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ABSTRACT
Navigational collisions are one of the major safety concerns in many seaports. Despite the extent of recent works done on port navigational safety research, little is known about harbor pilot's perception of collision risks in port fairways. This paper uses a hierarchical ordered probit model to investigate associations between perceived risks and the geometric and traffic characteristics of fairways and the pilot attributes. Perceived risk data, collected through a risk perception survey conducted among the Singapore port pilots, are used to calibrate the model. Intra-class correlation coefficient justifies use of the hierarchical model in comparison with an ordinary model. Results show higher perceived risks in fairways attached to anchorages, and in those featuring sharper bends and higher traffic operating speeds. Lesser risks are perceived in fairways attached to shoreline and confined waters, and in those with one-way traffic, traffic separation scheme, cardinal marks and isolated danger marks. Risk is also found to be perceived higher in night.

Keywords: Navigational collision risk, Risk perception, Fairway, Harbor pilot, Hierarchical regression.

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INTRODUCTION

Navigational collisions are one of the major safety concerns in many seaports. Navigational collisions account for a substantial portion of major shipping accidents in port waters, as reported by a number of researchers (e.g., *1-5*). Furthermore, the increasing growth of world fleet (see, *6*) is likely to result in increased traffic movements within busy seaports, which in turn could increase collision likelihood in these congested and restricted waters (*5, 7*).

To address this safety concern some recent studies have focused on port navigational safety issues from different aspects; such as analyses of trends and causes of accidents (*2, 4, 5, 8*); analyses of injuries and fatalities in port water accidents (*1, 2*); analyses of involved parties in port water conflicts (*7*); and modeling accident probabilities (*9*). These studies analyzed port water incidents to address the general safety issues in port navigation. To address the behavioral issues in port navigational safety, some studies focused on pilot fatigue (*10-12*); sleep and watchkeeping (*13*); mental workload (*14*); and the pilot's operational relationships and communications with ship crews (*15, 16*). Despite the extent of works done, little is known about other behavioral issues, particularly on pilot's perception of collision risks.

Studying pilot's perception of collision risks is important because risk perception is considered as a precursor of an individual's actual behavior (see *17*). Cohn et. al. (*18*) indicated that risk perception is negatively related to risk behavior in general, i.e., a lower level of perceived risk is associated with a higher probability that a pilot would be involved in such risk. Thus, by examining their perception of risk, the pilot's behavioral characteristics can be understood.

This paper aims at examining the relationships between perceived risks and characteristics of fairways and pilots by employing a hierarchical ordered Probit model that would account for the correlations in an individual pilot's perceived risks. Using perceived risk data, which are collected through a risk perception survey conducted on Singapore port pilots, the geometric and traffic factors of fairways as well as the pilot attributes affecting such risks are identified.

METHODOLOGY

A hierarchical ordered probit model (HOPM) is formulated that could account for the potential correlations in risks perceived by an individual pilot. The risk data are collected through a risk perception survey, where a subjective risk scale (see Table 1) is used for perceiving risks in five categories. Thus, the risks are ordinal in nature and have a hierarchical structure as an individual pilot perceives risks in different fairways. The HOPM formulation, its assessment process and the design process of the risk perception survey are discussed in the subsequent sections.

Hierarchical Ordered Probit Regression

Model Formulation

While descriptive statistics may give a quick assessment of the influencing factors on the perceived risks, regression analysis is a more appropriate technique to determine the relationships between perceived risks and the characteristics of fairways and pilots. This is because all the explanatory factors may be considered simultaneously.

Since the risk levels obtained in the survey are subjective but ordered in nature, an ordered categorical analysis will be most appropriate to treat such data. Two possible regression models may be used: the ordered Probit or ordered Logit models. The former assumes a normal distribution of errors and is less restrictive and is preferred. In any case, both models produce very similar results.

Furthermore, in the presence of within-panel correlation in response variable, models without appropriately considering the hierarchical data structure might yield biased results. To account for this correlation, a hierarchical regression model (HRM) is necessary (see 19). In this study, the perceived risk data has a hierarchical structure with potential within-panel correlation as the risks perceived by an individual pilot could be correlated due to his/her risk perception characteristics. To account for this within-pilot correlation, a HRM with two-level specification is necessary and more correct than the ordinary regression model (ORM). In case of an ORM, the correlation of the regression errors within level-2 units will violate the error term's independency assumption, which results in obtaining falsely significant results (see *19*).

