Physical Risk Analysis of Ship Grounding

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Abstract

This study presents an analysis on the factors contributing to groundings when ships transit in and out of ports. The study has been part of a three-year project on "Ship Transit Risk". By verifying the grounding location database generated during the first two years of the project against the United States Coast Guard's grounding accident data, an updated database was established in this research. Within the frame of this new database, two factors were analyzed—tide and time of day. The results suggest that tide forecast error (predicted tide water level minus observed tide water level) had no significant effect as a risk factor, and that night navigation was far more risky than day navigation.

I. Introduction

Groundings of commercial ships contribute to one third of all commercial maritime accidents, including some of the worst in the United States' history. While clearly any efforts to reduce transit risk are important and beneficial to maritime transport, this study presents an analysis of the physical risk component contributing to groundings when ships transit in and out of ports.

More specifically, this study is part of project "Ship Transit Risk" that employs historical casualty data to build models for quantitative assessment of navigational risks entailed by vessels during transits into and out of ports. The previous study by Jebsen and Papakonstantinou[1] summarized a good portion of the work performed over the first two years of the project. The efforts during that period focused on the modeling of grounding risk at the port level, with special emphasis on the contribution of inaccuracies in navigation charts. This study continues to collect, verify, assimilate, evaluate, and analyze historical data on grounding accidents in five U.S. ports between 1981 and 1995, especially focusing on two factors—tide and time of the day.

II. Literature Review

A risk model has been developed by Kite-Powell et al. [3] to help predict the risk of groundings and associated economic damage, such as loss of cargo and environmental resources. This model attempts to estimate the conditional probability of A (A is defined as the event that a transit results in a grounding (G) or a collision (C)) given a specified value x of explanatory variables X:

$p(A|x) = l(x|A)\, p / (l(x|A)\, p + l(x|S)\, (1-p))$,

where p is the unconditional probability of A and where $l(x|A)$ and $l(x|S)$ are the likelihoods of x given A and S, respectively. S denotes the event that the transit is completed safely (for a more detailed description, see [3]). This approach has the advantage of permitting the inclusion of a range of potential contributing factors.

Studies done by Prof. M. E. Paté-Cornell (for a more detailed review, see [1]), and Prof. Martha Gabowski [7] on risk analysis and risk management applied to offshore platforms are helpful for our physical risk factors analysis. Another approach is presented by Amrozowicz et al. [8,9,10]. In these studies by Amrozowicz et al., fault tree analysis has been used to provide a more detailed view of how groundings are caused. In addition, the studies incorporated the method of probabilistic risk assessment (PRA) and utilized the Technique for Human Error Rate Prediction (THERP) as a quantitative method to predict individual human error probabilities (HEPs). The grounding PRA model noted that because individual errors are a subset of human failures, which are a subset of system failures, it is critical that the reduction of individual error rates should be encompassed with a total systems approach. However, this approach requires an extensive quantitative data set, which is beyond what is available in the historical record.

Psaraftis et al. [4] utilized a systematic approach to analyze factors contributing to maritime transportation risk. Some databases such as Lloyds List Casualty Reports were used. Additionally, some extracted physical risk factors such as ship flag, ship type, ship age, ship size, etc. were analyzed. When dealing with the historical accidents database, they encountered the same problem we faced—deficiency of data (e.g., lack of incident causes) and lack of homogeneity in quality of the data. Savenije [5] follows a different approach. He characterized risks associated with navigation hazards by calculating a subset of available accident data and estimating the probability of accident. In addition, sensitivity analysis was used for understanding and analyzing the total process. This approach could also be found in "The Port Needs Study" [2] and Dickins and Krajczar [11].

Silver et al. [6] presented another risk-based methodology to determine optimum channel depth. The study presented a predicting system for underkeel clearance and the corresponding risk of grounding especially for deep draft vessels transiting shallow entrance channels. The results indicated significant cost reduction on dredging and environmental impacts.

