inspection
- company

Descriptions of "name of reporting authority", "ship flag state", and "ship classification society" are standardized using IDs. Description of "company" is free-form information. For this item, approximately 90 % of all records are filled with some kind of company information.

As history data, four kinds of calculation result using last four inspection data are recorded.

- Time since last inspection (months); x_{time}
- Number of detentions during last 4 inspections; x_{det}
- Number of deficiencies during last 4 inspections; x_{def}
- Number of outstanding deficiencies during last inspection; x_{out}

Three items are recorded as inspection result.

- Total number of deficiencies
- Number of detainable deficiencies
- Detention (yes/no)

In this research we propose a method to estimate if a given ship assessed to be a ship of detention or not, from a set of data given before inspection.

Estimatable parameters

Approximate figures of the following statistics are estimatable if inspection data has been stored. However, we need to note that PSC inspection is neither 100% inspection nor random inspection, so the universe has bias if compared with perfect inspection data.

- Ship flag detention rate(%); x_{flag}
- Classification society detention rate (%); x_{CS}

The following two items can be calculated from a list of the classification societies that belongs to IACS, and build date.

- IACS or Non-IACS; x_{IACS} {0, 1}, 0=false, 1=true
- Ship age; x_{age}

Target System

Target system is a formula that calculates a score from ship types, ship ages, inspection history data, and so on. The formula proposed by Paris MOU and “2003 revised target system” proposed by Tokyo MOU are among famous target systems. In the “2003 revised target system”, score z is calculated using detention rate by ship flag state (x_{flag}), ship type (type), IACS or Non-IACS (x_{IACS}), ship age (x_{age}), time since last inspection (x_{time} (months)), number of detentions during last 4 inspections (x_{det}), number of deficiencies during last 4 inspections (x_{def}), number of outstanding deficiencies during last inspection (x_{out}).

$$Z = Z_{flag} + Z_{type} + Z_{IACS} + Z_{age} + Z_{time} + Z_{det} + Z_{def} + Z_{out}$$

where,

$$Z_{flag} = \max \{ x_{flag} - x_{flag}, 0 \}$$

$$z_{\text{type}} = \begin{cases} 4 & \text{if } \text{type} \in \{13, 30, 40, 55, 60, 61, 70\} \vee x_{\text{age}} > 15 \\ 0 & \text{otherwise} \end{cases}$$

$$z_{\text{IACS}} = \begin{cases} 0 & \text{if } x_{\text{IACS}} = \text{true} \\ 10 & \text{otherwise} \end{cases}$$

$$z_{\text{age}} = \begin{cases} 0 & \text{if } 0 < x_{\text{age}} \leq 5 \\ 5 & \text{if } 5 < x_{\text{age}} \leq 10 \\ 10 & \text{if } 10 < x_{\text{age}} \leq 15 \\ 10 + 1/(x_{\text{age}} - 15) & \text{if } 15 < x_{\text{age}} \leq 20 \\ 15 + 2/(x_{\text{age}} - 20) & \text{otherwise} \end{cases}$$

$$z_{\text{time}} = \begin{cases} 3 & \text{if } 6 < x \leq 12 \\ 6 & \text{if } 12 < x \leq 24 \\ 50 & \text{if } 24 < x \\ 0 & \text{otherwise} \end{cases}$$

$$z_{\text{det}} = \begin{cases} 15 & \text{if } x_{\text{det}} = 1 \\ 30 & \text{if } x_{\text{det}} = 2 \\ 60 & \text{if } x_{\text{det}} = 3 \\ 100 & \text{if } x_{\text{det}} = 4 \\ 0 & \text{otherwise} \end{cases}$$

$$z_{\text{def}} = 0.5 \cdot x_{\text{def}}$$

$$z_{\text{out}} = 2.0 \cdot x_{\text{out}}$$

Some parts of the functions, for example, adding points to z_{type} if the ships are older than 15 years, are defined from political requirement rather than experience or technical intuition.

DISCRIMINANT ANALYSIS

Outline of discriminant analysis

Discriminant analysis is a method to distinguish between two or more categories or groups using a set of predictors. For two-group discrimination, linear discriminant analysis and a discriminant analysis based on the Mahalanobis' generalized distance are widely used. Linear discriminant is a classification method that projects high-dimensional data onto a line and performs classification in this one-dimensional space (Fig. 1a). The projection maximizes the distance between the means of the two classes while minimizing the variance within each class. Mahalanobis' generalized distance is a normalized distance in the normal distribution from the center to a point (Fig. 1b).

