Pump Upgrade:
Survival Analysis

Survival Analysis
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Executive Summary

The goal of our team is to recommend upgrades for 20 pumps that failed due to flooding during Hurricane Katrina to the Army Corps of Engineers. According to our analysis of the association between the flooding failure time and different factors relating to the pump stations, we recommend servomechanism upgrades for 20 pumps listed in the following report since the selected pumps would achieve the longest combined extra functioning time during a storm. All the pumps in the list will function 1.385 times longer during a storm and increase the total functioning time by 192 hours after the upgrades. To achieve a better optimization of pump upgrades, we recommend considering all failed pumps for upgrading in next step.

Analysis & Results

The dataset provided by the Steering Committee of the Center for Risk Management contains information on 770 pump stations on the Gulf Coast. Within the critical 48-hour storm period, 59% of the 770 pump stations underwent different types of failure. Among all the pump stations with failure, 25% of them are due to flooding with a median survival time of 26 hours. To understand the possible relationship between different factors and the failure of the pump stations due to flooding, we treated everything that failed due to flooding as the event and anything else as censored. The seven factors provided in the dataset are shown below (Table 1).

Factor Name	**Description**
Backup	*Whether a backup pump is present to protect the station from flooding when the main pump is not operating*
Bridgecrane	*Whether a crane is present to allow vertical access to equipment and protect materials*
Servo	*Whether a servo is present to provide control of the desired operation*
Trashrack	*Whether a cleaner is present to provide hydraulic structures*
Elevation	*Elevation of the pump station*
Slope	*Ravine slope surrounding the pump station*
Age	*How long the pump has been installed*

Table 1. Description of Factors in the Dataset

Our final accelerated failure time model follows the Weibull distribution. This model makes sense since, as any storm continues, overflow or accumulation of water increases and is more likely to cause pump failure due to flooding. The main reasons for choosing the Weibull distribution are: 1) after plotting the cumulative hazard against time, the Weibull distribution fits the data better than the exponential, log-normal, or log-logistic distributions (Figure 1 & Appendix), and 2) flooding risk increasing over time within the first 48-hour storm period could be characterized by the Weibull distribution.

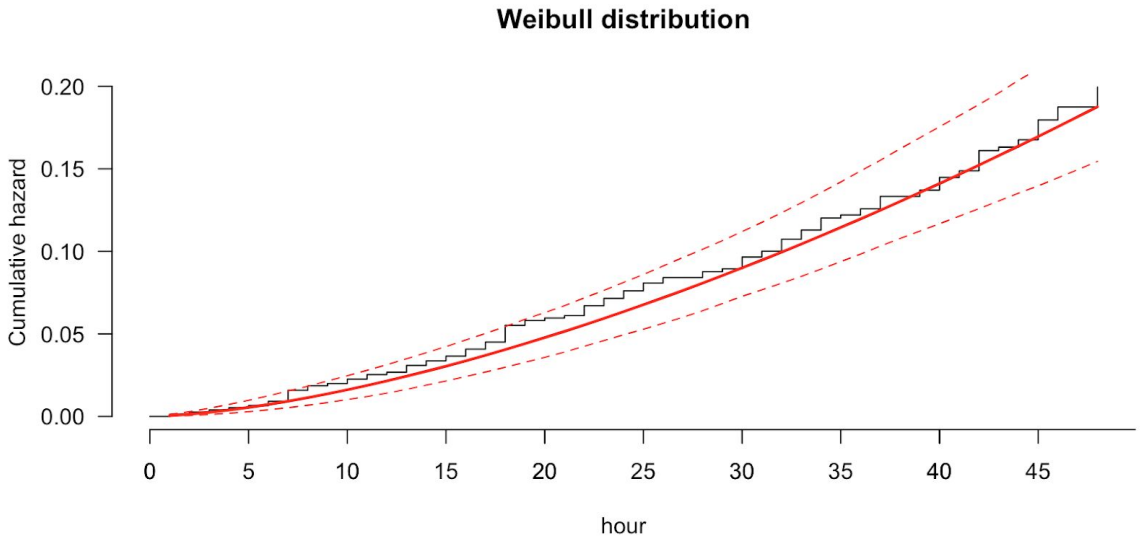


Figure 1. Cumulative Hazard against Time with the Weibull Distribution

The coefficient estimates represent how variables would accelerate/decelerate flooding failure time (Table 2). Servo has the largest coefficient estimate, 0.3258. Exponentiated, this means the predicted flooding failure time of pumps with servomechanisms is 1.385 times longer than those without. Slope has a coefficient estimate of -0.06, meaning the predicted flooding failure time, when the estimate is exponentiated, is 0.94 times shorter for every one additional slope increase. The coefficient estimate of Age indicates ages of pumps are associated with longer predicted survival time, which is counterintuitive. We think the coefficient estimates and standard errors of Age, Elevation, and Bridgecrane indicate that these variables had little effect on pump survival.[1]

Variable	Coefficient Estimate	Standard Error
Backup	0.2434	0.1244
Bridgecrane	-0.2193	0.1979
Servo	0.3258	0.1383
Trashrack	-0.2314	0.1244
Elevation	0.0524	0.0779
Slope	-0.0600	0.0175
Age	0.0591	0.0688

Table 2. Coefficient Estimates of Factors Related to Flooding Failure

[1] The standard error can be used to calculate the 95% confidence interval which in the case of the three variables mentioned, means the intervals include zero.

