IMPACT FROM ANALYZING THE RUN LIFE STATISTICS USING SURVIVABILITY CURVES METHODOLOGY ON ESP KEY PERFORMANCE INDICATORS

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Abstract
Evaluating Electrical Submersible Pumps (ESPs) run-lives and performance in unconventional well environments is challenging due to many different factors -including the reservoir, well design, and production fluids. Moreover, reviewing the run-lives of ESPs in a field can be rather complex since the run-life data is incomplete. Often ESPs are pulled while they are still operational, or the ESP has not been allowed to run until failure. These are some of the complications that arise when gauging ESP performance.

A large dataset of ESP installs was assessed using Kaplan-Meier survival analysis for the North American unconventional application to better understand those factors that may affect ESP run lives. The factors were studied including but are not limited to the following:

- Basin and producing formation
- Comparing different ESP component types such pumps and motors, and new or used ESP components
- Completion intensity of the frac job (lb/ft of proppant)

Kaplan-Meier survival analysis is one of the commonly used methods to measure the fraction or probability of group survival after certain time periods because it accounts for incomplete observations. Using Kaplan-Meier analysis generates a survival curve to show a declining fraction of surviving ESPs over time. Survival curves can be compared by segmenting the runlife data into buckets (based on different factors), therefore, to analyze the statistical significance of each and how they affect ESP survivability.

Kaplan-Meier analysis was performed on the aforementioned dataset to answer these questions in order to better understand the factors that affect ESP runlives in North American unconventional plays.

This work uses a unique dataset that encompasses several different ESP designs, with the ESPs installed in different North American plays. The observations and conclusions drawn from it, by applying survival analysis, can help in benchmarking ESP runtimes and identifying what works in terms of prolonging ESP runlife. The workflow is also applicable to any asset in order to better understand the drivers behind ESP runlife performance.

Introduction

Understanding the challenges to optimize ESP performance requires a holistic approach with consideration of many variables such as downhole conditions downhole conditions, condition of the equipment being considered (new vs used components), the different technologies employed, and the producing formation to name a few. Not all of the variables that affect ESP runlife are optimizable (such as the target formation), but even then studying how those variable affect ESP performance provides an engineer with benchmarks to help set proper expectations and know where ESPs as an artificial lift method would be the most appropriate.

Another aspect that needs to be accounted for is that not all ESPs are run to failure. Some ESPs can be pulled proactively for different reasons, and in such cases, the ESP was still functional as designed. The reasons for these proactive pulls may include a hole in tubing or casing, redesign of the ESP equipment, or failure of other downhole equipment that was defined as not a part of the ESP system. Normalizing the results of a comparative failure analysis can be done using Kaplan Meier by proper identification and categorization of the reason for the ESP being pulled.[SS3]

Common ESPs failure modes:

- Thermal cycling and overheating due to low or no production,
- Mechanical failures such as broken shafts,
- Wellbore and completion failure,
- Manufacturing and service defects,
- Improper ESP operation,
- Holes in production equipment, and
- Plugging of flow paths.

The root cause of these failure modes can come from high volumes of free gas into the ESP, buildup of organic and inorganic deposits, corrosion of production equipment, sand production leading to mechanical wear, and human error. Any given ESP failure can be expected to comprise of multiple different failure modes and root causes, with each contributing to the failure to different degrees, and are often referred to as the primary and secondary failure modes and root causes.

The dataset is used in this study encompasses several major unconventional US Land basins namely the Permian (including but not limited to the following sub-basins: Delaware, Midland, and Central Basin Platform), Williston and Midcontinental or MidCon basins (including the Arkla and Arkoma basins). The dataset comprises of ESPs installations in all the major formations located in the aforementioned basins including Wolfcamp, Bone Springs, Spraberry, San Andres, Bakken, and Three Forks. The dataset comprises of over 10,000 ESP installations[NA5] from 2013 to mid-2021. The dataset includes runs until failures and runs where the ESP was still currently functional. All of the ESP runs tracked in the dataset are for horizontal wells only.

Methodology

The goal of Kaplan Meier analysis is to estimate the survival curve of a population from a sample representative dataset. If all the data points are allowed to continue until failure, then the survival curve is easily calculated by observing the number of data points (or ESP runs in our case) survival probability at each time. However, as mentioned previously, some of the studies data points may not always reach failure or have not had time to reach failure. A Kaplan-Meier analysis allows the predication of survival probability over time, even when data points are not allowed to run until failure or if the data points are studied for different lengths of time. The probability of failure is calculated for each time interval based on how many ESPs failed or were pulled (while still operational) and the data is censored going forward to the next time step.

The survival analysis for this study was performed in R using the “survival” and “survminer” libraries.
For the purpose of this study, the ESP runlife dataset was merged with public data to append more useful information such as formation, geo spatial coordinates and location, completion date of the wells, oil/water/gas production volumes, and proppant and fluid volumes for hydraulically fractured wells to name a few.

The aspect that turned out to be the most difficult to track was previously used equipment and components. For the most part, used pumps and motors were tracked properly and had a trail that could be followed to assess if an ESP design employed new or used components, and even how much runtime the used part had accumulated. Such details are necessary when analyzing how an ESP’s performance is affected when reusing old equipment.

Results

1. ESP installs by basin and formations

The most significant underlying variable in determining a baseline of expected runtime is the basin where the ESP is installed. Historically since 2013, ESP 50% survival probability runtimes in the Williston Basin have been less than 6 months while the Permian and MidCon Basin have been over 9 months and 12 months respectively. This difference of the runlife is due to the difference in underlying conditions of the unconventional plays and formations being produced. The different application variables including water cut, depth, and gas volumes are discussed.

As well as the major basins, the individual sub basin and producing formation can also have substantial differences as well. For the Permian, the sub basins of the Midland, Delaware, and Central Platform have a minor difference in survival probabilities, while the producing formation plays a much greater role. The same effect can also be seen in the Williston and MidCon Basins.

Figures 3 to7 provide the survival curves for the different basins by formation. These results can used to understand typical run times for ESPs and benchmarking their performance.

2. <u>ESP survival probability by install year</u>

The survival curves below compare the change in survival probability by basin and install year. Figs 8, 9, and 10 show the improvement in survival probability over the years. There are several reasons that can explain this improvement, namely:

- Better operational practices based on past experience (such as flowback techniques, wellbore cleanouts, application of better well chemistry)
- Better technologies and ESP component design for harsher conditions (such as software and gas/sand handling equipment)
- Better design knowledge based on past experience

While ESP runtimes in unconventional basins have been improving over time, there has also been a large shift since 2013 where most of the ESP installations occurred initially in the MidCon Basin and now are predominately in the Permian Basin. Based on the last exercise of comparing the major basins, one would expect to have worse runtime as more ESPs are run in the Permian Basin (because MidCon had a higher median survival probability than Permian), but overall runtime across all the 3 basins are still shown to improve.

The survival comparison within the Permian basin demonstrates the improvement of the ESP performance year over year. The same improvement trend can also be seen in the Williston Basin. However, in the MidCon Basin in Fig. 10, the improvement year over year is less consistent.

3. <u>ESP survival probability by install number per well</u>

It is expected during the life of a well to have multiple ESP installations to address the changing production rates and well conditions observed during the life of an unconventional well. Hence the install number is the sequential ESP number installed in the same well. A new install can utilize the same equipment from the previous run if it is salvageable (based on the operator's discretion) where only the failed component is replaced. The analysis comparing the difference in survival probabilities of new versus used components is discussed later.

Understanding the significant performance differences of ESPs in different Basin and change in sequential installation performance requires understanding the different production quality of the different basins. Overall, across the three major basins, there is not a change in sequential installations, but looking at basin-by-basin reveals trends that are more interesting. MidCon shows improvement in the later life of well with multiple installation. Permian shows performance degradation of runlife with sequential installations while Williston shows minimal performance degradation for sequential installations. Understanding why different 3 basin show different ESP reliability trends in sequential installations is thought to be due to how the well conditions change with time and would need to be explored more in future work.

4. <u>ESP survival probability by gas-liquid ratio (GLR), true vertical depth (TVD), and watercut (WC)</u>

The below figures show comparatives of water cut, gas-liquid ratio, true vertical depth. All three factors show to have an effect on ESP reliability. The most significant variable found are in water cut, TVD, and GLR in excess of 1500 scf/bbl have been found to degrade runtimes.

Not able to look water cut and gas ratios in MidCon due to lack of available water and gas data.

The TVD effect on runtimes is closely tied with formation effect seen in the previous section showing the effect of deeper formations. It can be inferred that the deeper formations having higher temperatures is leading to the degradation of ESP runtimes. It can also be inferred that the higher water cuts leading to better ESP runtimes is due to water having a better cooling effect than oil or gas and being a non-compressive fluid ideal for ESP applications. Increases in gas liquid ratio has a minimal effect runtime until GLR is more than 1500 Mscf/bbl. The conclusion is this is the turning point in which current ESP gas handling technologies begins to hit limitations and effect the overall system performance.

5. <u>ESP survival probability by proppant pumped per foot of a horizontal hydraulically fractured well</u>

Proppant intensity was not found to lead to a decrease in survival probability for the Permian and Williston basins (the MidCon basin did not have completion data widely available across all the wells). The proppant data was filtered to 2018-2021 only to normalize for:

- Changing completion designs and trends within the unconventional markets
- Improvement in ESP design and component technologies over time

The hypothesis the authors put forward at this point is that the tendency of an ESP to fail more or less due to sand failure could be more due to the qualities of the producing formation, and an operator's sand mitigation practices during and after flowback. Moreover, it could also be due to the industry learning from past experiences and optimizing operational practices such as flowback procedures. Information is not available at this point to test these theories.

6. <u>ESP survival probability for new vs used components</u>

This analysis was limited to a dataset in the Williston basin only. As expected, newer components have a higher 50% survival probability, especially pumps. Since pumps can have several stages, they were grouped as all new pumps being in the bin “1”, pumps with less than 60% of stages being new were put in the bin “<60%” and pumps with 60-99 percent of stages being new were grouped in the bin “60-99%”.

The main takeaway is used pumps are more likely to cause shorter run times as compared to motors and cables. The disclaimer is that dataset was limited (and the p-value is also greater than 0.05). The analysis needs to be expanded on using a larger dataset to make stronger conclusions.

<u>Conclusions and future work</u>

Evaluating ESP run lives and performance in unconventional well environments can be achieved by using Kaplan Meier analysis. The key take away is that an unconventional well environment can vary widely and affect ESP reliability. The understanding of these effects is crucial to optimizing ESP performance and extend longevity to know where an ESP can perform to expectations and be of the most value as a form of artificial lift. Based on the analysis with a several variables (basin, producing formation, water cut, and gas-liquid ratio), the ESP survival rate can be reasonable predicted. The workflow can also be used to assess the impact of change in design or operation practices on ESP runtimes in order to prolong ESP lives.

For the wells studied:

- MidCon basin had the highest median survival probability followed by Permian and Williston basins
- For the Permian basin formations, Wolfcamp and Brushy Canyon had the highest survival probability in the Delaware basin and Spraberry in the Midland Basin.
- Mississippi Lime and Three Forks had the higher median survival probability for the MidCon and Williston basins respectively.
- The first and second installs have the highest survival probability in the Permian. Subsequent installation have shorter runtimes. Low GLRs (<1500 scf/stb) and high watercuts (>75%) correspond to higher survival probabilities.
- Proppant/ft does not significantly affect survival probability (for wells completed from 2018-2021 included in the study).