In order to vary the derived discriminant boundary, we decided to apply the more simple method of the two, i.e. linear discriminant analysis.

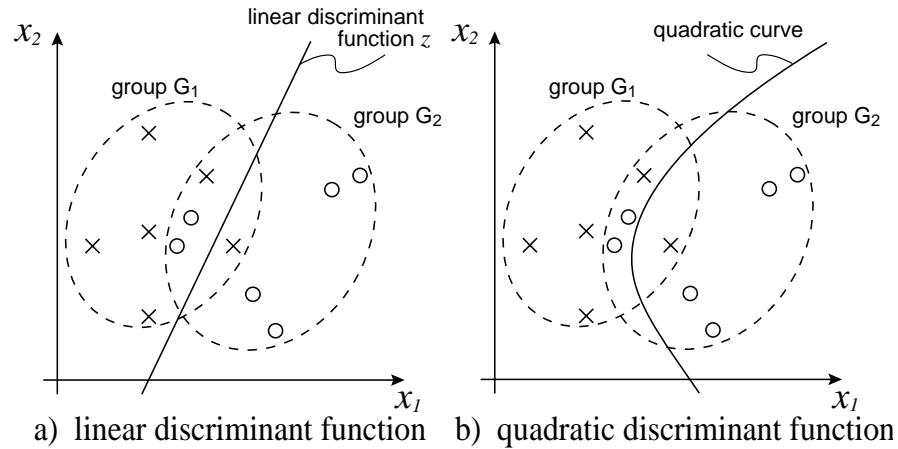


Figure 1. Discriminant analysis

Discrimination using linear discriminant function

Suppose that x_1, \dots, x_p are variables and a_1, \dots, a_p are constants, discriminant score is calculated by a function,
 $z = a_1x_1 + \dots + a_px_p$ (2)
 We define the coefficient factors (a_i).

Selection of explanatory variables

Table 1 shows correlations of main variables. There are two pairs that are strongly correlated ($\pm 0.7 - \pm 1.0$): $x_{CS} - x_{flag}$ and $x_{IACS} - x_{CS}$, and nine pairs that are correlated ($\pm 0.4 - \pm 0.7$).

Table 1. Correlation matrix of main variables

	x_{flag}	x_{CS}	x_{det}	x_{def}	x_{out}	x_{age}	x_{time}	x_{IACS}
x_{flag}	1	0.782	0.424	0.402	0.238	0.372	-0.113	-0.687
x_{CS}	0.782	1	0.450	0.403	0.227	0.374	-0.119	-0.902
x_{det}	0.424	0.450	1	0.618	0.318	0.289	-0.084	-0.409
x_{def}	0.402	0.403	0.618	1	0.599	0.371	-0.116	-0.402
x_{out}	0.238	0.227	0.318	0.599	1	0.220	-0.047	-0.220
x_{age}	0.372	0.374	0.289	0.371	0.220	1	-0.002	-0.351
x_{time}	-0.113	-0.119	-0.084	-0.116	-0.047	-0.002	1	0.115
x_{IACS}	-0.687	-0.902	-0.409	-0.402	-0.220	-0.351	0.115	1

In the case that there are correlated variables like this, selection of explanatory variables should be adopted. Here, we use step-wise method, and confirm that the coefficient values in the result (positive or negative) matches with the actual impacts.

RESULTS OF DISCRIMINANT ANALYSIS

Discriminant Function

We divided sample data set (result of 37,106 inspections conducted through Jan. 2002 to Dec. 2003) into two groups.

- Jan. 2002 ... Aug. 2003 (23,121 records) : for function construction (discriminant data)
- Sep. 2003 ... Dec. 2003 (4,985 records): for validation (validation data)

We calculated discriminant analysis using SPSS software with step-wise method ($F_{in} = 3.84$, $F_{out} = 2.71$). Table 2 shows the result of discriminant analysis.

Table 2. Coefficients for the discriminant function

x_i	standardized coefficient	coefficient
x_{flag}	0.409	0.053
x_{CS}	0.274	0.040
x_{det}	0.210	0.388
x_{def}	0.123	0.009
x_{age}	0.190	0.023
x_{IACS}	-0.115	-0.341
(const.)		-0.909

This result shows that the discriminant function is defined like the following function.

$$z = 0.053 x_{flag} + 0.040 x_{CS} + 0.388 x_{det} + 0.009 x_{def} + 0.023 x_{age} - 0.341 x_{IACS} - 0.909$$

Discrimination Result

Table 3 is cross-tabulation table that shows the result of discrimination with the function, and Figure 2 shows the frequency distribution graph of the z values.