The structural form of a HOPM is formulated as a latent variable framework (see *19* for detailed description of such model):

$$y_{ij}^{*} = \beta_{0j} + \mathbf{X}_{ij}\boldsymbol{\beta}_{\mathbf{1}} + \mathbf{Z}_{j}\boldsymbol{\beta}_{\mathbf{2}} + e_{ij}\ ;\ i = 1,\ \ldots\ , N\ ;\ \ j = 1,\ \ldots\ ,P \tag{1}$$

where y_{ij}^{*} is a continuous latent variable measuring collision risk in fairway *i* perceived by pilot *j*; β_{0j} is the intercept of the model; $\mathbf{X}_{ij}$ and $\mathbf{Z}_{j}$ are vectors of explanatory variables at level-1 and level-2 respectively; $\boldsymbol{\beta}_{\mathbf{1}}$ and $\boldsymbol{\beta}_{\mathbf{2}}$ are the corresponding vectors of unknown parameters explaining effects of explanatory variables; e_{ij} is the random error term at level-1, which is assumed to be normally distributed with zero mean and unit variance; *N* is total number of fairways whose risks are perceived; and *P* is the total number of pilots responded in the survey.

In the HOPM, correlation among perceived risks of each pilot is specified as:

$$\beta_{0j} = \alpha + u_{j} \tag{2}$$

where α is average intercept across all observations and all clusters; u_{j} is unobserved random effects of pilot *j* assumed to follow normal distribution with mean zero and variance $\sigma_{u}{}^{2}$.

The measurement model, in which the latent variable y_{ij}^{*} is mapped on to an observed ordinal variable y_{ij}, the collision risk in fairway *i* perceived by pilot *j*, is formulated as:

$$y_{ij} = \begin{cases} 1 & \text{if} \quad -\infty \le y_{ij}^{*} < \tau_{1} \quad \text{[SAFE]} \\ 2 & \text{if} \quad \tau_{1} \le y_{ij}^{*} < \tau_{2} \quad \text{[Low risk (LR)]} \\ 3 & \text{if} \quad \tau_{2} \le y_{ij}^{*} < \tau_{3} \quad \text{[Moderate risk (MR)]} \\ 4 & \text{if} \quad \tau_{3} \le y_{ij}^{*} < \tau_{4} \quad \text{[High risk (HR)]} \\ 5 & \text{if} \quad \tau_{4} \le y_{ij}^{*} < \infty \quad \text{[Very high risk (VHR)]} \end{cases} \tag{3}$$

where the threshold values $\tau_{1}, \tau_{2}, \tau_{3}$, and τ_{4} are unknown parameters to be estimated.

Based on the normality assumption of the error term, the probabilities of the risk levels can be predicted as:

$$\Pr\left(y = m \middle| \mathbf{X}_{ij}, \mathbf{Z}_j\right) = F\left(\tau_m - \boldsymbol{\beta}_1 \mathbf{X}_{ij} - \boldsymbol{\beta}_2 \mathbf{Z}_j\right) - F\left(\tau_{m-1} - \boldsymbol{\beta}_1 \mathbf{X}_{ij} - \boldsymbol{\beta}_2 \mathbf{Z}_j\right); \ \sum_{m=1}^{M} \Pr\left(y = m \middle| \mathbf{X}_{ij}, \mathbf{Z}_j\right) = 1 \tag{4}$$

where F is the cumulative distribution function for e_{ij}.

Model Assessment
In order to examine the degree of correlations among the level-1 units belonging to the same level-2 units, the intra-class correlation coefficient (ICC) is usually used (*19, 21*). It is expressed as the proportion of level-2 variance (σ_u^2) in total residual variance:

$$\rho = \frac{\sigma_u^2}{\sigma_u^2 + 1} \tag{5}$$

The ICC is an indicator of the magnitude of the within-pilot correlation. A value of ρ close to zero indicates that there is very small variation between different pilot's risk perception characteristics, implying that an ORM would be adequate for the data. On the other hand, a relative large value of ρ, significantly different from zero, indicates appropriateness of a HRM over an ORM.