- Used pumps are more likely to cause shorter run times compared to used motors and cables, but the analysis needs to be expanded on using a larger dataset.

Another avenue to explore in future studies is the mode of failures or competing risk analysis. This requires an objective determination of the root cause of failure and the failure mode (the failure root cause analysis is subject to biases by the involved parties). There can be several failure root causes affecting the ESP at a given time. Distinguishing the effect of each can help an engineer better understand the primary root causes and devote one's time and resources accordingly. Moreover, performing root cause failure analysis (RCFA) and determination of failure modes is a time-consuming operation and hence limits the amount of data available for analysis. Using a competing risk analysis, one can determine which root causes and failures modes are contributing more to ESP failures, which might change based on downhole conditions (i.e. they can be different for different basins and formations).

Furthermore, another aspect that can be studied is "useful life" of individual components i.e. the time in which a piece of equipment is no longer fit for use. The analysis in Fig 21 below shows the useful life of different ESP components as component can be used in different installations and wells. Such an analysis helps an engineer identify the weakest link in an ESP design when reusing older components, but it requires thorough tracking of each component across different ESP install and wells.

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Appendix

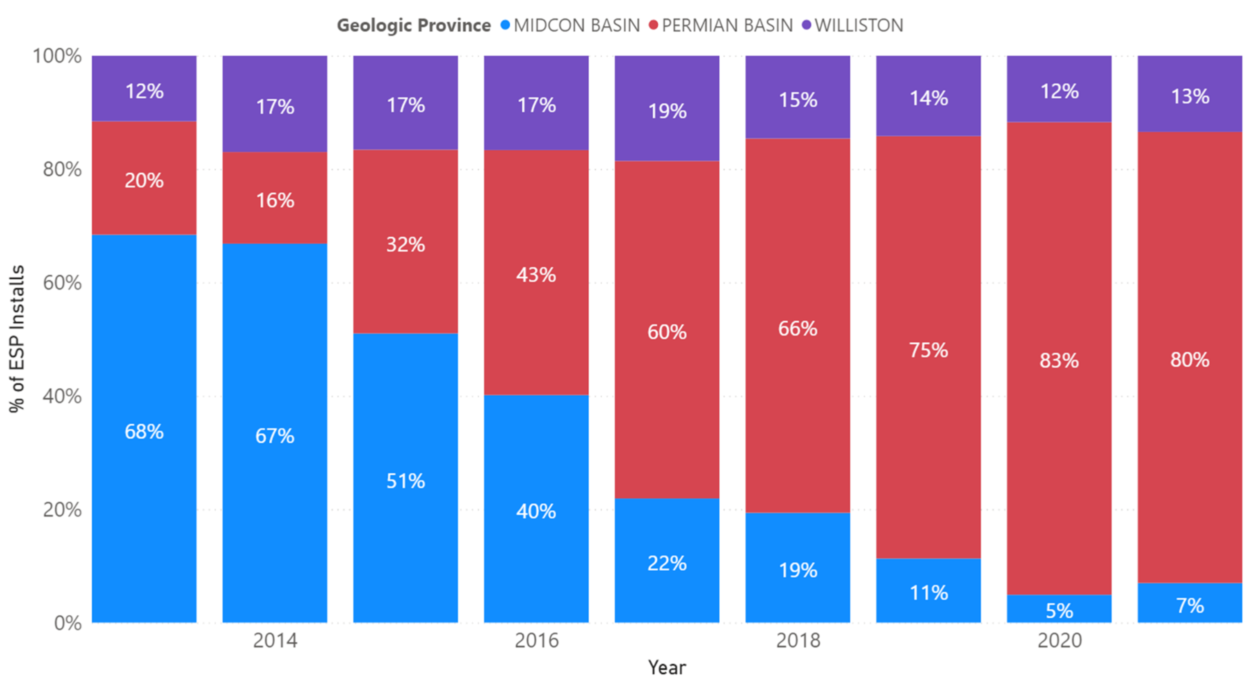

Figure 1 Breakdown by year of ESP installs between the Permian, Williston and MidCon basins in the dataset

