# Survival Analysis for the Army Corps of Engineers - Homework 2

Blue team 12

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## Executive Summary

The purpose of this report is to recommend which pumps the Army Corps of Engineers should upgrade with their limited resources to maximize time before pump failure due to flooding in the critical first 48 hour of hurricane Katrina. Our recommendation as the Steering Committee of the Center for Risk Management is to upgrade the servomechanism in the following pumps: 417, 364, 343, 318, 397, 329, 347, 419, 350, 410, 352, 367, 369, 376, 317, 358, 319, 321, 404, and 408. We predict that upgrading the servomechanism in those pumps will lead to a 233 total additional hours of pump life before failure due to flooding. These pumps were selected by maximizing the predicted increase in survival time on the condition that the new predicted failure time was within the 48-hour event time.

## Results

During Hurricane Katrina, 41% of 770 pump stations survived. Half of the pump stations failed after 45 hours. Being jammed by trash or landslide material was the most likely cause of pump stations failure (15.1%), followed by being flooded (14.9%), mechanical failure (14.5%), and structural damage (14.4%).

Reducing casualties and damage from Hurricane Katrina can be achieved by coordination and maintenance of pumps during the critical first 48-hour period. Data on this first 48 hours was provided to us, and Steering Committee of the Center for Risk Management asks for a recommendation on an upgrade for 20 pumps to increase their survival time.

In order to figure out the suitable pumps to upgrade, we first built an Accelerated Failure Time Model (AFT model) with seven variables (backup pump, bridge crane, servomechanism, trash rack, elevation, slope, and age). The AFT model allowed us to test each variable's influence on the survivability of the pump stations associated with the flood. In order to build this AFT model, we tested which distribution we should use to fit the data with the model. After plotting the data within exponential, Weibull, lognormal, and log-logistic distributions (Figure 1 and Appendix Figure A1-A3), Weibull distribution appeared to be the best distribution. Compared with other distributions, the nonparametric estimate of the cumulative hazard in Weibull distribution matches relatively well with the cumulative hazard of our data. As a result, we chose to use Weibull distribution to fit our AFT model.

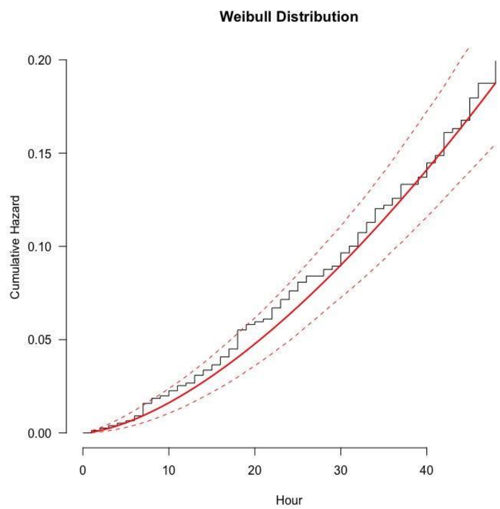


Figure 1. Cumulative Hazard with Weibull Distribution

The results of the AFT model fitted with Weibull distribution are summarized in Table 1 below. Servo and backup pump appeared to be significant to a pump's survival time. The pumps with servo upgraded are 1.39 times more likely to survive than those pumps that do not have the servomechanism upgraded. Also, pumps with backup pump upgraded are 1.28 times more likely to survive than those that do not have backup pump upgraded. In addition, the predicted survival time is 1.05 times longer for each additional foot in height of the elevation of the pump station.

Table1. Summary of Weibull Distribution

| | **Value** | **Exp_Value** | **Standard Error** |
|---|---|---|---|
| **(Intercept)** | 4.5225 | 92.07 | 0.5706 |
| **Backup pump** | 0.2434 | 1.28 | 0.1244 |
| **bridgecrane** | -0.2193 | 0.80 | 0.1979 |
| **servo** | 0.3258 | 1.39 | 0.1383 |
| **trashrack** | -0.2314 | 0.79 | 0.1244 |
| **elevation** | 0.0524 | 1.05 | 0.0779 |
| **slope** | -0.06 | 0.94 | 0.0175 |
| **age** | 0.0591 | 1.06 | 0.0688 |

According to Table 1, upgrades to backup pump or servo will help increase a pump's survival time. In order to decide which 20 pumps should be selected for an upgrade, we predicted the failure time of each pump with each factor upgraded (new time) and compared them with the failure time of each pump not upgraded (old time). We selected pumps that had the greatest improvement in survival time over the 48-hour critical period. After looking at the twenty pumps with the largest difference between new time and old time of each factor, upgrading backup pump will result in an additional of 171 hours of survival time, and upgrading servos will increase 233 hours of survival time (Table A2). As a result, we recommend the Army Corps of Engineers to upgrade the servomechanism for the following 20 pumps: 417, 364, 343, 318, 397, 329, 347, 419, 350, 410, 352, 367, 369, 376, 317, 358, 319, 321, 404, and 408.

## Conclusion

Overall, based on the AFT model we built with a Weibull distribution, we recommend upgrading the servomechanism to increase the survival time of pump stations. Also, we recommend using data related to the pump location, impact on human life, and potential damage caused by failures of pumps for supplementing further analysis. It is likely that these variables would influence our recommendation. This is because extending the life of a pump for a shorter amount of time to save more lives will always be a better decision than maximizing pump life that does not save lives.