Risk Perception Survey
To gain information on pilot's perceived risks and attributes, a risk perception survey is designed where the pilots are asked to perceive collision risks in fairways. To facilitate the perception process a five-point scale is developed based on the 'likelihood of a close quarter situation (CQS) in a fairway', as presented in Table 1. A CQS is a critical incident that poses risk of collision but not necessarily involve a collision. It is assumed that the risk of collision is higher when the likelihood of CQS is higher.

In this survey, a total of 16 fairway sections in Singapore port are considered. From operational definitions of fairways (see *22*) the fairways are divided into sections with approximately uniform geometric and traffic control characteristics. A map showing the fairways is presented in Figure 1. Since navigation in day and night attribute different characteristics in terms of visibility, watchkeeping, traffic operational characteristics (see *5*), the pilots are asked to perceive risks separately for day and night. The fairway sections are divided into four groups so that each pilot is required to perceive risks only in four fairways for day and night.

In designing the survey, considerations need to take into account potential biases in perceived risks. Four general sources of biases, identified by Weinstein (*23*) and Fischhoff et. al. (*24*), are carefully examined in the design process. The first is 'unwarranted optimism bias', which indicates that people tend to be excessively optimistic and overconfident while judging likelihood of own involvement in risky events. This could lead the pilots to overrate their pilotage skills and to consider themselves as less likely to be involved in risky events. To avoid this bias in this survey, the pilots are asked to perceive risks in such a way that it does not relate to the risk of their own involvement. They are asked to perceive the overall risks in fairways so that these could reflect the actual risks.

The second is 'anchoring bias' in which respondents tend to anchor their risk estimates around some known values of actual risk (e.g., from collision statistics). In this survey, no statistics are provided so that pilots will not make biased responses.

The third is 'availability bias' and this is the bias that could result from collision experiences or disproportionately available information regarding collisions in media, such as highlighted news which are easily remembered. Therefore, a pilot, who has experienced a collision in a particular fairway or read/seen news regarding collisions in media, could rate higher collision risk in that fairway, compared to a pilot who has no such experience or information. In order to avoid this potential source of bias, pilots are asked to perceive risks from their judgments regarding likelihood of CQSs in fairways. The reason of using the CQSs, instead of collisions, is that the CQSs are likely to occur considerably more frequently than collisions (*25*). This increases the probability of having CQS experiences for all pilots, whereas their chance of having collision experiences is very low. Thus, most of the pilots could have CQS experience, resulting in a uniform bias in their perceptions. Moreover, CQS are usually not reported in media, thus reducing the chances of obtaining disproportionately available information.

The fourth bias is the tendency of respondents to overestimate the risk of very rare events and to underestimate the risks of events that occur very frequently. Since collisions are very rare events, using them as basis in risk perception could result is biased perceptions. On the other hand, the CQSs do not occur very frequently so that the perceptions could be biased due to underestimation. Thus, using the CQS as basis in risk perception could reduce this bias.

The perception questionnaire was sent to 160 pilots who are familiar with the port waters in Singapore. Response was anonymous and participation was voluntary. A total of 70 responses were received giving a response rate of 44%. Among the respondents, the age ranged from 28 to 61 years. The age distribution (Figure 2) reveals that the sample is more than adequate to capture the effects of pilot's characteristics on perceived risks.

DATASET FOR ANALYSIS

The survey data includes the perceived risks in the 16 fairway sections as well as attributes of the pilots, such as age, experience and training information. From the 70 responses, a total of 560 observations are found that are used to calibrate the model. Data of the fairway characteristics are collected from various sources, such as navigational charts, tables and the Singapore port traffic database.

A total of 21 explanatory variables assumed to influence perceived risks are included in the model. As shown in Table 2, they include fairway characteristics, time effects as well as pilot attributes. Since collision risks in fairways are influenced by traffic in its boundary waters, it is necessary to consider the boundary effects. The waters around a fairway are described by five waterway types, such as shoreline, confined waters, anchorage, intersection, and international fairway. Confined waters comprise the port terminal berth areas and the low depth waters with scattered land obstacles. The fairways outside port waters are referred to as international fairways, while the others are defined according to their standard definitions. The boundary waters are defined as binary variables in the model based on their presence.

Geometric characteristics of fairways include the water depth of navigation, average navigable width, the number of bends, the degree of bend (described by the maximum angular deflection from a straight line extended from the straight fairway section prior to a bend) and whether the traffic separation scheme (TSS) is enforced. Presence of TSS represents if traffic streams in a fairway are separated by some between space margins.