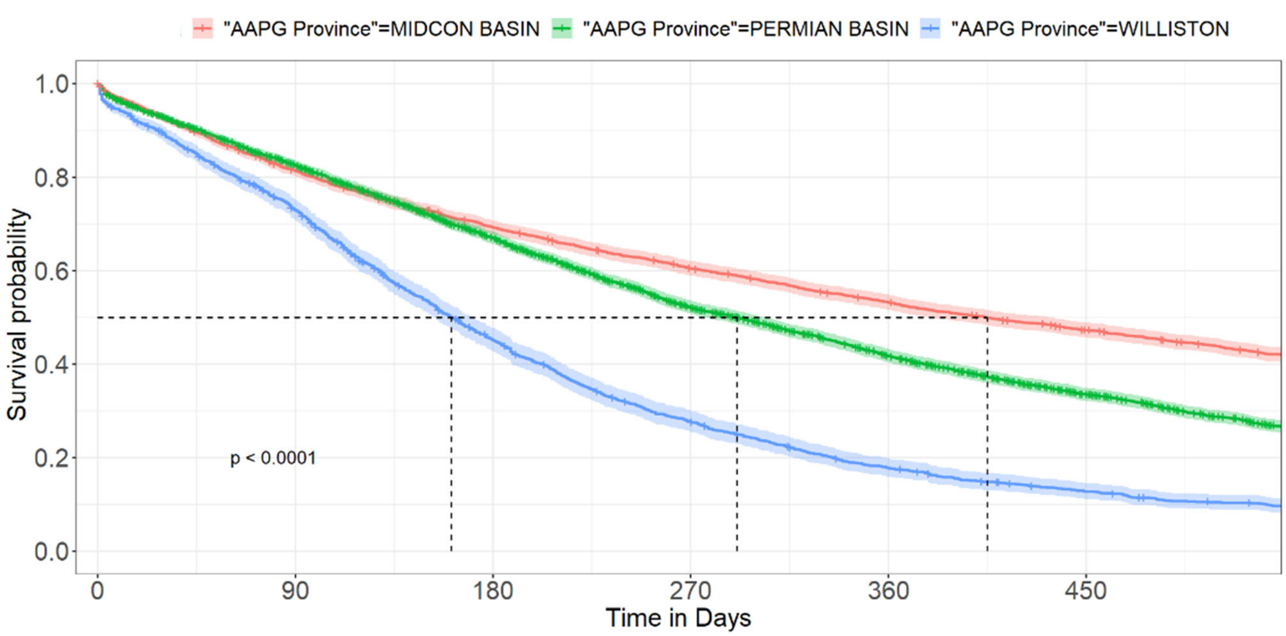

Figure 2 ESP survival curves by major basins

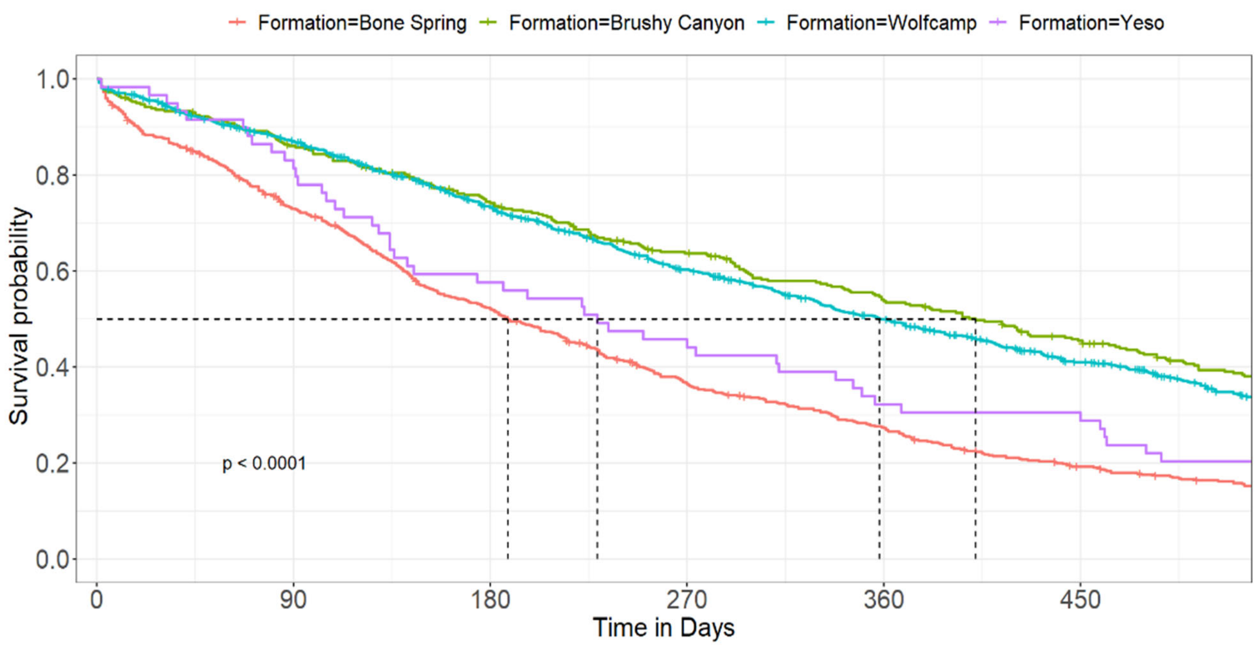

Figure 3 ESP survival curves by Delaware basin formations

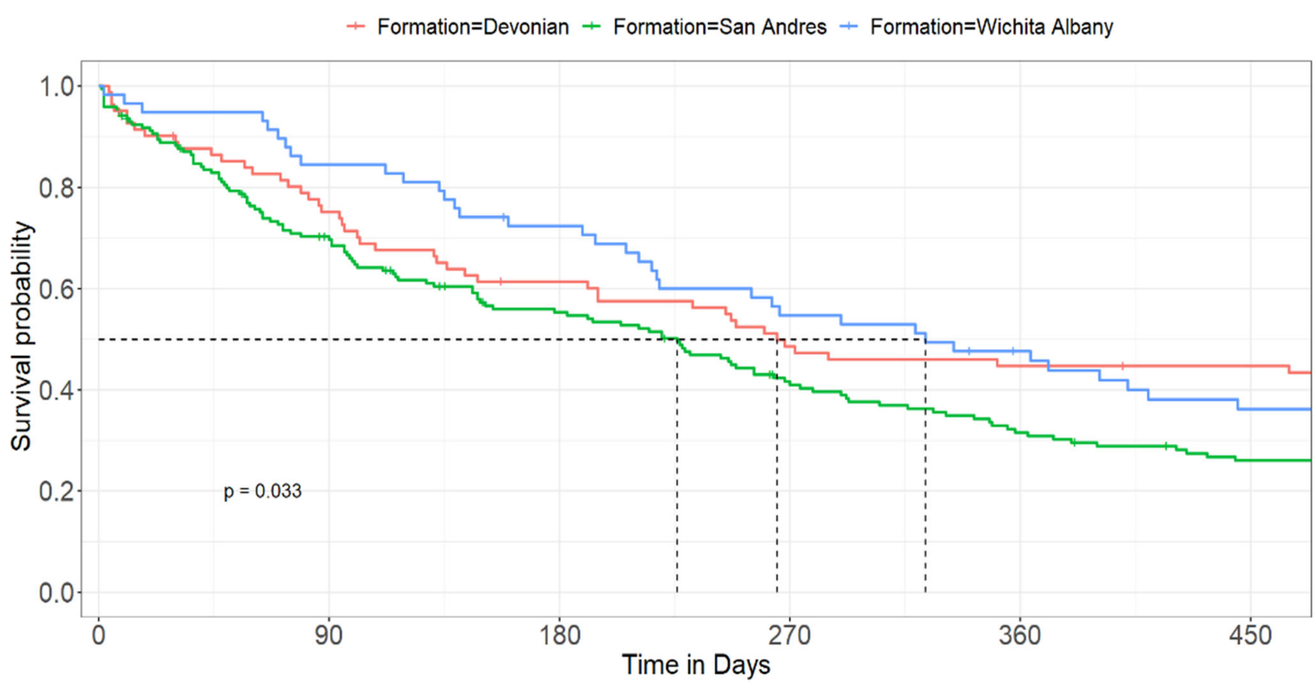

Figure 4 ESP survival curves by Central Basin Platform formations

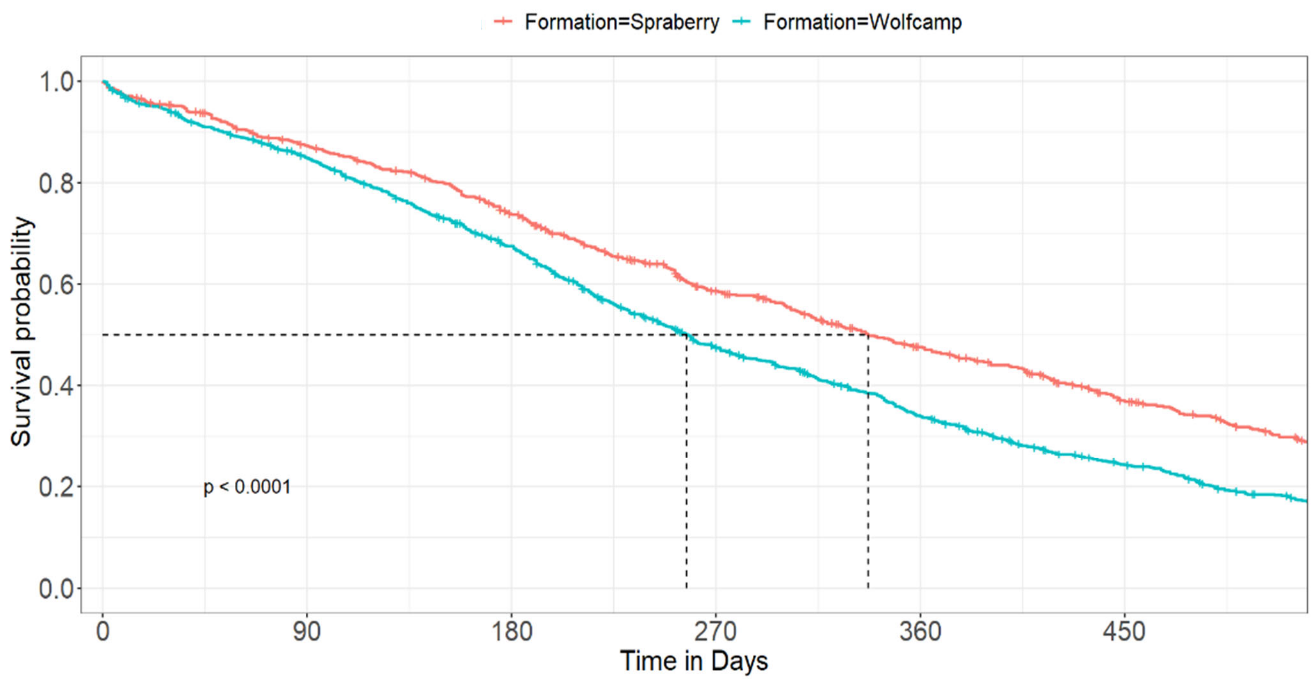

Figure 5 ESP survival curves by Midland basin formations

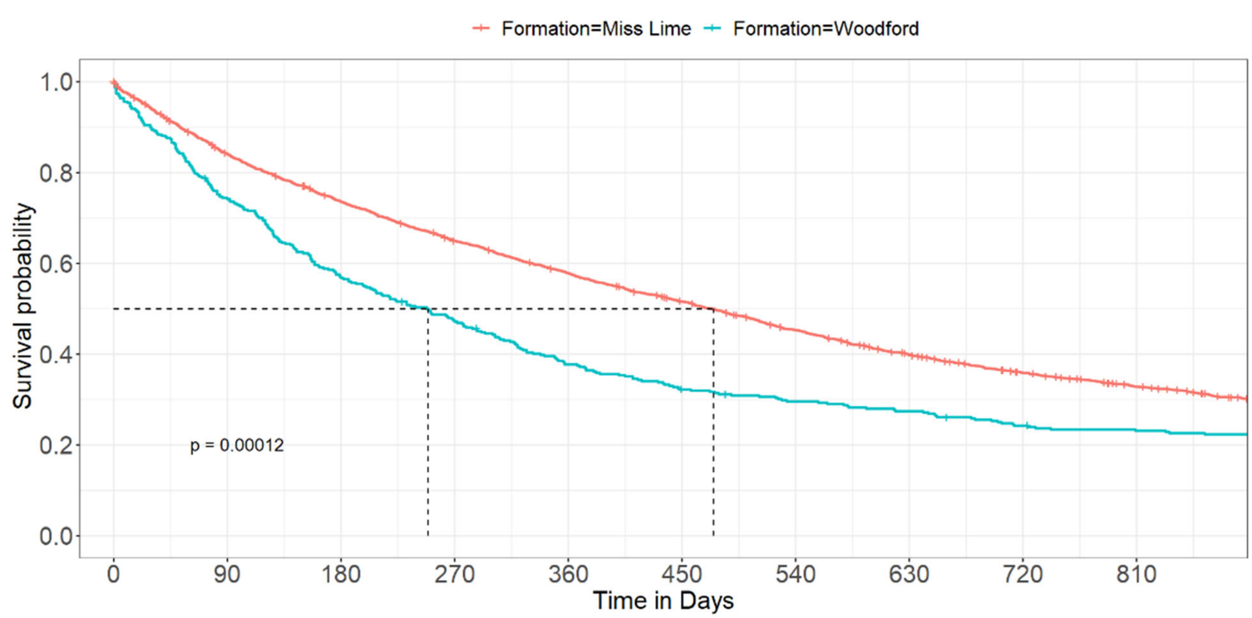

Figure 6 ESP survival curves for MidCon basin formations

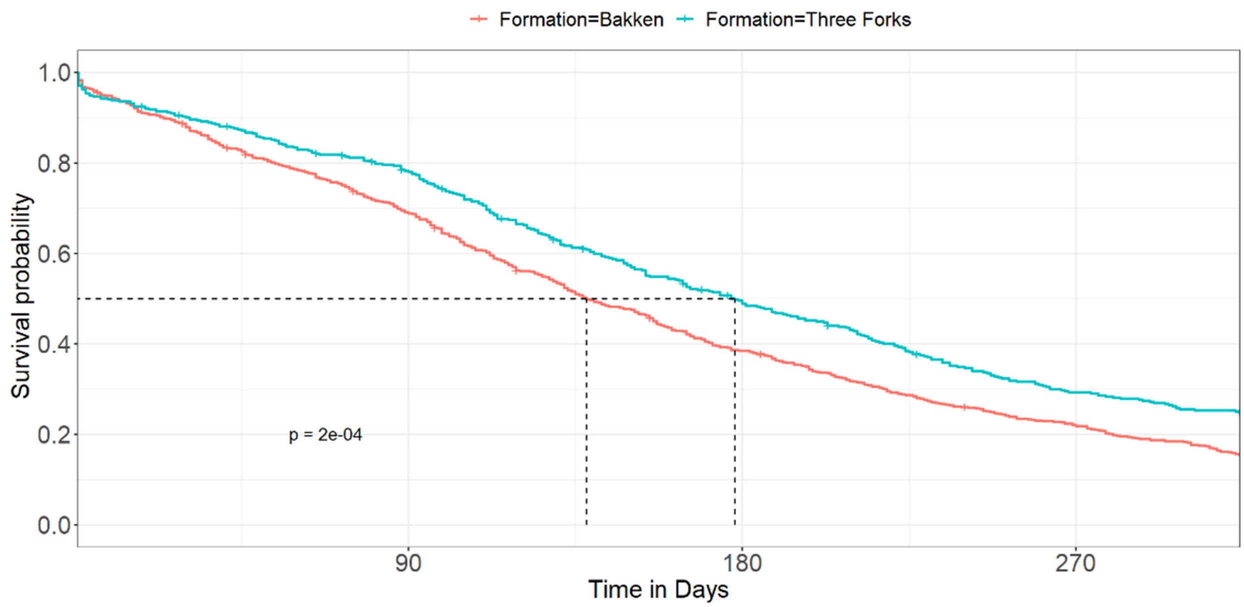