Table 3. Classification matrix of training data (z = 2.3)

		detention (yes/no)	estimated group		Total
			no	yes	
original data	frequency	no	28,305	1,308	29,613
		yes	1,702	806	2,508
	%	no	95.6	4.4	100.0
		yes	67.9	32.1	100.0

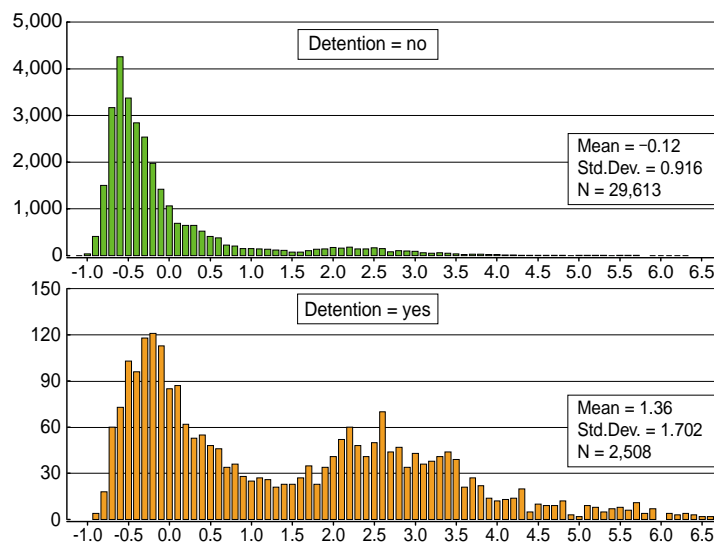


Figure 2. Distribution of z values

ESTIMATION OF INSPECTION RATE AND ACQUISITION RATE

In order to execute inspection the ships that should be inspected, limited inspection resources should be distributed adequately. Thus, we need to know required inspection rate to meet the target acquisition rate. In this section, a simple method to explore the required inspection rate to meet target acquisition rate.

Figure 3 shows a basic idea of the exploration. The result function retrieved in the preceding section is shown as a boundary line. If we vary the constant of the discriminant function, then the boundary translates in parallel. Using this mechanism, required inspection rate is searched with an algorithm shown in Figure 4.

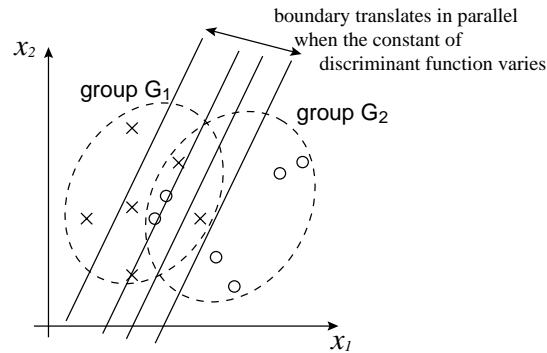


Figure 3. Shifting the boundary of z value

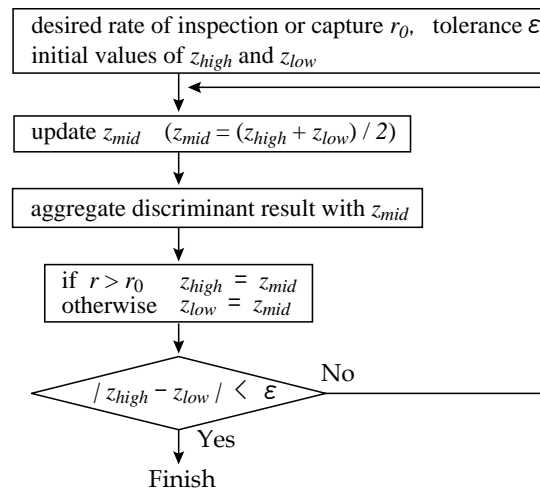


Figure 4. A method to estimate z value corresponds to a given capture rate

Table 4 shows the relations of capture rate, z value, and inspection rate, resulted from the exploration algorithm with discriminant data. Figure 5 compares the result of discriminant analysis and 2003 RTS with discriminant data.