Characteristics of navigational aids (e.g., navigational buoys/lights) in fairways are represented by four types of such facilities, as specified in the IALA Maritime Buoyage System (*26*). These include lateral marks, cardinal marks, isolated danger marks and safe water marks. Lateral marks are represented based on their presence, while the others are described as the numbers of marks present in fairways.

Traffic characteristics of fairways are obtained from the vessel traffic information system database of Singapore port. These include the traffic densities, and operating speeds of fairways. Traffic density is described as the average numbers of dynamic vessels per square nautical mile, while operating speed represents the average speed of vessels navigating in fairways. The average values are obtained for both the day and night situations. Furthermore, to account for the effects of differences in navigational characteristics in day and night a binary variable representing the two periods are considered.

Pilot attributes influence the perceived risks. Based on review of risk perception literature (e.g., 17, 27) several attributes are considered (1) age, (2) pilotage experience and (3) time since last pilotage training. Five ordered categories of recent training time are specified while the group of untrained pilots is kept as reference category.

MODEL CALIBRATION AND VALIDATION

It is necessary to examine the characteristics of day and night risks before estimating the model parameters. A test for examining if the day and night risks are of similar magnitude yields a paired-t = 18.81 (df = 279, p < 0.01). While the risks are not similar, the next step is to test whether they should be modeled separately or not. To evaluate the statistical significance of separating the day and night models, a likelihood-ratio (LR) test (see *20*) can be conducted. The test statistics is:

$$LR = -2\left\{LL_{DN}\left(\beta\right) - LL_{D}\left(\beta\right) - LL_{N}\left(\beta\right)\right\} \tag{6}$$

where $LL_{DN}\left(\beta\right)$ is the log likelihood (LL) at convergence of the model estimated on the day and night risks together; and $LL_{D}\left(\beta\right)$ and $LL_{N}\left(\beta\right)$ are the LL at convergence of the model estimated separately on the day risk and night risk respectively. The test statistics is χ^2 distributed with degrees of freedom equal to the sum of the number of parameters estimated in the disaggregate models minus that in the aggregate model.

The results of the LR test are presented in Table 3. The resulting LR is lower than the critical value of a χ^2 distribution at 95% confidence level. Hence, the explanatory effects are consistent between risks in day and night, thus suggesting an aggregate model.

The parameters of the HOPM were derived using the maximum likelihood estimation method in the software GLLAMMs (*28*). A backward elimination procedure (see, *29* for detail) is employed to obtain the best fitted model by minimizing the Akaike information criteria (AIC) (see *20*). An AIC value of 1250.4 is obtained for the model. The estimated parameters along with statistical significance are presented in Table 4, and the results are discussed in the next section.

As shown in Table 4, the level-2 variance indicating the magnitude of between-pilot variance is 0.78 and it accounts for 43.7% of the total variance, which strongly suggests the appropriateness of the hierarchical model for the analyzed dataset. If an ORM was used instead, the model estimates will be biased and inaccurate.

Changes in the predicted probabilities of each risk categories can be computed to examine the substantive explanatory effects. These are obtained by computing the effect of a unit change in a continuous explanatory variable from its mean value or a change from 0 to 1 for a categorical variable while holding all other variables at their mean. For variables with more than two categories, the changes are computed based on a category change from 0 to 1 while the other categories and the other variables are kept at 0 and the mean respectively (see *20*). The computed probability changes are presented in Table 5 and discussed in the next section.

DISCUSSION ON SIGNIFICANT VARIABLES

Presence of Anchorage at Fairway Boundary

Anchorage attached to fairway shows significant positive association with perceived risk (beta = 0.416, p = 0.042) with corresponding increase in the probability of VHR state of 79%. The numbers of vessel movements are high if anchorages are present near fairways including merging to fairway, diverging to anchorage as well as cross traffic interactions. For example, a fairway vessel, turning on her port side in order to get into an anchorage that is on the other side of the fairway, will need to cross her port side traffic stream. These interactions could lead to higher perceived risks. In addition, C.-P. Liu et. al. (*4*) contended that vessels with clear boarding schedules tend to anchor near boundary so that they can enter the fairway in a shorter period of time. For this reason, pilots of vessels plying in fairways could have lesser time for risk perception and mitigation, thus leading to increased risks. Providing dedicated navigational management service for such waters, such as monitoring and assisting pilots by providing relevant information regarding vessels plying in such areas, could be a potential strategy to enhance safety.