III. Approach

Statistical analysis of existing historical databases of accidents and safe transits was used in this study. Five U.S. ports, including Boston, Houston/Galveston, New York/Battery, Tampa/St. Petersburg, and San Francisco, were the study regions. The study period was between 1981 and 1995. The casualty data was from the United States Coast Guard, the transit data was from U.S. Army Corps of Engineers, and the environmental data was from NOAA.

IV. Data Processing

First, we extract the grounding data sets from historical data such as USCG's CASMAIN and MINMOD, and from NOAA environmental data. Secondly, for the purpose of accuracy, we verify the database which includes the grounding accidents in open water and dredged channels in five ports established by Jebsen and Papakonstantinou [1] and establish an updated grounding location database. By using this new data set, further research such as tide analysis and time of day/night analysis is performed. Thirdly, we collect tide data from NOAA, verifying the data set, converting the different elevation datum, adjusting time difference, and eliminating the unmatched records between observed and predicted data files. Fourthly, we calculate the probability density function and cumulative distribution function for predicted water height, observed water height, and their difference for each port. Last, we separate time slots to daytime and nighttime from the groundings database, then work on time analysis to see whether it is a potential factor contributing to groundings. In order to conduct the analysis, we planned to compare groundings in day and night with ACE (Army Corps of Engineers) safe transit data in that same time slot, which, unfortunately we are not able to obtain. Hence, we made the assumption that the number of vessel transits during daytime is equal to that of nighttime every day for each port.

V. Results and Discussion

1. Open water versus dredged channels

Table 1 presents the accident numbers in the major grounding locations for each city. Of the total 1116 grounding accidents in the five ports, 908 had a valid location, i.e., clearly reported latitude and longitude. 687 (76%) were in or very close to dredged channels and 75 (8%) in the open water. However, 146 (16%) were in a "Questionable location", such as land or very shallow areas. Most of the results obtained in this study were precisely the same as the results obtained by Jebsen and Papakonstantinou [1], while some were slightly different.

Port area:	Boston	Houston/ Galveston	San Francisco	Tampa/ St. Petersburg	New York/ Battery	5 ports Total
Number of accidents in area:	26	615	94	171	210	1116
No location:	6	107	24	18	53	208
Valid accidents:	20	508	70	153	157	908
of which were located in:						
Dredged channel:	9	362	44	135	137	687
Open water:	9	24	20	14	8	75
Questionable location:	2	122	6	4	12	146
Valid accidents:	20	508	70	153	157	908

Table 1 Summarized Grounding Location Information

Table 2 presents the average wind speed (meters/second), visibility (km) and the accident numbers in dredged channels and open water for each port. The results show no noticeable pattern among the five ports. The average wind speed and visibility in dredged channel groundings was significantly higher than in open water in Houston/Galveston and Tampa. However, the results obtained in New York, Boston and San Francisco showed a different pattern. Such observations suggest that wind speed and visibility effects are not significantly different for accidents occurring in dredged channels and in open water. In a future study, a more careful analysis of the data for Houston/Galveston, San Francisco, Tampa/St. Petersburg, and New York/Battery is suggested to verify these two risk factors.

Port area:	Boston		Houston/ Galveston		San Francisco		Tampa/ St. Peters.		New York/ Battery	
	Dredged Channel	Open Water	Dredged Channel	Open Water	Dredged Channel	Open Water	Dredged Channel	Open Water	Dredged Channel	Open Water
Valid accidents:	9	9	362	24	44	20	135	14	137	8
Average Wind(m/s):	6.17	6.41	3.71	3.65	5.11	4.62	3.64	3.28	6.06	6.53
Average Visibility(km):	10.64	9.53	14.05	11.57	17.35	21.84	12.73	10.94	11.41	13.95

(Average wind: meters/sec; Average visibility: kilometer)

Table 2 Average Wind Speed and Visibility

2. Tide analysis-predicted and observed water levels

For the port of Boston, the results are shown in Figures 1 and 2. Figure 3 to 10 present the tide analysis for the other four ports. Figures 1 and 9 show a similar tide pattern between Boston and New York. Figures 2, 4, 6, 8, and 10 illustrate the water level forecasting error. These results confirm that the difference between the predicted records and the observed records is small for all of the five ports. The results also show that predictions tend to underestimate tide level for the past 15 to 18 years, except for Houston/Galveston.