Figure 7 ESP survival curves for Williston basin formations

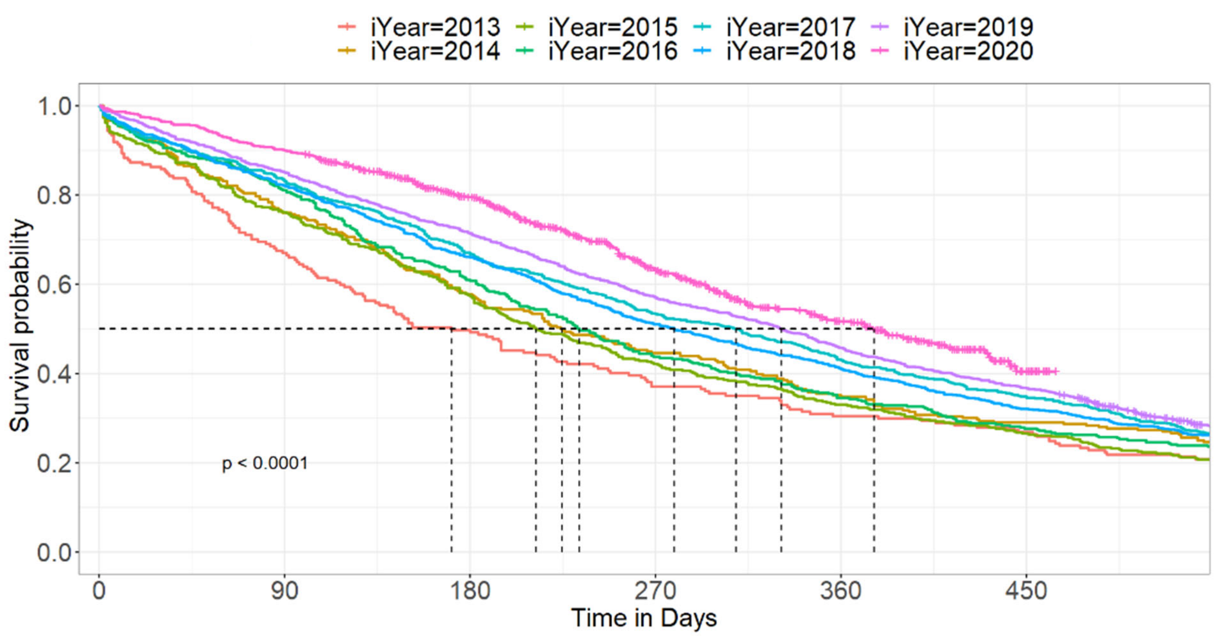

Figure 8 ESP survival curves by install year for the Permian basin

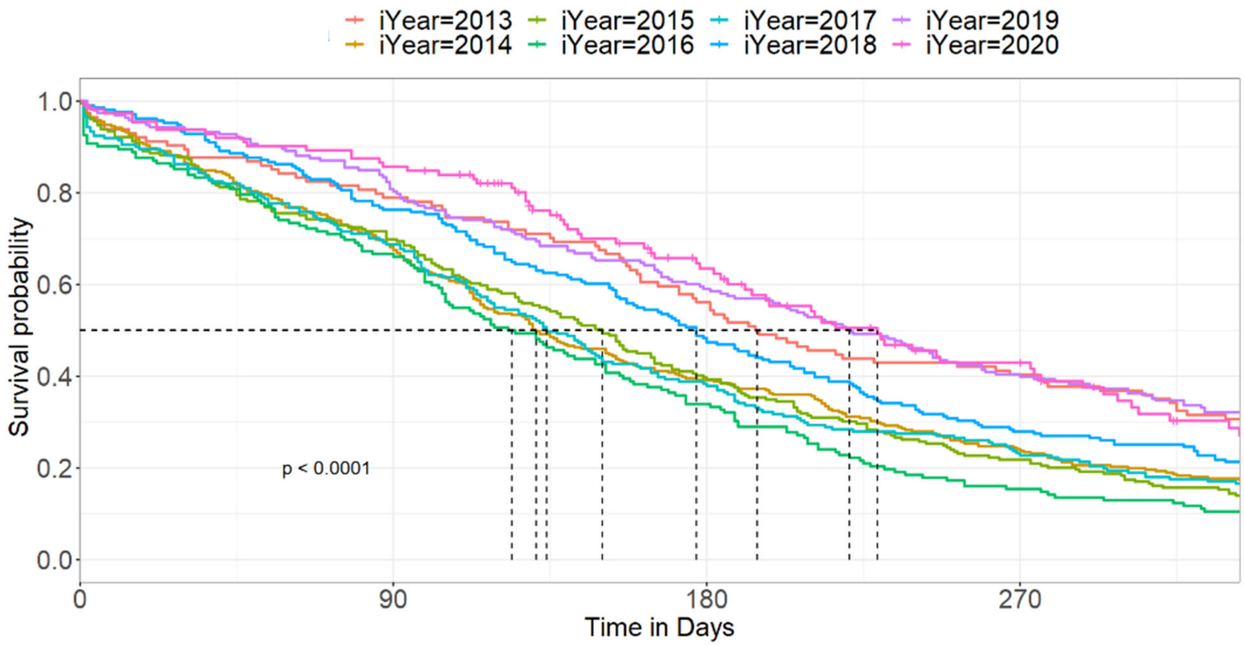

Figure 9 ESP survival curves by install year for the Williston basin

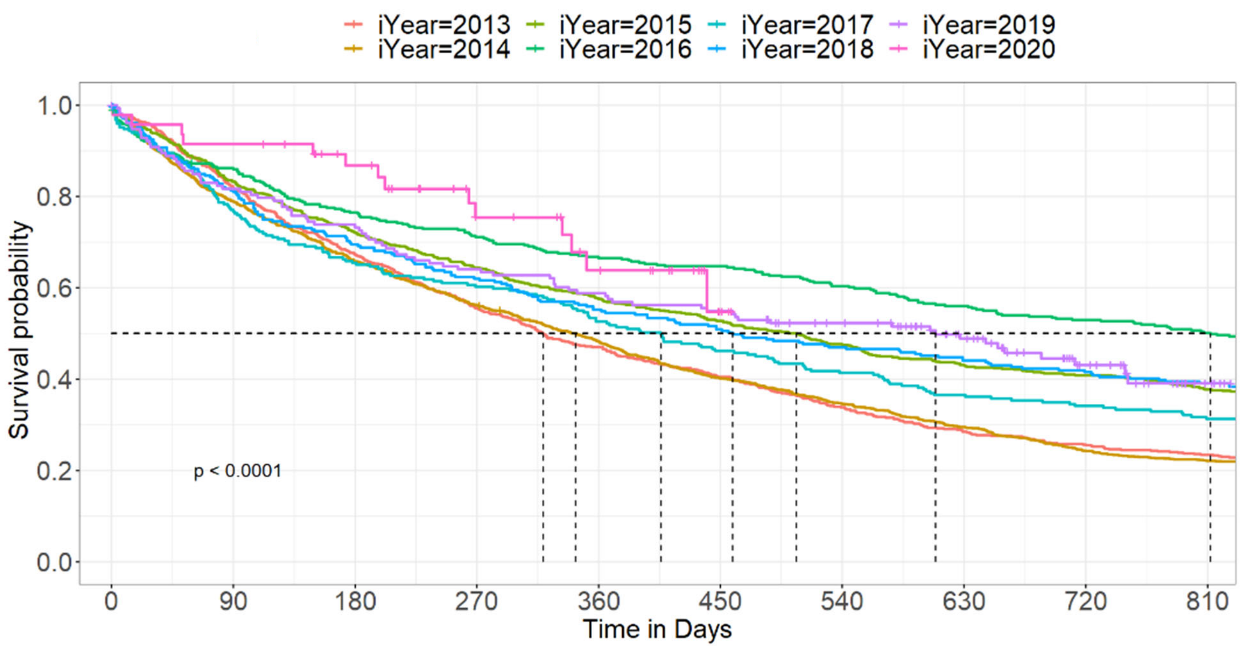

Figure 10 ESP survival curves by install year for the MidCon basin

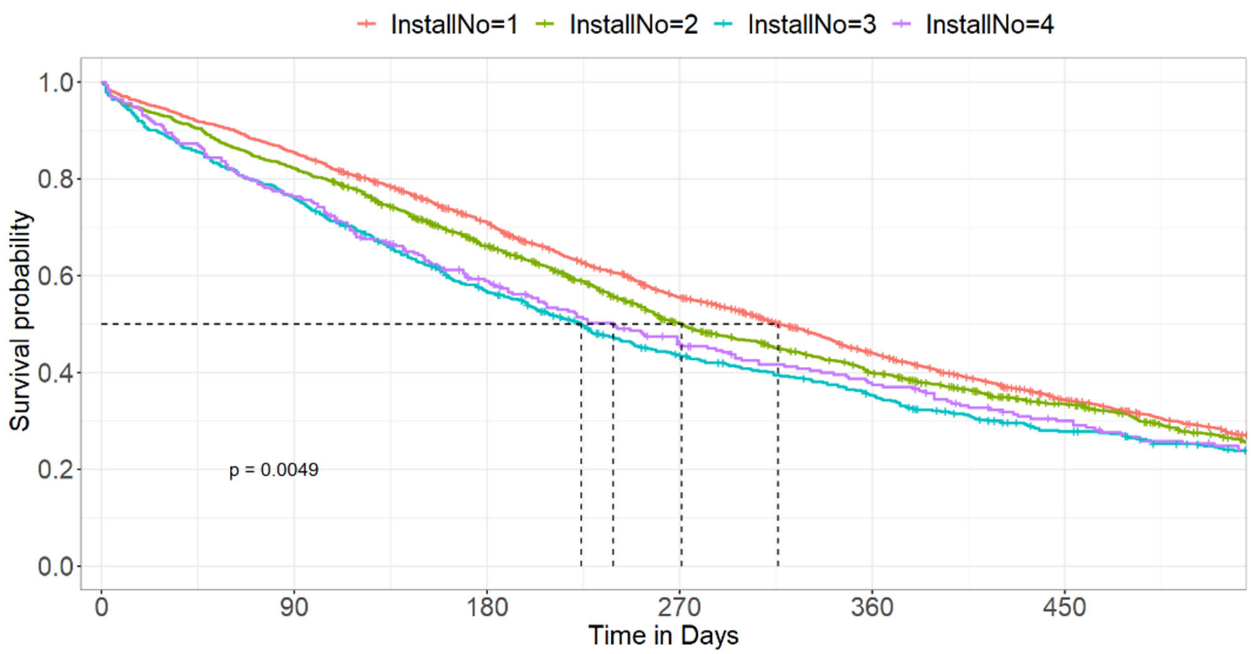

Figure 11 ESP survival curves by install number for the Permian basin

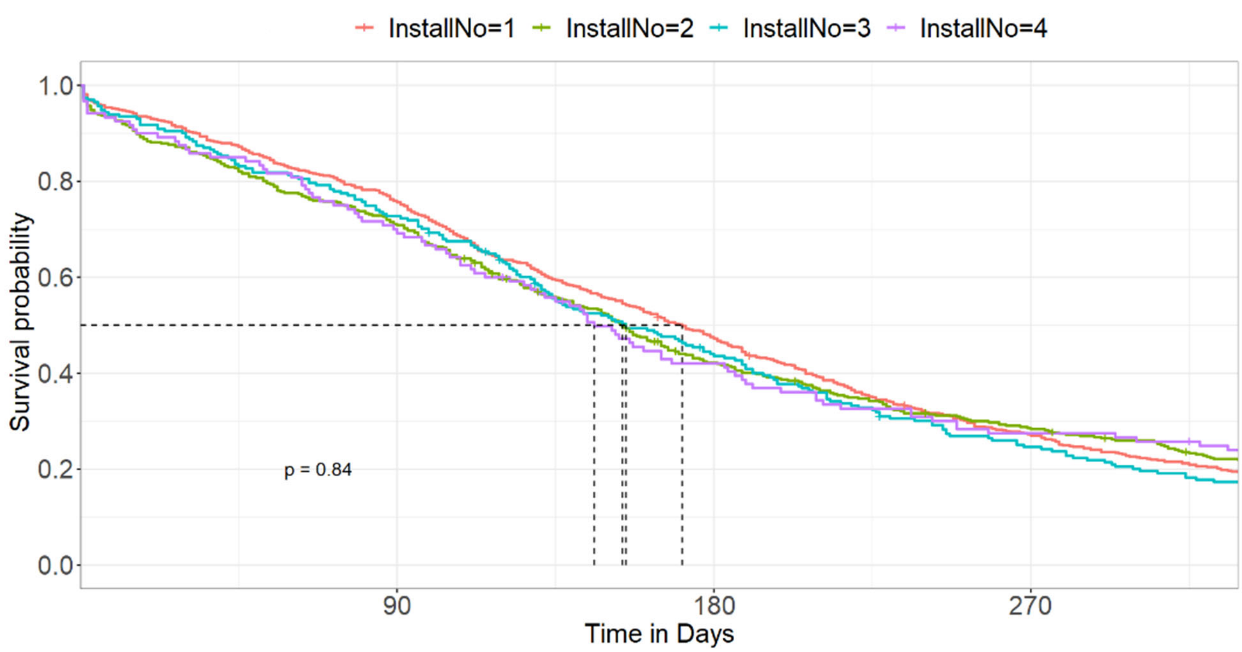