Presence of Shoreline at Fairway Boundary

The presence of shoreline shows significant negative association with perceived risk (beta = -2.11, *p* = 0.000). Since there is no incoming vessel from such boundary, lesser risks are perceived that increases the probability of SAFE state by 96.4 folds.

Presence of Confined Waters at Fairway Boundary

Perceived risks in fairways bounded by confined waters are found to be decreased (beta = -1.91, p = 0.000) with corresponding 26.7 times increase in probability of SAFE state. Confined waters characterize low density vessel movements of slow speeds in the berth areas, while in low depth waters only the small vessels (e.g., pilot boats, speed boats) operate. For low speed movements, risks in attached fairways could be perceived lower.

Presence of Intersection at Fairway Boundary

The presence of intersection shows significant negative association with perceived risk (beta = -1.20, p = 0.001). One probable reason of this is that pilots become more aware of potential collisions while approaching an intersection. However, while the perceived risk in a fairway connected to an intersection is low, it could be high in an intersection because of the cross traffic interactions at intersections.

Degrees of Bend

Increasing degrees of deflection is found to positively influence the perceived risk (beta = 0.022, p = 0.000). This finding is consistent with that of Roeleven et. al. (*9*) who reported that decreasing bend radius (i.e., increasing degree of deflection) gives rise to the probability of collision. This is generally expected as vessels need larger navigation room for course alteration in case of sharper bends (*30*) and traffic interactions are more complicated at bends, compared to straight sections. Furthermore, rear and forward views could be restricted prior to and during course alternation at bends due to presence of land obstacles, which could impede the timely evasive action taking process. Interestingly results show a 2.36 times increment in the probability of VHR state in a fairway with a 40 degree bend compared to a straight fairway, given that all other conditions are same. While this may be obvious, increasing sight distance by managing land obstacles could improve safety at bends.

Controlling Water Depth of Navigation

The navigable water depth is found to have a negative association with perceived risk (beta = -0.08, p = 0.000). In general, while navigating in deeper waters pilots do not need to worry about under keel clearance, squat effects, or monitoring echo-sounder, thus allowing earlier risk mitigating actions. Hence lesser risk is perceived in deeper waters.

Presence of Traffic Separation Scheme (TSS)

The presence of TSS is found to have very significant negative effect on perceived risk (beta = -3.21, p = 0.000) so that the probability of SAFE state increases by 87.8 times while that of VHR state decreases by 99.8%. This implies that fairway with TSS will improve safety perception. The TSS can particularly reduce the risk of head-on collisions greatly as it separates traffic streams with some between space margins. Hashimoto and Okushima (*31*) showed that presence of TSS reduces head-on collision risk by about 90%. Sarioz et. al. (*30*) and Akten (*5*) also reported that the numbers of collisions are drastically reduced upon introduction of TSS in the Strait of Istanbul. Hence navigational safety in port waters could be significantly improved by implementing TSS in fairways.

Traffic Type

In comparison with both-direction fairways, perceived risks are found to be lesser in one-direction fairways (beta = -1.93, p = 0.000). The corresponding probability of the SAFE state increases by 27.4 folds, while that of the VHR state decreases by 95%, implying that pilots perceive vessel passages in one-way fairways are safer, compared to both-way fairways.

Isolated Danger Marks

The number of isolated danger marks is found to have significant negative effect on perceived risk (beta = -1.06, p = 0.002). With regard to fairways without any isolated danger marks, results show that the likelihood of VHR state reduces by 81% and the likelihood of SAFE state increases by 5.49 folds in fairways having a single mark, given that all other conditions are same. These marks convey information to pilots regarding the marked danger so that they avoid navigating too close to these marks. Vessels that navigate close to such marks would have less flexibility in taking risk-mitigating actions because of the presence of, for example, low-depth waters than those that navigate by keeping a clear distance margin from the marks. Since pilots can know about the potential danger beforehand, lesser risks are perceived.

Cardinal Marks

The number of cardinal marks shows a negative effect on perceived risk (beta = -0.13, p = 0.097). A cardinal mark indicates the deepest water side around the mark. Pilots could perceive less risk as they can gather information about water depth from the marks.