3. Effect of Tide Forecast Error on Groundings

Results of the previous study [1] in this project clearly showed that environmental factors, wind speed and visibility, have an effect on the grounding risk. However, in that study, other important physical waterway characteristics, such as tide, were not discussed. The tide factor was addressed and further studied in this study to determine the significance of this factor to groundings. To understand the effect of tide, the forecast error of tide, i.e. the difference between predicted water level and observed water level, was used.

Our hypothesis was that a larger positive tide forecast error, the difference between predicted water level and observed water level, causes a greater potential risk for grounding. This hypothesis was not confirmed by the findings of this study. It was observed that in dredged channels and open water, there was no significant correlation between large forecast errors and the incidence of groundings.

Results of the effect of the forecast error on the groudings for four ports are presented in Figures 11 to 14. Due to very few data for groundings in Boston, it is not possible to draw accurate conclusions based on the data. The results of Figures 11 to 14 show that there is no significant relationship between positive tide forecast error and grounding accidents. However, in Figure 12, the positive tide forecast error appeared to lead to more grounding accidents in open water in Houston/Galveston.

4. Effect of Time on Groundings

As discussed previously in section 4, grounding times were divided by daytime and nighttime. The daytime was defined from 6:00am to 6:00pm local time, and nighttime was defined from 6:00pm to 6:00am local time. The reason for dividing time slots was that the corresponding time code in pre-MINMOD (1992) accident spreadsheets fell into four ambiguous levels: day time, night time, twilight (morning or evening), and no information -- none of which corresponds with accurate time records. In addition, due to lack of information about distributions of transits by time of day from the Army Corps of Engineers (ACE), this study made the assumption that the number of vessel transits during daytime was equal to that during nighttime every day for each port. Results of the effect of time on the groundings for five ports are presented in Table 3. It demonstrates no consistent pattern among the five ports whether night navigation in dredged channels is safer than in open water or vice versa. However, the results suggest that, consistent with our intuition, night navigation was far more risky than day navigation (although dredged channel navigation in New York port was an exception).

VI. Conclusions

This study presents an analysis of potential factors contributing to groundings when ships transit in and out of ports. Two important results are obtained: first, the results suggest that tide forecast error has no significant effect as a risk factor for groundings in dredged channels and open water; second, the results suggest that night navigation is far more risky than day navigation.

Other products of this study include: An updated grounding location database was established for this research. This data source could be used for more efficient risk modeling in the future. Secondly, the tide analysis showed that the predictions of tide level tended to underestimate actual water levels for the past 15 to 18 years; and the probability density function of tide levels generated for the past two decades is a useful data source that can be applied to future tide-related research. Finally, the results suggest that wind speed and visibility effects are not significantly different for accidents occurring in dredged channels and in open water. In a future study, a more careful analysis of the data is suggested to verify these two risk factors.

For data gathering, Kite-Powell et al. [3] summarized some suggestions to the United States Coast Guard for USCG casualty data collection for future research: first, generally: (a) adopt consistent criteria across ports/reporting units for determining what events merit an entry in the database; (b) each entry should be consistent with each accident, i.e., no two reports coincident with one accident; (c) accuracy and completeness are the key issues, e.g., the location of each accident and its corresponding physical parameters such as wind speed, time, visibility, tide levels, wave conditions, etc. Specifically (a) more vessel-specific parameters such as draft, trim, speed, heading should be collected; (b) more environmental parameters such as current speed and direction should be collected; (c) use/presence of tugs, presence of pilot(s) should be collected.