# Appendix

Figure A1. Exponential Distribution

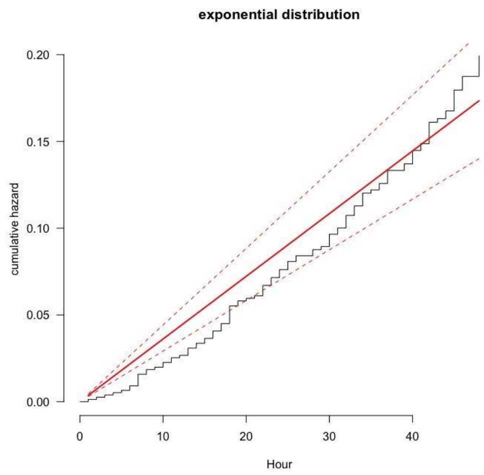


Figure A2.  Lognormal Distribution

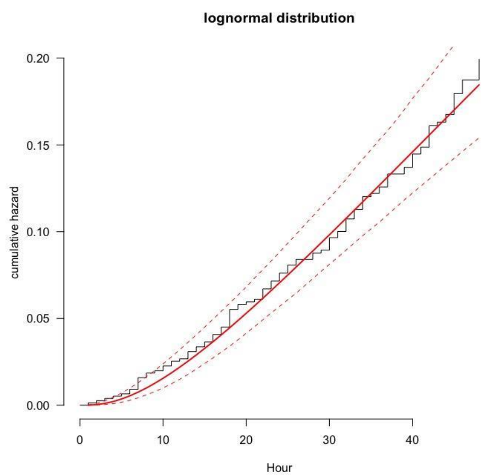


Figure A3. Log-logistic Distribution

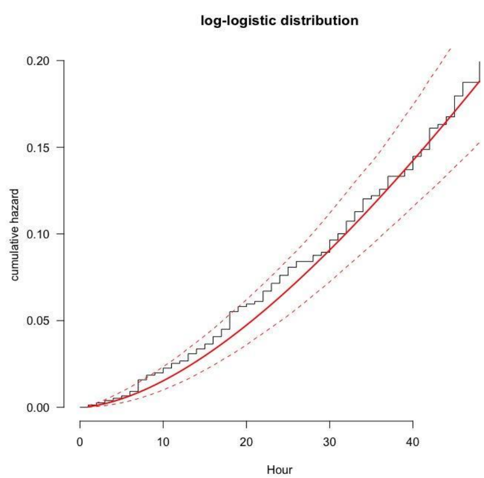

Table A1. Summary of AFT Model

| | Value | Standard Error | z | p |
|---|---|---|---|---|
| **(Intercept)** | 4.5225 | 0.5706 | 7.927 | 2.25E-15 |
| **backup pump** | 0.2434 | 0.1244 | 1.956 | 0.05041 |
| **bridgecrane** | -0.2193 | 0.1979 | -1.108 | 0.26785 |
| **servo** | 0.3258 | 0.1383 | 2.356 | 0.01848 |
| **trashrack** | -0.2314 | 0.1244 | -1.861 | 0.06281 |
| **elevation** | 0.0524 | 0.0779 | 0.672 | 0.50144 |
| **slope** | -0.06 | 0.0175 | -3.422 | 0.00062 |
| **age** | 0.0591 | 0.0688 | 0.859 | 0.39056 |
| **Log(scale)** | -0.4469 | 0.0858 | -5.205 | 1.93E-07 |

Table A2. Summary of Predicted Time

| | ID | surv_prob | old_time | new_time | pred_time_diff |
|---|---|---|---|---|---|
| **1** | 417 | 0.88 | 34 | 47.10 | 13.10 |
| **2** | 364 | 0.79 | 35 | 48.00 | 13.00 |
| **3** | 343 | 0.87 | 33 | 45.71 | 12.71 |
| **4** | 318 | 0.85 | 33 | 45.71 | 12.71 |
| **5** | 397 | 0.90 | 33 | 45.71 | 12.71 |
| **6** | 329 | 0.87 | 32 | 44.33 | 12.33 |
| **7** | 347 | 0.94 | 32 | 44.33 | 12.33 |
| **8** | 419 | 0.87 | 36 | 48.00 | 12.00 |
| **9** | 350 | 0.87 | 31 | 42.94 | 11.94 |
| **10** | 410 | 0.83 | 31 | 42.94 | 11.94 |
| **11** | 352 | 0.91 | 30 | 41.56 | 11.56 |
| **12** | 367 | 0.83 | 30 | 41.56 | 11.56 |
| **13** | 369 | 0.83 | 30 | 41.56 | 11.56 |
| **14** | 376 | 0.79 | 30 | 41.56 | 11.56 |
| **15** | 317 | 0.78 | 37 | 48.00 | 11.00 |
| **16** | 358 | 0.84 | 37 | 48.00 | 11.00 |
| **17** | 319 | 0.91 | 28 | 38.79 | 10.79 |
| **18** | 321 | 0.85 | 26 | 36.02 | 10.02 |
| **19** | 404 | 0.57 | 25 | 34.63 | 9.63 |
| **20** | 408 | 0.90 | 25 | 34.63 | 9.63 |