Figure 12 ESP survival curves by install number for the Williston basin

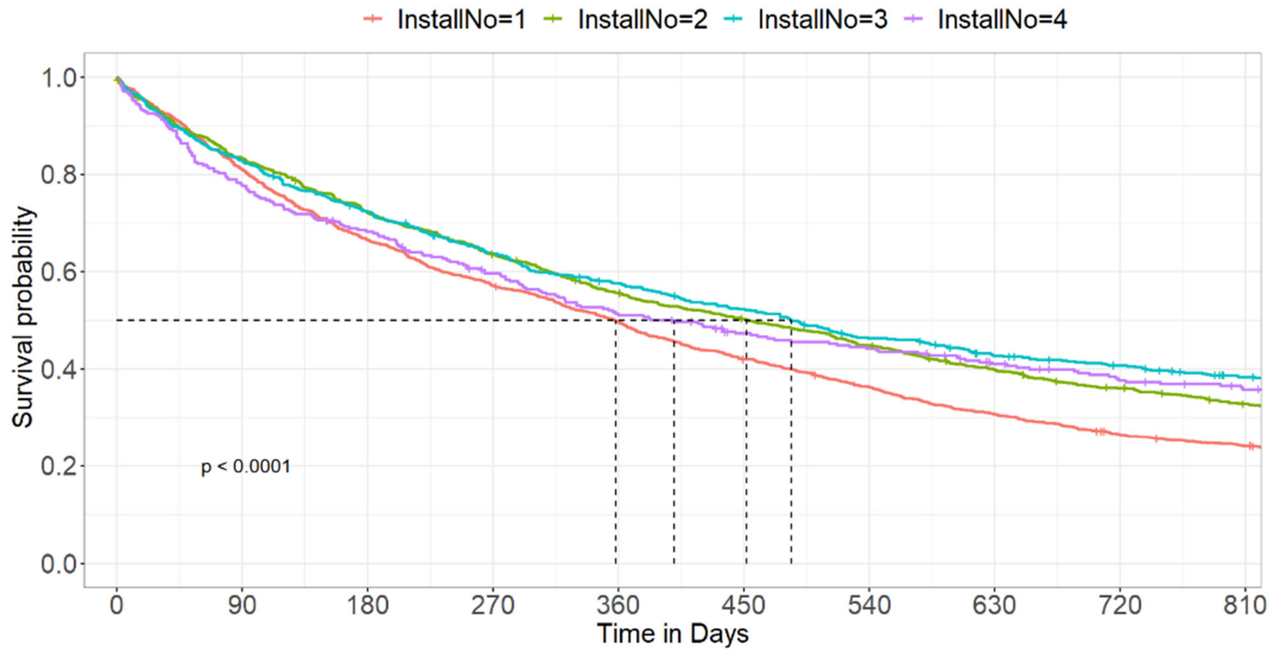

Figure 13 ESP survival curves by install number for the MidCon basin

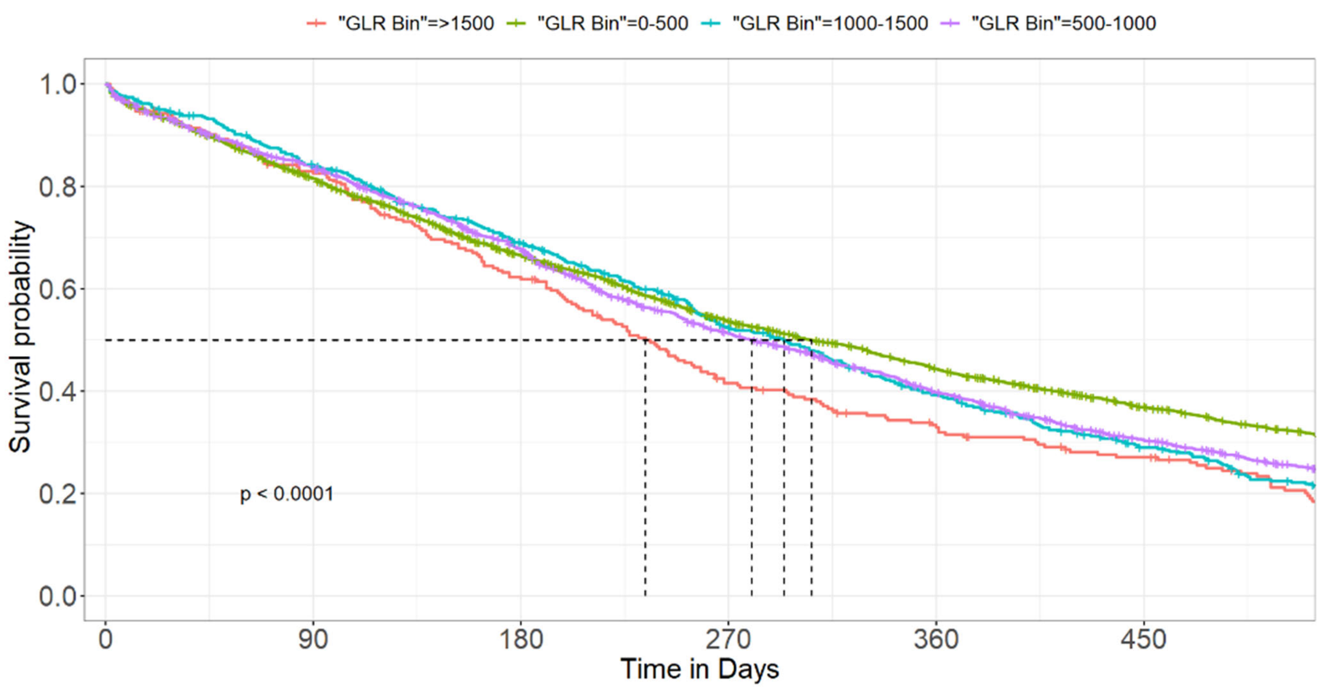

Figure 14 ESP survival curves by binned gas-liquid ratio in the Permian basin

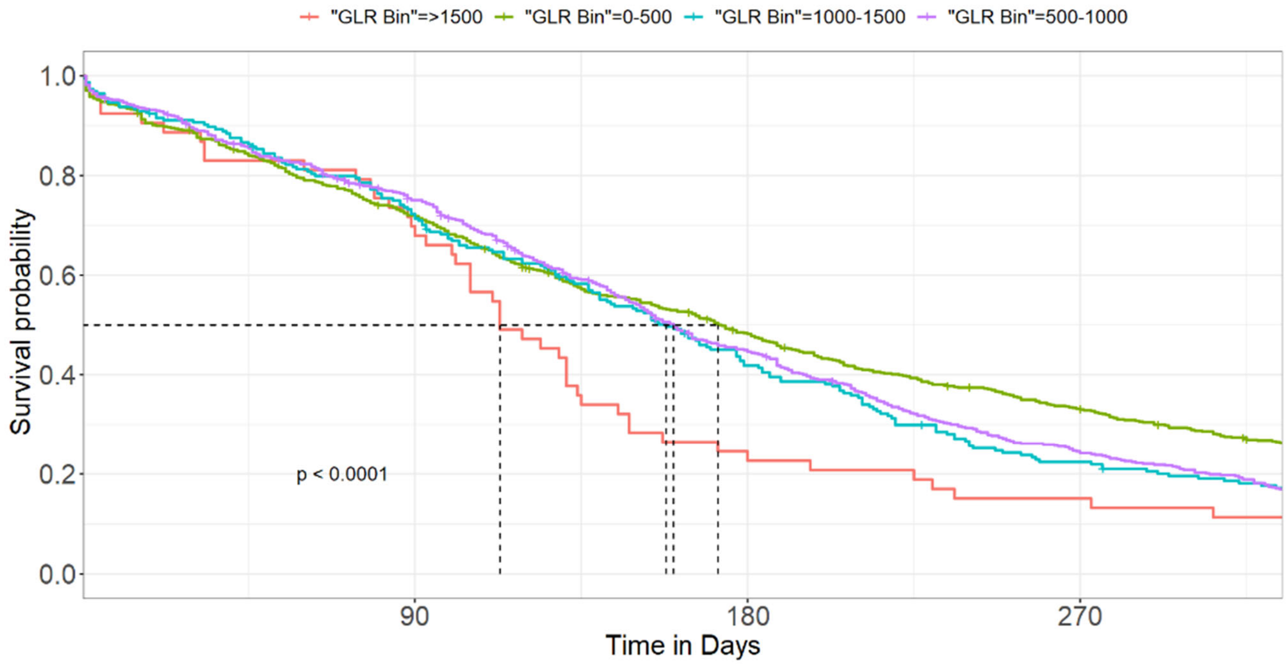

Figure 15 ESP survival curves by binned gas-liquid ratio in the Williston basin

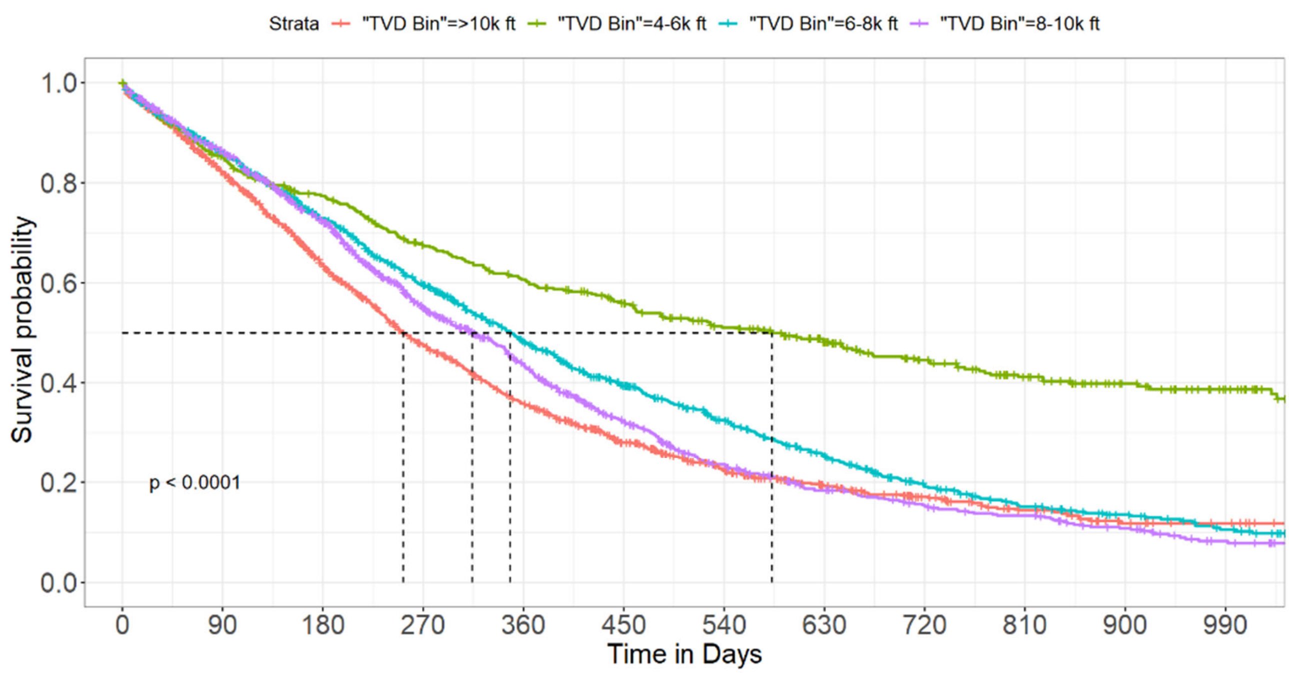

Figure 16 ESP survival curves by formations depths

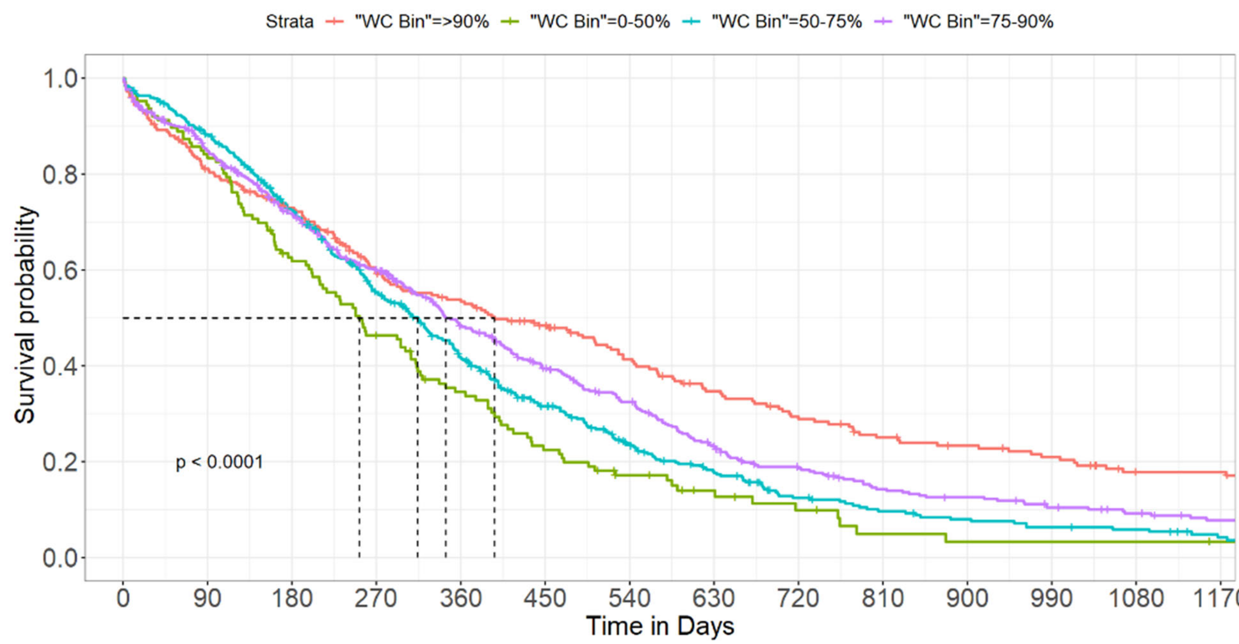