In the near future, a larger-scale model of risk is expected to incorporate results of the port-level analysis and investigate more local factors, such as specifics of channel design, navigational aids configuration, currents, etc. Meanwhile, an advanced model of economic risk providing estimates of economic loss associated with the physical risk of grounding for a given region is an important topic for further study.

Acknowledgements

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Table 3 Summarized Grounding Ratio Information

Boston Area:

Accidents of which were located in:	Day Time	Night Time	Evening or Morning	Question-able Time	Total	Total Accidents
Dredged channel:	0.22	0.56	0.00	0.22	1.00	9
Open water:	0.67	0.33	0.00	0.00	1.00	9
Questionable location:	0.00	1.00	0.00	0.00	1.00	2
No location:	0.33	0.50	0.00	0.17	1.00	6
Total	0.38	0.50	0.00	0.12	1.00	26

New York Area:

Accidents of which were located in:	Day Time	Night Time	Evening or Morning	Question-able Time	Total	Total Accidents
Dredged channel:	0.49	0.37	0.08	0.06	1.00	137
Open water:	0.38	0.50	0.13	0.00	1.00	8
Questionable location:	0.50	0.50	0.00	0.00	1.00	12
No location:	0.55	0.38	0.04	0.04	1.00	53
Total	0.50	0.39	0.07	0.05	1.00	210

Houston/Galveston Area:

Accidents of which were located in:	Day Time	Night Time	Evening or Morning	Question-able Time	Total	Total Accidents
Dredged channel:	0.08	0.44	0.43	0.05	1.00	362
Open water:	0.08	0.13	0.63	0.17	1.00	24
Questionable location:	0.03	0.42	0.51	0.04	1.00	122
No location:	0.07	0.51	0.40	0.01	1.00	107
Total	0.07	0.44	0.45	0.05	1.00	615

Tampa/St. Petersburg Area:

Accidents of which were located in:	Day Time	Night Time	Evening or Morning	Question-able Time	Total	Total Accidents
Dredged channel:	0.05	0.50	0.37	0.08	1.00	135
Open water:	0.00	0.29	0.50	0.21	1.00	14
Questionable location:	0.00	0.25	0.50	0.25	1.00	4
No location:	0.00	0.33	0.61	0.06	1.00	18
Total	0.04	0.46	0.41	0.09	1.00	171

San Francisco Area:

Accidents of which were located in:	Day Time	Night Time	Evening or Morning	Question-able Time	Total	Total Accidents
Dredged channel:	0.00	0.41	0.48	0.11	1.00	44
Open water:	0.00	0.60	0.35	0.05	1.00	20
Questionable location:	0.20	0.40	0.20	0.20	1.00	5
No location:	0.08	0.50	0.33	0.08	1.00	24
Total	0.03	0.47	0.40	0.10	1.00	93

Total Area:

Accidents of which were located in:	Day Time	Night Time	Evening or Morning	Question-able Time	Total	Total Accidents
Dredged channel:	0.15	0.44	0.35	0.07	1.00	687
Open water	0.15	0.35	0.40	0.11	1.00	75
Questionable location:	0.08	0.43	0.45	0.05	1.00	145
No location:	0.20	0.46	0.31	0.03	1.00	208
Total	0.15	0.43	0.36	0.06	1.00	1115

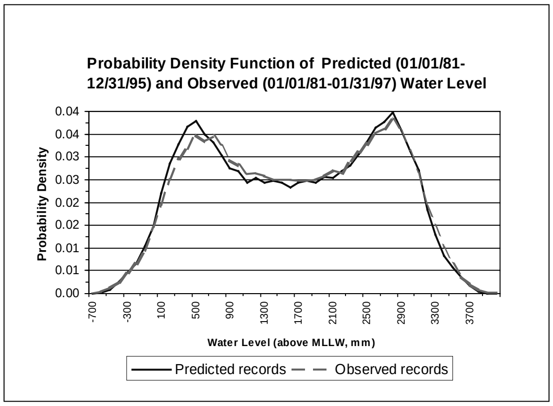

Figure 1 – Probability Density Function of Predicted and Observed Water Level, Boston