The 20 pumps we selected for upgrade have the greatest ratio increases in flooding failure time within the critical 48-hour storm period (Table 3). All the pumps in the list would gain the maximum extra functioning time after servomechanism upgrades. Since we only looked for increases of event time within the first 48 hours, we did not consider any extra predicted survival time exceeding 48 hours after upgrades; this kept the optimization from recommending the longest lasting pumps for an upgrade. To maximize the benefits for each pump as well as the overall functioning time, we used two criteria in choosing the pumps: 1) the highest percent improvement in failure time after one upgrade, 2) the largest hour differences after upgrading. The pumps recommended below should function 1.385 times longer each during a storm and 192 hours longer in total after the servomechanism upgrades.

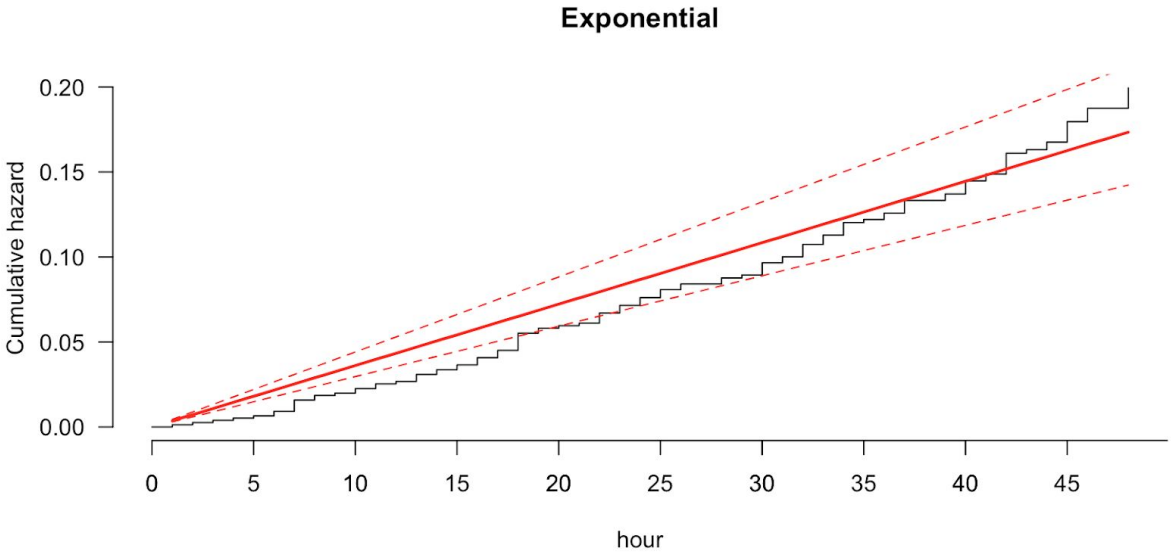
ID	Actual Failure Time	Predicted Failure Time	Time Difference	Upgrade
343	33	45.71	12.71	servo
318	33	45.71	12.71	servo
329	32	44.33	12.33	servo
347	32	44.33	12.33	servo
350	31	42.94	11.94	servo
352	30	41.56	11.56	servo
367	30	41.56	11.56	servo
369	30	41.56	11.56	servo
376	30	41.56	11.56	servo
319	28	38.79	10.79	servo
321	26	36.02	10.02	servo
377	23	31.86	8.86	servo
368	20	27.70	7.70	servo
353	18	24.93	6.93	servo
384	18	24.93	6.93	servo
346	18	24.93	6.93	servo
365	17	23.55	6.55	servo
336	17	23.55	6.55	servo
363	16	22.16	6.16	servo
340	16	22.16	6.16	servo

Table 3. Pumps Upgrades List

Conclusion

Through our analysis of the association between the flooding failure time and different factors relating to the pump stations, we recommended 20 pumps for servomechanism upgrades to achieve maximal benefits for each pump as well as the overall functioning time. All 20 pumps recommended should improve their survival time during a storm by 192 hours in total after the upgrades. Given the fact that we only account for the pumps with flooding failure, we recommend considering all failed pumps, regardless of the failure cause, in the next step to achieve a better optimization of the pump upgrades.