Figure 17 ESP survival curves by binned watercut for the Permian basin (filtered to 6000-8000 ft TVD range)

Watercut seems to be less of a factor in the Permian, but when normalizing for depth and only looking at a limited range of 6000-8000 ft TVD, a much more pronounced effect of watercut can be seen.

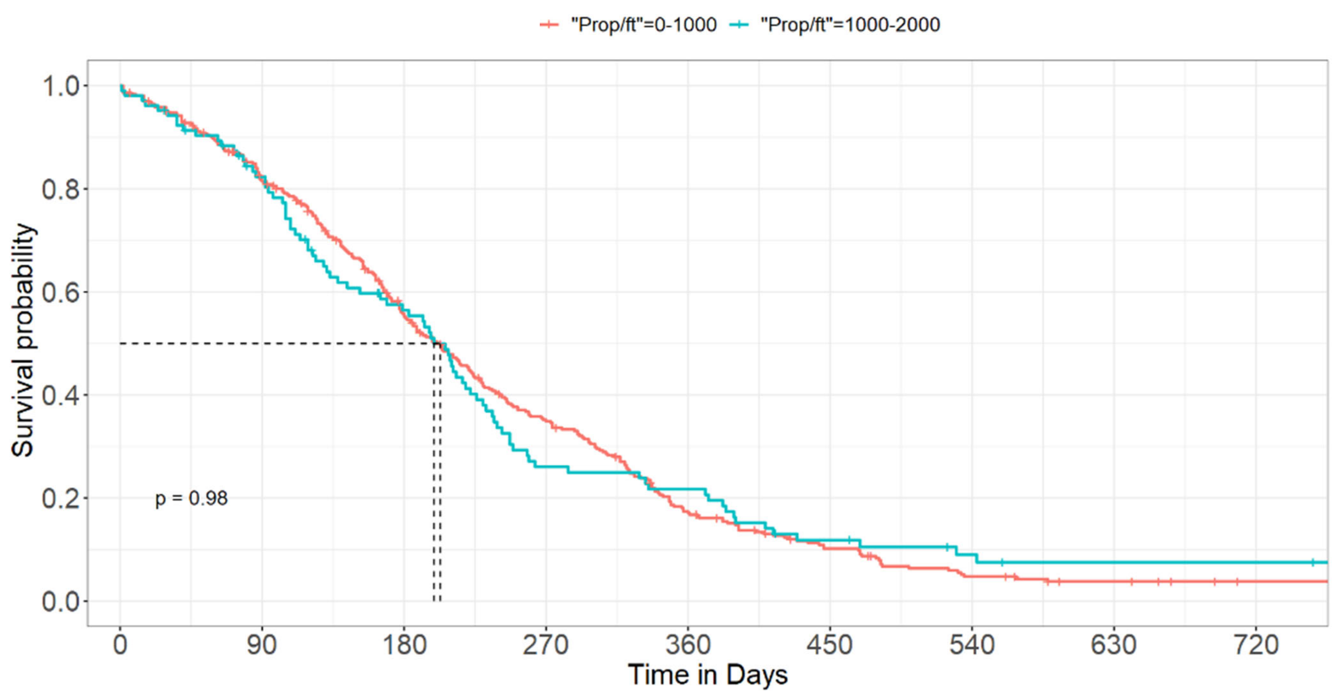

Figure 18 ESP survival curves by binned proppant /ft in the Williston basin (from 2018 to 2021 only)

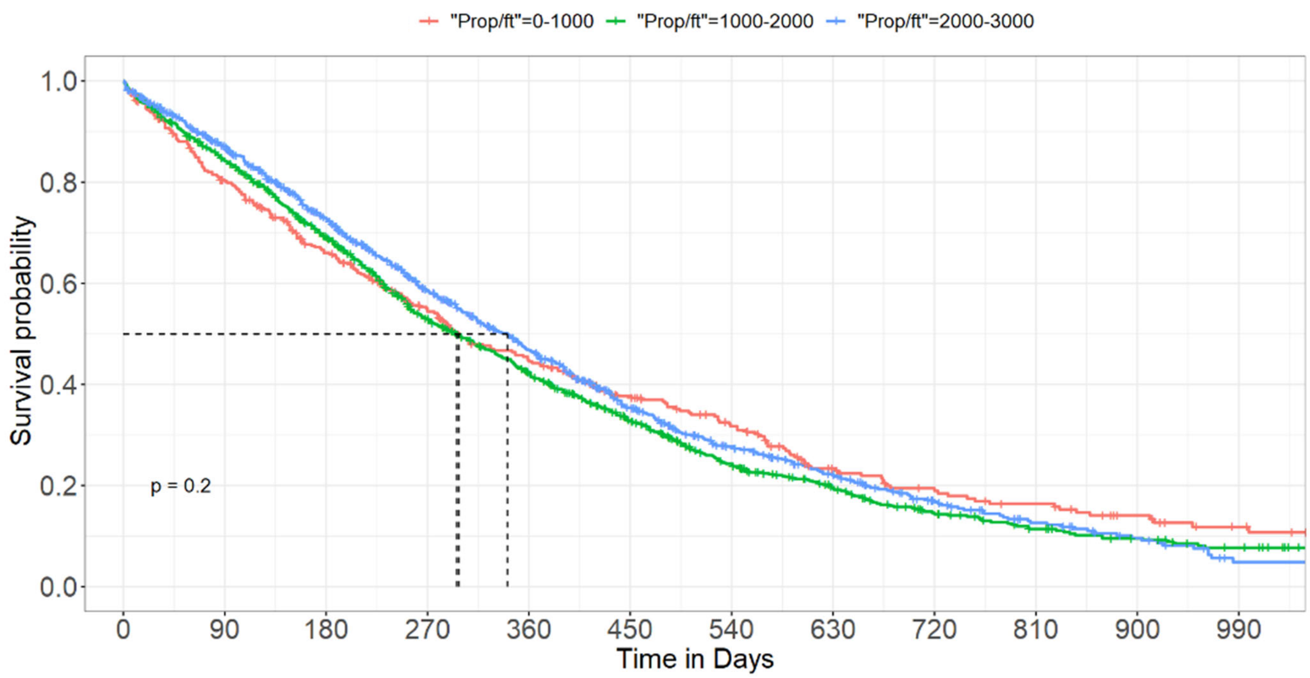

Figure 19 ESP survival curves by binned proppant /ft in the Permian basin (from 2018 to 2021 only)