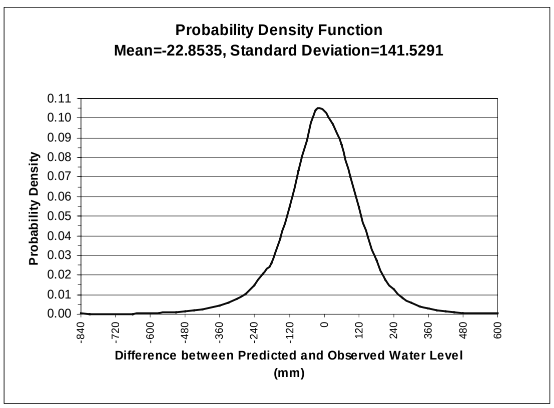

Figure 2 – Probability Density Function of Difference between Predicted and Observed Water Level

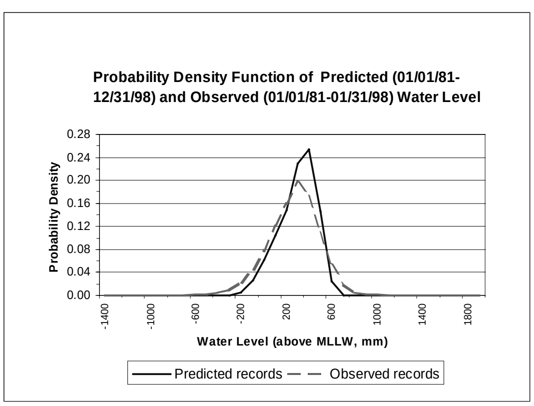

Figure 3 – Probability Density Function of Predicted and Observed Water Level, Houston-Galveston

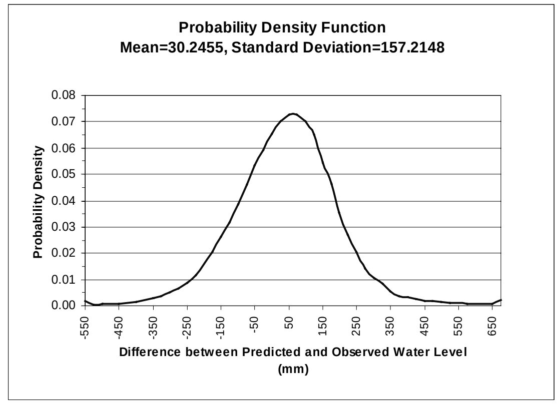

Figure 4 – Probability Density Function of Difference between Predicted and Observed Water Level, Houston-Galveston

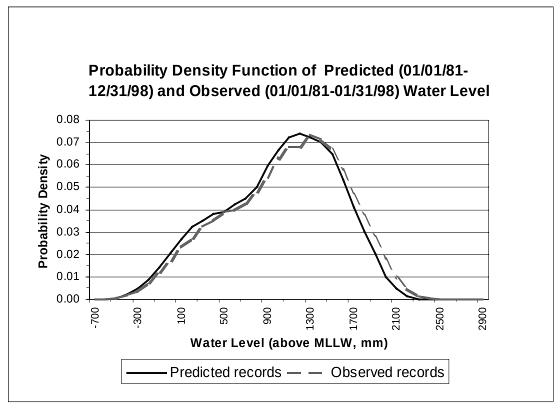

Figure 5 – Probability Density Function of Predicted and Observed Water Level, San Francisco