Safe Water Marks

The number of safe water marks shows significant positive association with perceived risks (beta = 2.13, p = 0.000). Interestingly results show that the VHR probability in fairways with a safe water mark is 13.4 times higher than that in fairways having no such marks, given that all other conditions are same. A safe water mark is used particularly to represent the mid channel (e.g., TSS starting points, fairway bends) or landfall (e.g., fairway ends, intersections). Risks at bends or intersections are likely to be high. Thus, a safe water mark may not influence the risk; instead it represents the high risk waters. Pilots could become aware of the high risk waters by viewing the marks, thus perceiving higher risk.

Operating Speed

Perceived risk is found to be higher with increased operating speed (beta = 0.044, p = 0.043). Results show that for a unit increment in speed, from an average value of 6.5 knots, the probability of the VHR state increases by 6.1%. Pilots have less time to take evasive actions while operating at higher speed, thus increasing the risk. This finding is consistent with Debnath and Chin (*7*) who reported that smaller vessels (usually faster moving) are highly involved in riskier encounters.

Time Effects

Perceived risks at night are found to increase significantly (beta = 1.26, p = 0.000) with increments of 93% and 4.59 folds in the probabilities of HR and VHR states respectively, compared to the risks in day. This could be because during the day the speeds, distances between vessels and even any change of courses can be judged readily than in the night. In night pilots need to rely on navigational aids (e.g., radar, navigational lights etc.), which makes the risk perception and mitigation process difficult. Furthermore, naturally visibility deteriorates in night which could hinder the watchkeeping process leading to confusions in navigation. Effectiveness of navigational lights can be reduced in night due to bright background lights at shore and nearby islands (see *4, 5*).

Pilot Training

Risk perception is found to be influenced by the time when the recent pilotage training was attended. The groups of pilots other than untrained pilots are found to perceive lower levels of risks than the untrained pilots. The untrained pilots are usually the new and trainee pilots who have less knowledge regarding the port waters and traffic, which could be a cause of perceiving higher risks than the others.

CONCLUSION

A hierarchical ordered probit model was employed to investigate how variations in levels of perceived risks are associated with the geometric and traffic factors of fairways as well as the characteristics of pilots. Perceived risk data, collected through a risk perception survey conducted among the Singapore port pilots, were used to calibrate the model. This model is helpful to account for the correlation in risks perceived by individual pilots. Estimation of random effects using the ICC showed that between-pilot variance accounts for 43.7% of the total variance, which strongly suggests the appropriateness of the hierarchical model.

Results show that pilots seem to have reasonable grasp of the characteristics of navigational collision risks in port fairways. Perceived risks are found to be higher in fairways attached to anchorages, whereas lesser risks are found in those attached to shoreline, confined water or intersection. Fairways with one-way traffic and TSS are perceived to be safer than those with both-way traffic and no TSS. The navigational aids – cardinal marks and isolated danger marks show negative effect on such risk. Fairways featuring lower water depth, higher operating speed and safe water marks are found to be positively associated with such risk. Risk is also found to be perceived higher in night.

Arising from the findings, there are several potential implications in enhancing port navigational safety. Since this research has identified several associations between pilot's perceived risks and fairway characteristics, these findings may be helpful in developing navigational risk mitigation strategies. As the findings suggest, implementing TSS in fairways might be useful in mitigating collision risks. Increasing sight distance by managing land obstacles could improve safety at fairway bends. To enhance safety in fairways attached to anchorages, dedicated navigational management service can be provided that will monitor and assist the pilots who are navigating in such waters.

Most navigational data are hierarchical in nature (e.g., accident data of different locations and time periods, respondents of different groups in a questionnaire). Without applying a hierarchical model, the results can be biased at best and possibly incorrect. Given the advances in statistical analysis, it is now possible to apply hierarchical models in behavior-based safety studies. This paper indicates that a more advanced method of studying navigational safety can be achieved using hierarchical models.