Appendix


Exponential
Cumulative hazard
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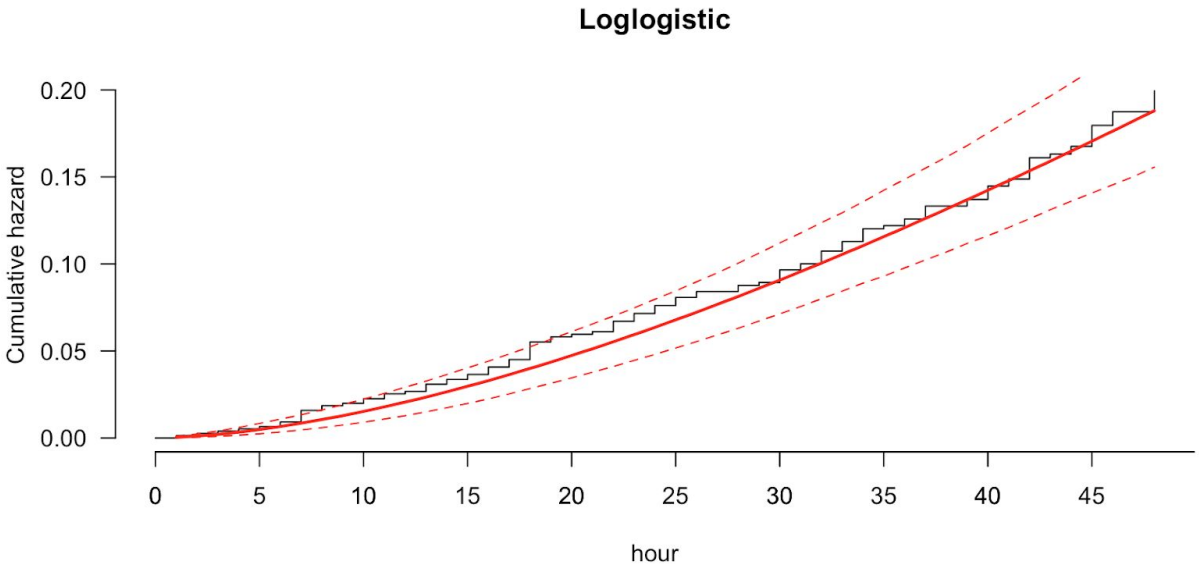
0.10
0.15
0.20
0
5
10
15
20
25
30
35
40
45
hour


Loglogistic
Cumulative hazard
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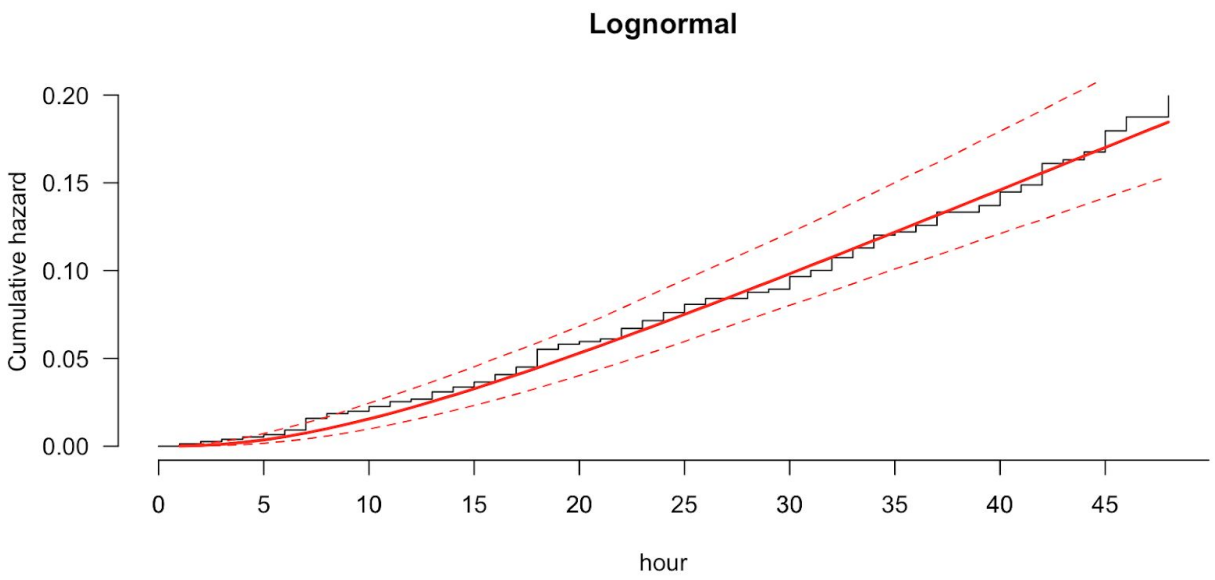
0.05
0.10
0.15
0.20
0
5
10
15
20
25
30
35
40
45
hour


Lognormal
Cumulative hazard
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0.15
0.10
0.05
0.00
0
5
10
15
20
25
30
35
40
45
hour