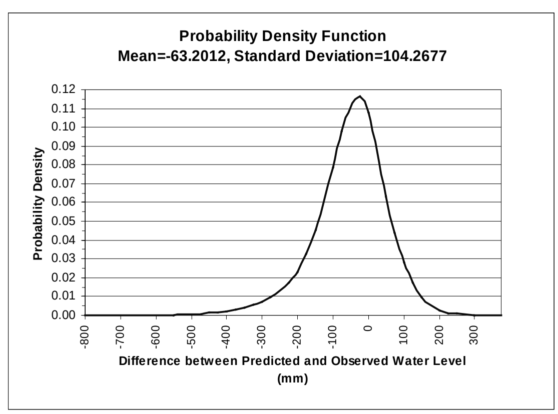

Figure 6– Probability Density Function of Difference between Predicted and Observed Water Level, San Francisco

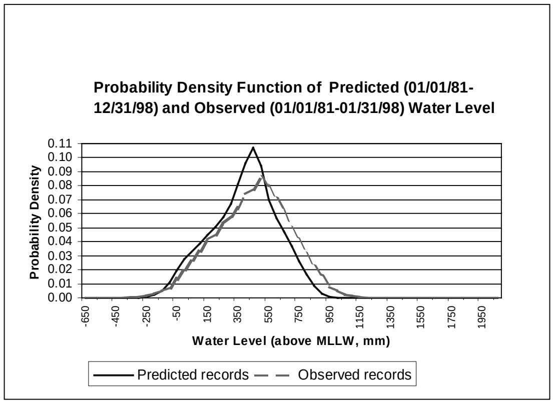

Figure 7 – Probability Density Function of Predicted and Observed Water Level, Tampa/St. Petersburg

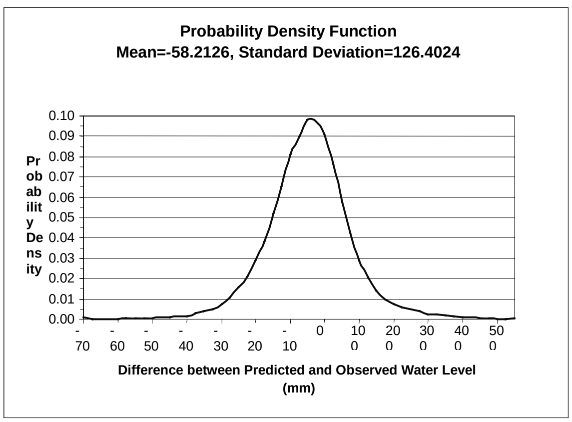

Figure 8 – Probability Density Function of Difference between Predicted and Observed Water Level, Tampa/St. Petersburg

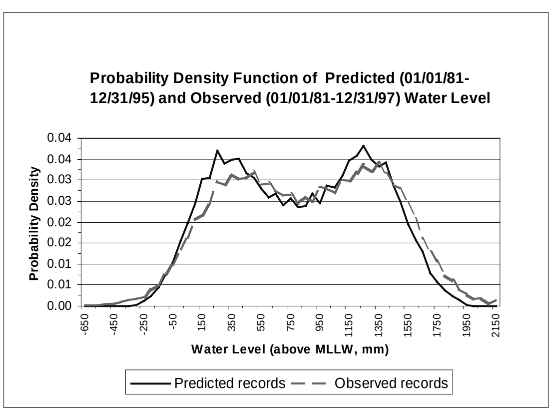

Figure 9 – Probability Density Function of Predicted and Observed Water Level, New York/Battery

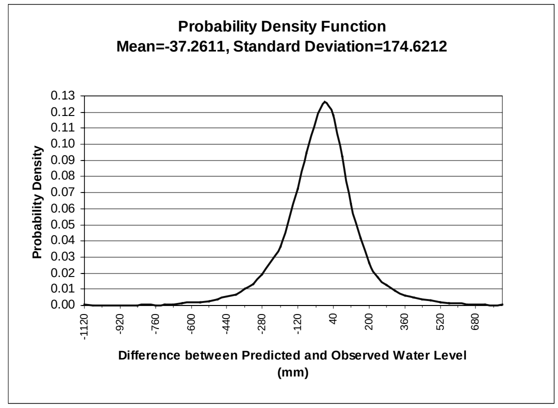

Figure 10 – Probability Density Function of Difference between Predicted and Observed Water Level, New York/Battery