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LIST OF TABLES AND FIGURES

TABLE 1 Risk Perception Scale

Score	Risk level	Likelihood of a close quarter situation in a fairway
1	Safe	Very unlikely
2	Low risk	Unlikely
3	Moderate risk	Moderate chance
4	High risk	Likely
5	Very high risk	Very likely

TABLE 2 Summary of Explanatory Variables Used in the Regression Model

Explanatory variables	**Description**	**Mean**	**S. D.**
Fairway Characteristics			
Fairway boundary			
Anchorage	1 if present, else 0	0.686	0.465
Shoreline	1 if present, else 0	0.254	0.435
Confined water	1 if present, else 0	0.682	0.466
Intersection	1 if present, else 0	0.557	0.497
International fairway	1 if present, else 0	0.375	0.485
Water Depth	Controlling water depth of navigation (meters)	17.454	9.043
Width	Average navigable width (meters)	1164.61	703.21
Number of bend	Number of fairway bends	0.889	0.862
Degree of bend	Max. of fairway centerline deflections (degrees)	22.204	23.609
Traffic separation scheme	1 if present, else 0	0.129	0.335
Traffic type	1 if one-way, 0 if both-way	0.254	0.435
Lateral marks	1 if present, else 0	0.625	0.485
Isolated danger marks	Number of isolated danger marks	0.125	0.331
Cardinal marks	Number of cardinal marks	0.868	1.492
Safe water marks	Number of safe water marks	0.375	0.603
Dynamic ship density	Avg. dynamic ship density in fairway (ships/sq NM)	1.675	1.170
Operating speed	Average operating speed in fairway (knots)	6.532	3.863
Time variable			
Day/Night	1 if night, 0 if day	0.500	0.500
Pilot Attributes			
Age	Pilot's age in years	43.021	9.726
Experience	Number of years as harbor pilot	11.789	10.671
Time to Recent Pilotage Training [a]			
< 2 months = 1	If time < 2 months = 1, otherwise 0	0.143	0.350
2 – 6 months = 2	If time within 2 – 6 months = 1, otherwise 0	0.314	0.465
6 – 12 months = 3	If time within 6 – 12 months = 1, otherwise 0	0.286	0.452
≥ 12 months = 4	If time ≥ 12 months = 1, otherwise 0	0.229	0.420
*Never trained = 5	If never trained = 1, otherwise 0	0.029	0.167

[a] categorical variable; * reference category

TABLE 3 LR Test of Consistency in Explanatory Effects on Risks in Day and Night

Model	LL at convergence	Degrees of freedom	LR (dof)	χ^2 critical value [a]
Aggregate model	-601.161	29	-30.48 (23)	35.17
Day model	-304.120	26		
Night model	-312.281	26		

[a] at 95% confidence level for 23 degrees of freedom

TABLE 4 Estimates of the Hierarchical Ordered Probit Model

Explanatory variables	Coefficient	S.E.	Z-stat	P-value
Fairway characteristics				
Fairway boundaries				
Anchorage	0.4159	0.2043	1.96	0.042
Shoreline	-2.1130	0.3541	-5.97	0.000
Confined water	-1.9139	0.3413	-5.61	0.000
Intersection	-1.2020	0.3666	-3.28	0.001
International Fairway	-0.3493	0.2243	-1.56	0.119
Degree of bend	0.0218	0.0046	4.71	0.000
Water depth	-0.0796	0.0168	-4.74	0.000
Traffic separation scheme	-3.2076	0.5732	-5.60	0.000
Traffic type	-1.9319	0.3251	-5.94	0.000
Isolated danger marks	-1.0573	0.3437	-3.08	0.002
Cardinal marks	-0.1345	0.0811	-1.66	0.097
Safe water marks	2.1285	0.4399	4.84	0.000
Operating speed	0.0437	0.0216	2.02	0.043
Time variable				
Day/Night	1.2562	0.1094	11.48	0.000
Time to recent pilotage training				
< 2 months	-2.0201	0.8178	-2.47	0.014
2 – 6 months	-2.2344	0.7859	-2.84	0.004
6 – 12 months	-2.3968	0.7884	-3.04	0.002
≥ 12 months	-2.1259	0.7947	-2.68	0.007
Thresholds				
τ_1	-7.9885	1.1292	-7.07	0.000
τ_2	-6.2981	1.1037	-5.71	0.000
τ_3	-4.6914	1.0936	-4.29	0.000
τ_4	-3.1378	1.0869	-2.89	0.004
Panel variance				
Level 2 variance, σ_u^2	0.7757	0.1769		
Level 1 variance	1.0000			
ICC	0.437			
Summary statistics				
Number of observations	560			
Log-Likelihood (model)	-602.206			
AIC	1250.411			