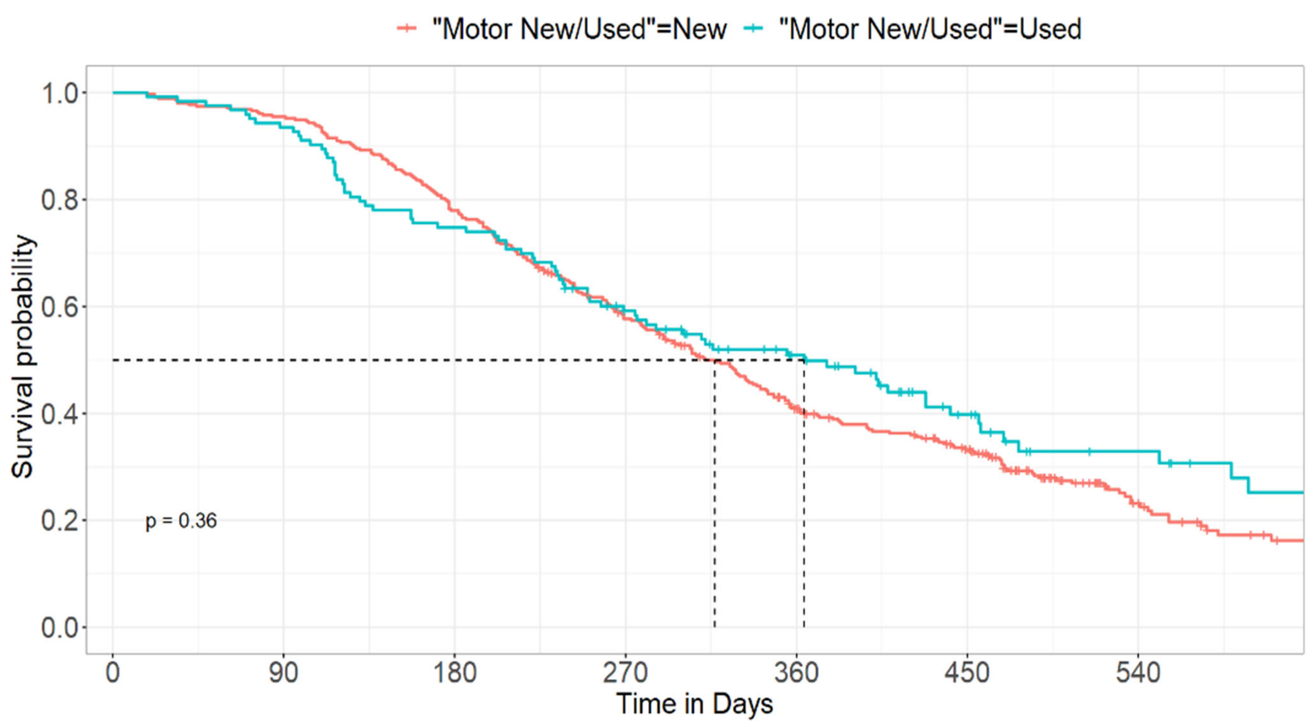

Figure 20 ESP survival curves for new and used motors

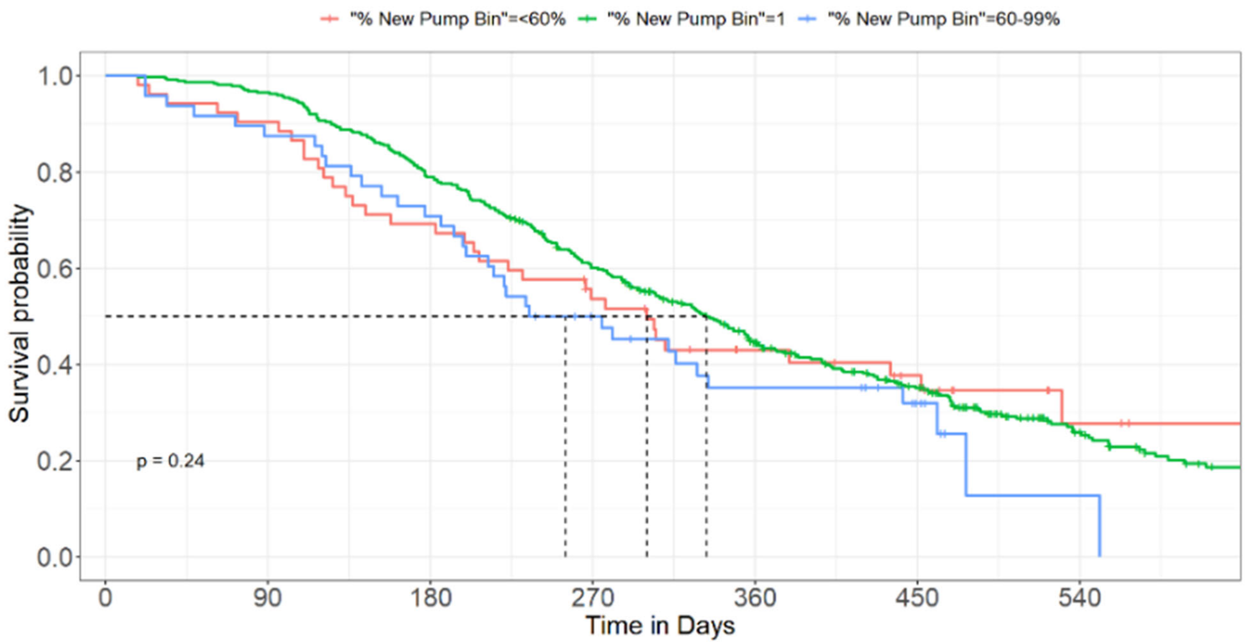

Figure 21 ESP survival curves for new and used pumps

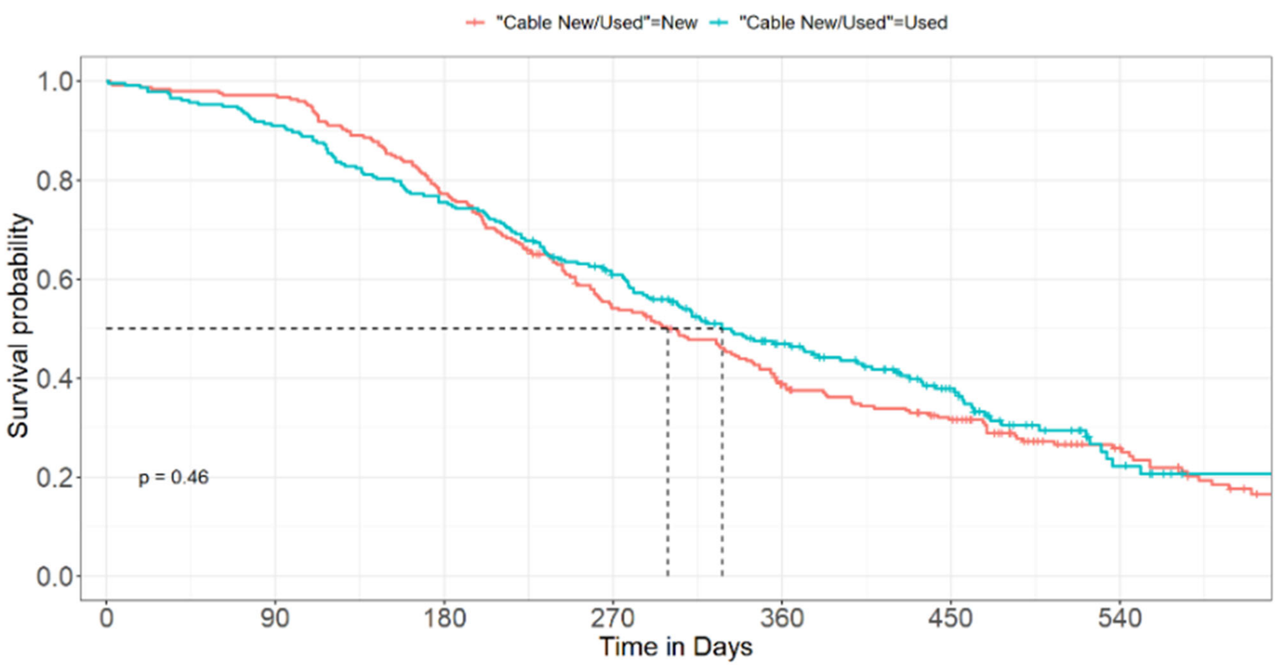

Figure 22 ESP survival curves for new and used cables

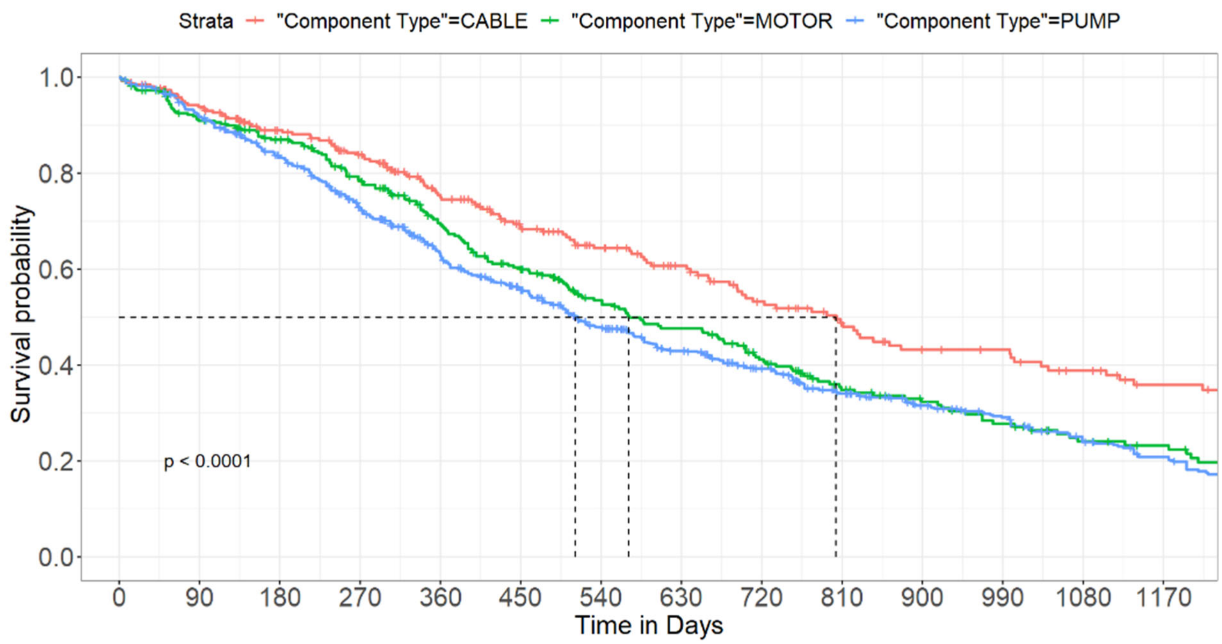

Figure 23 Survival rates based on "useful life" for individual ESP components in Delaware Basin

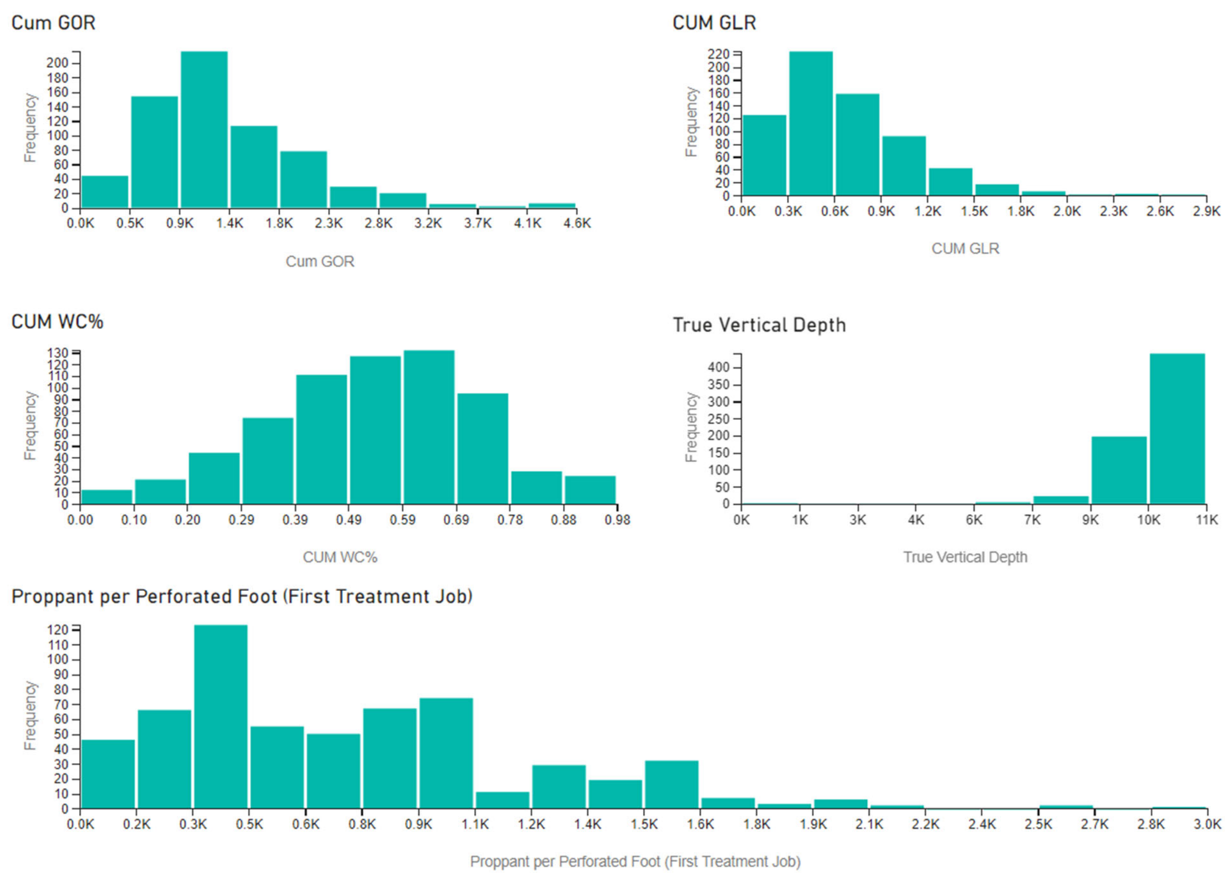

Figure 24 Frequency distributions histograms for the Williston basin wells in the dataset showing (from top left) cumulative gas-oil ratio, gas-liquid ratio, watercut, TVD and proppant/ft