Table 4. Relations of capture rate, z value, and inspection rate (discrimination data)

capture rate (%)	z	inspection rate (%)
0	6.50	0
10.0	3.59	1.4
20.0	2.92	3.2
30.0	2.40	5.9
40.0	1.90	9.2
50.0	0.94	13.5
60.0	0.31	20.1
70.0	-0.05	28.6
80.0	-0.28	40.2
90.0	-0.51	60.1
100.0	-1.00	99.9

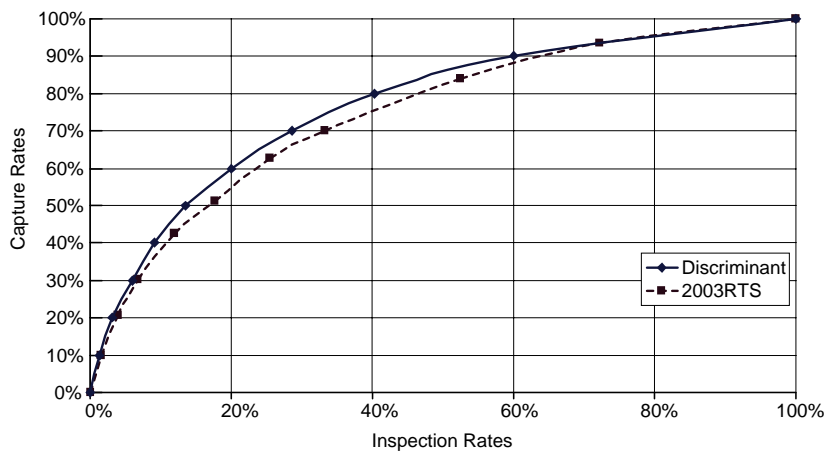


Figure 5. Result of discriminant analysis compared with 2003 RTS (discrimination data)

VERIFICATION

For verification of the function, we evaluated the estimation value (z) for verification data. Figure 6 shows the result. The dotted line shows the result using 2003 RTS function. In the range between 10 to 60 % discriminant function worked a few percent better, and in the other ranges it worked almost the same as the 2003 RTS function.

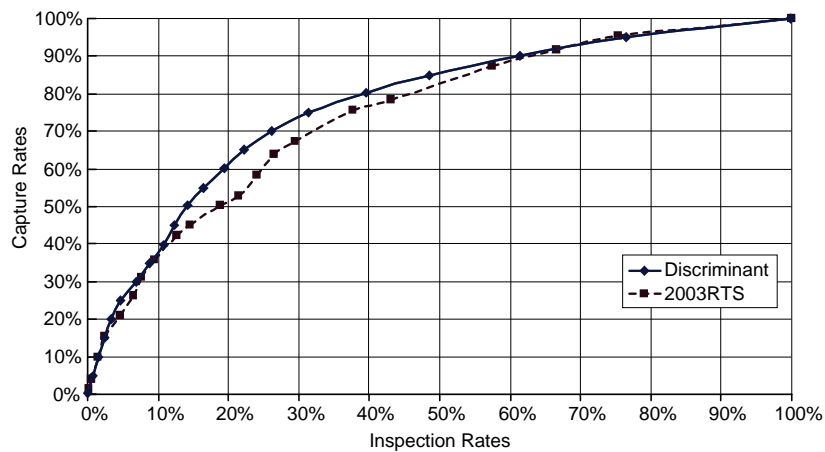


Figure 6. Result of discriminant analysis compared with 2003 RTS (verification data)

CONCLUDING REMARKS

In this research we introduced discriminant analysis as a risk assessment method, in order to promote the efficiency of PSC by developing a more accurate and flexible targeting system for ships-in-port classification. We applied Linear Discriminant Function to historical inspection data. Sixteen attributes recorded in Tokyo MOU database, e.g. ship type, ship age, flag state, and previous inspection results, are utilized as the variables of the function. Coefficients of variables are produced by 32,121 inspection data set collected through the years 2002 and 2003. The developed discriminant function estimates the possibility of detention for each arriving ship. However general solution of the Linear Discriminant Function maximizes the percentage of correct classification, adjustment of constant term enables us to calculate an overall detention rate for a given inspection ability. Among the attributes, flag state, classification society, and the number of detentions during last 4 inspections are the three major factors that influence the estimation. By extending the function, we also developed a function that estimates the required inspection rate to achieve a given rate of detention. Authorities can adopt it as a management measure because it helps to determine the number of inspection officers or other resources for their ports. The functions we proposed can be updated to adjust to the newly obtained data in MOU inspection database. Finally, this paper shows the comparison between the proposed targeting system and the 2003 revised targeting system developed by Tokyo MOU. The comparison result shows that the former provides better capture rates in the range of 10-60% inspection rates.

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