TABLE 5 Marginal Effects of Significant Variables

Explanatory variables	Change in Probability (Ratio of probability change relative to reference case to probability for reference case)				
	SAFE	LR	MR	HR	VHR
Fairway characteristics					
Fairway boundaries					
Anchorage	-0.55	-0.35	-0.09	0.26	0.79
Shoreline	96.37	14.02	1.66	-0.50	-0.92
Confined water	26.67	4.10	0.07	-0.77	-0.95
Intersection	10.11	2.85	0.44	-0.44	-0.80
International fairway	0.97	0.45	0.09	-0.17	-0.38
Degree of bend	-0.04	-0.02	-0.01	0.01	0.03
Water depth	0.17	0.09	0.02	-0.04	-0.10
Traffic separation scheme	87.77	3.89	-0.65	-0.97	-1.00
Traffic type	27.43	4.16	0.07	-0.77	-0.95
Isolated danger marks	5.06	1.38	0.01	-0.57	-0.82
Cardinal marks	0.30	0.15	0.03	-0.07	-0.17
Safe water marks	-1.00	-0.97	-0.82	-0.03	5.85
Operating speed	-0.08	-0.05	-0.01	0.02	0.06
Time variable					
Day/Night	-0.92	-0.74	-0.29	0.93	4.59
Time to recent pilotage training					
< 2 months	177.27	28.48	4.56	0.12	-0.83
2 – 6 months	271.83	36.34	4.91	0.01	-0.87
6 – 12 months	369.84	42.99	5.10	-0.09	-0.90
≥ 12 months	219.59	32.22	4.74	0.07	-0.85

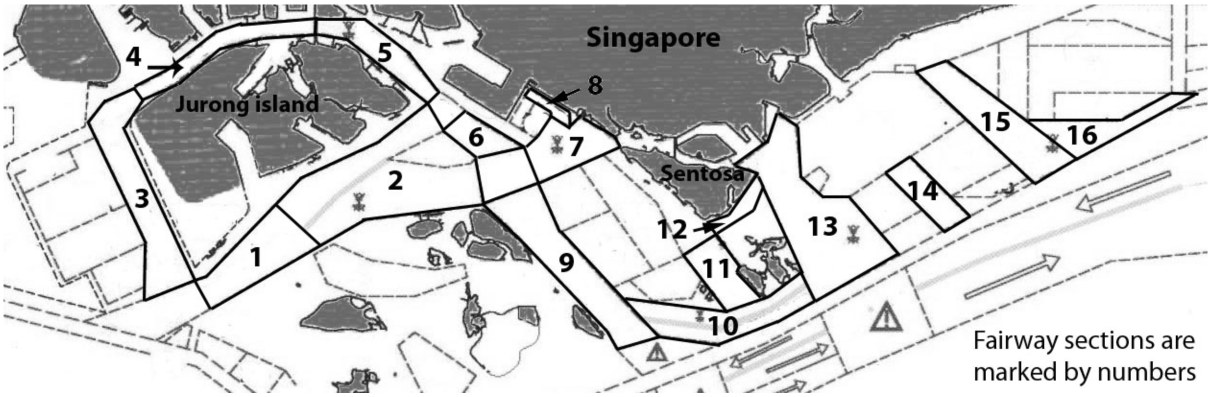

FIGURE 1 Singapore Port Fairways

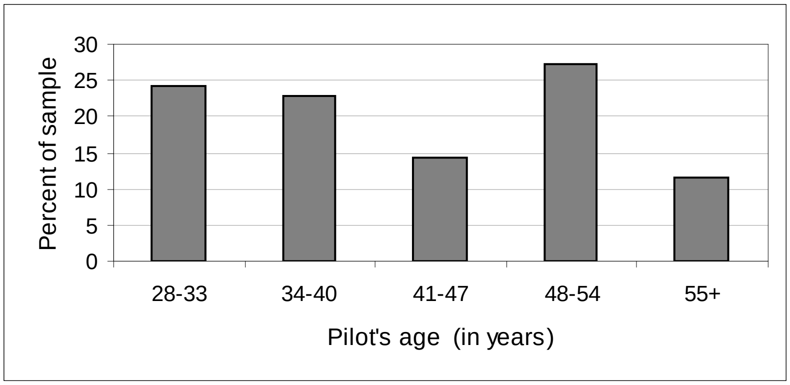

FIGURE 2 Distribution of Pilot's Age in Sample