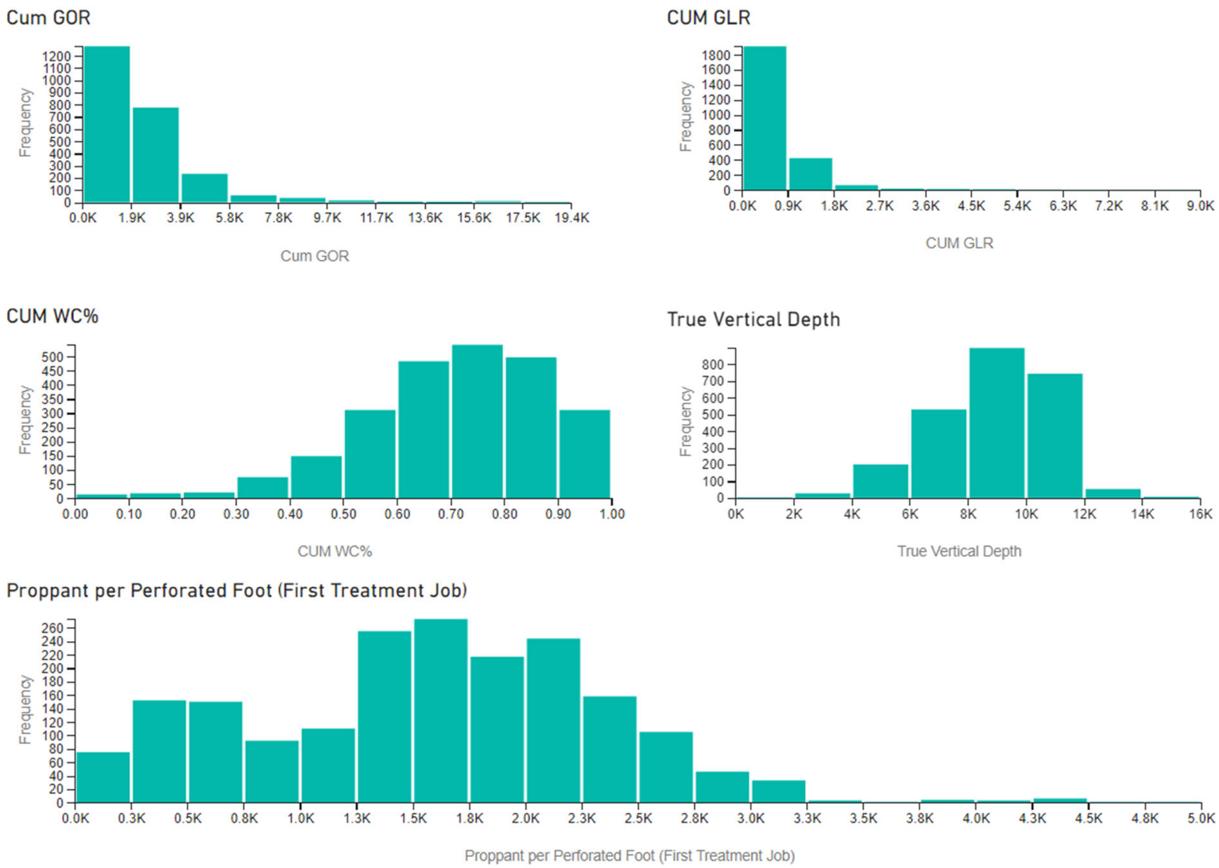

Figure 25 Frequency distributions histograms for the Permian basin wells in the dataset showing (from top left) cumulative gas-oil ratio, gas-liquid ratio, watercut, TVD and proppant/ft

MidCon frequency distribution histograms are not shown because proppant per foot, water and gas production was not widely available for all the wells

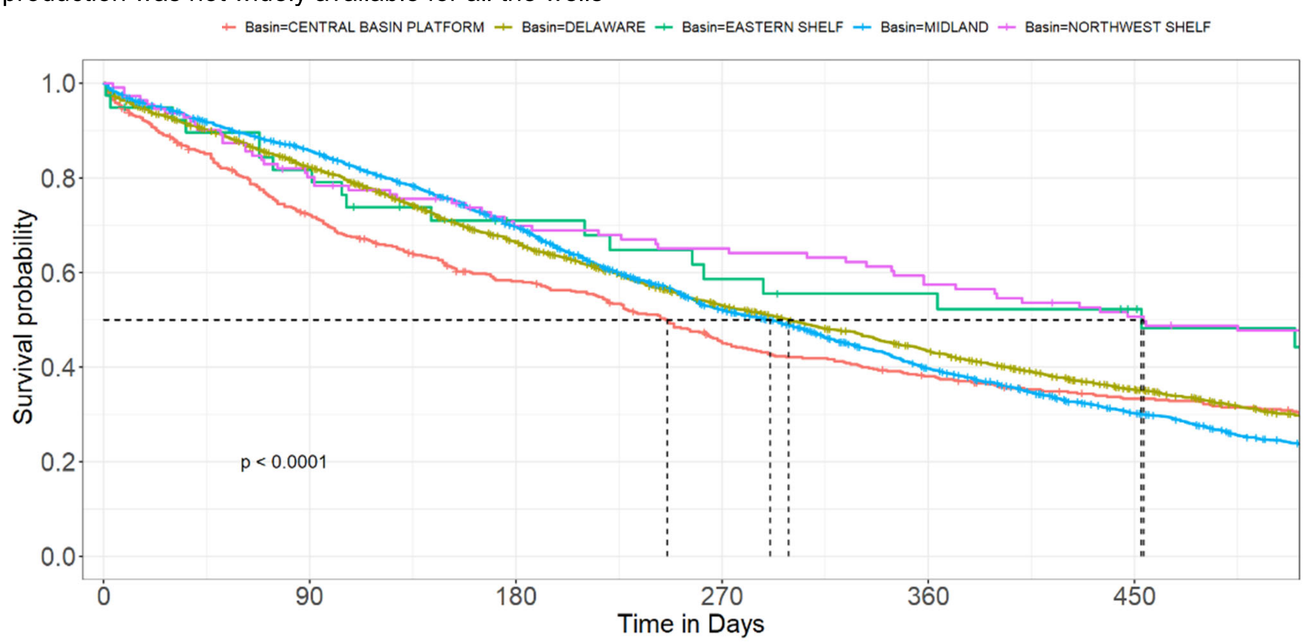

Figure 26 ESP survival curves by Permian sub basins

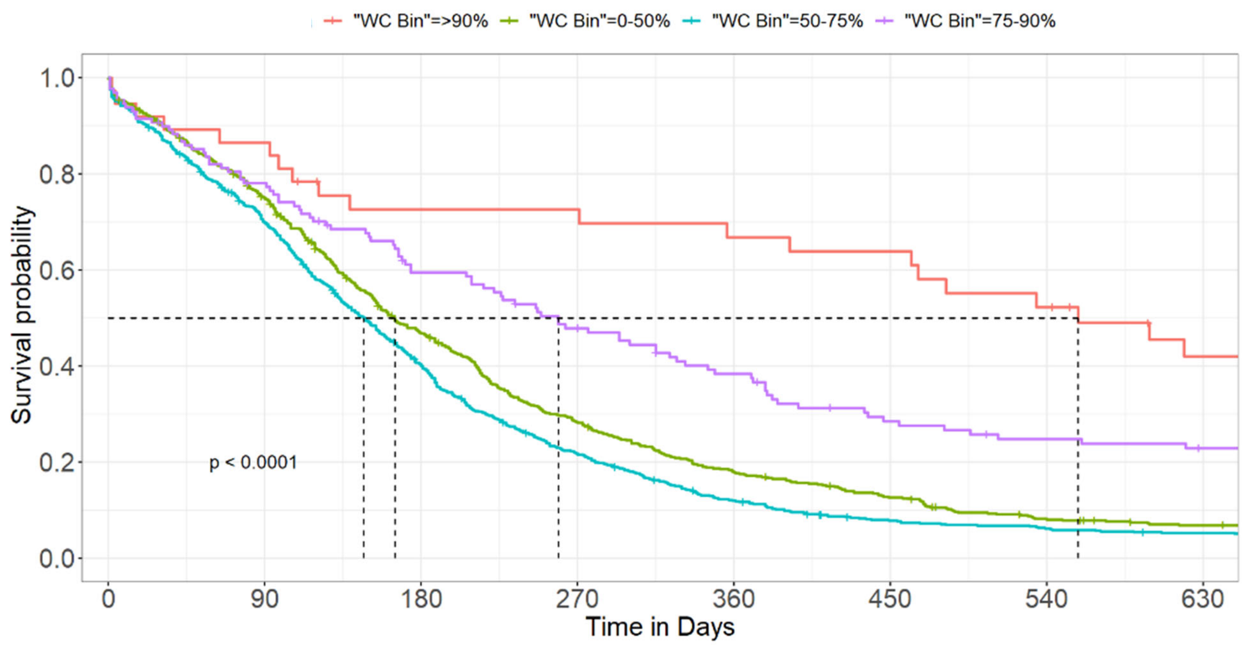

Figure 27 ESP survival curves by binned watercuts for the Williston basin

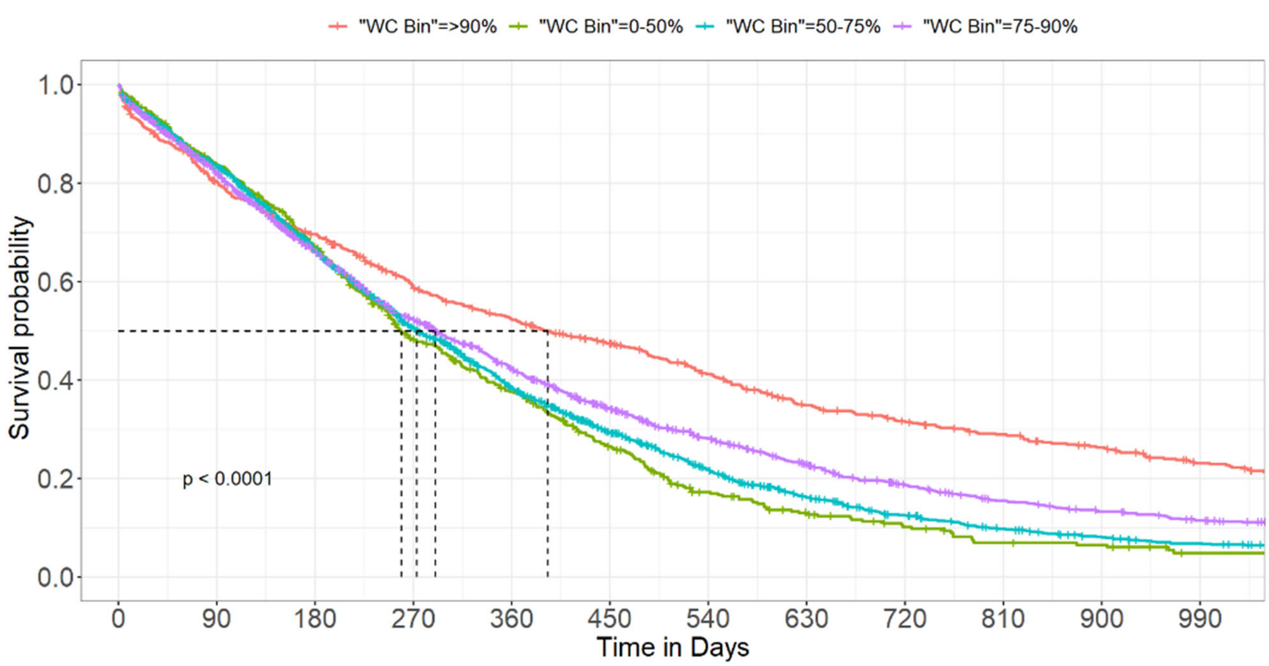

Figure 28 ESP survival curves by binned watercuts for the Permian basin