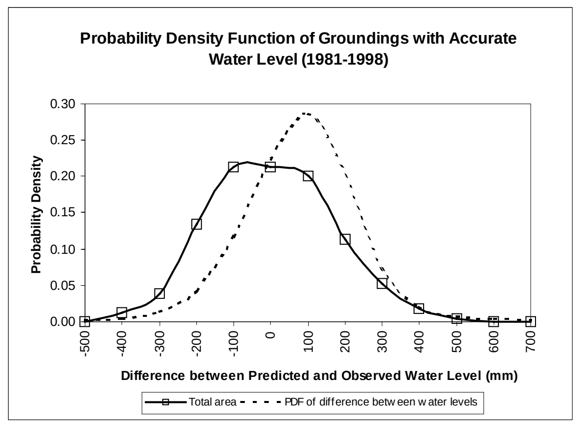

Figure 11 – Forecast Error of Water Level during Groundings, Houston-Galveston

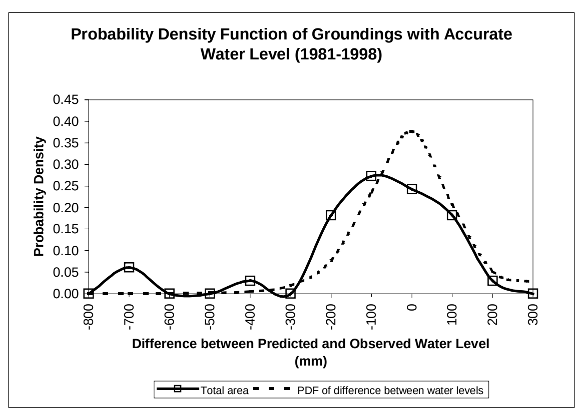

Figure 12 – Forecast Error of Water Level during Groundings, San Francisco

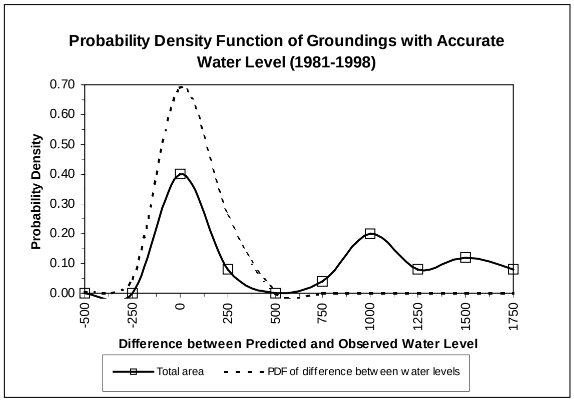

Figure 13 – Forecast Error of Water Level during Groundings, Tampa/St. Petersburg

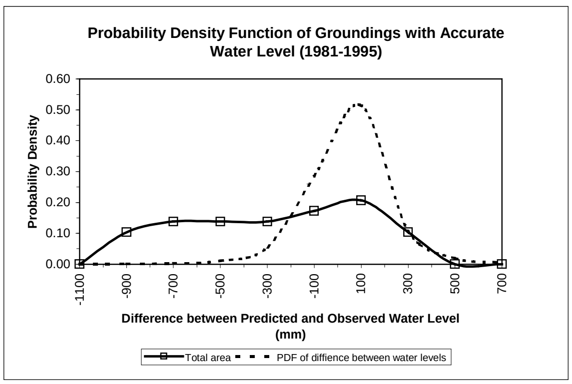

Figure 14 – Forecast Error of Water Level during Groundings, New York/Battery