PAM Analytics Predictive Asset Management

PAM Asset Deterioration Curves Module

Introduction

The Asset Deterioration Curves module is used for tactical level asset management optimisation. The output of the module is a series of asset deterioration (risk) curves. They curves are used to identify the asset type with the highest survival probabilities (or lowest cumulative hazards [cumulative risk at time *t* of asset failure]) as assets are used. The module produces:

- deterioration curves for single factors, for example manufacturer
- deterioration curves for stratified factors, for example manufacturer stratified by functional site
- deterioration curves for single assets that did not have maintenance interventions
- deterioration curves for single assets that had maintenance interventions.

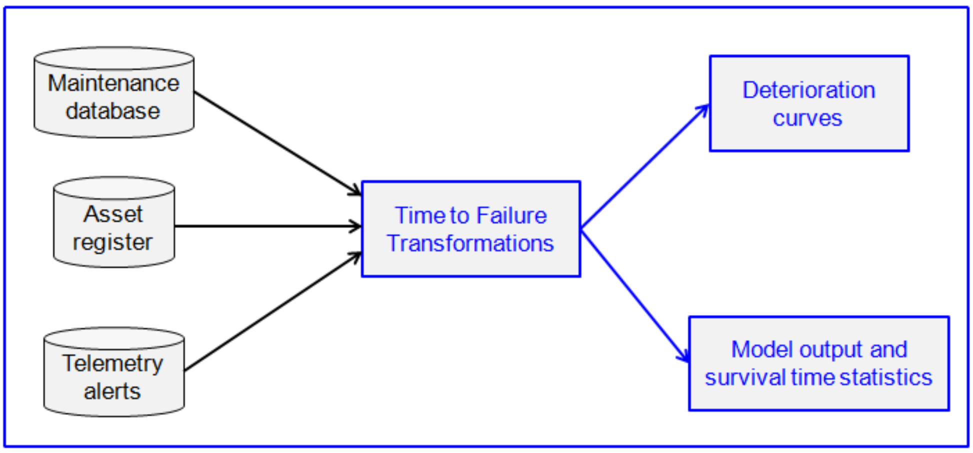
In addition to producing curves for times to the first failure, curves for the times between successive failures can also be produced.

The curves are produced using the Kaplan Meier estimator (see the appendix in *Introduction to PAM* in PAM Introduction).

Schema

Figure 1 shows the schema for the Asset Deterioration Curves module.

Figure 1

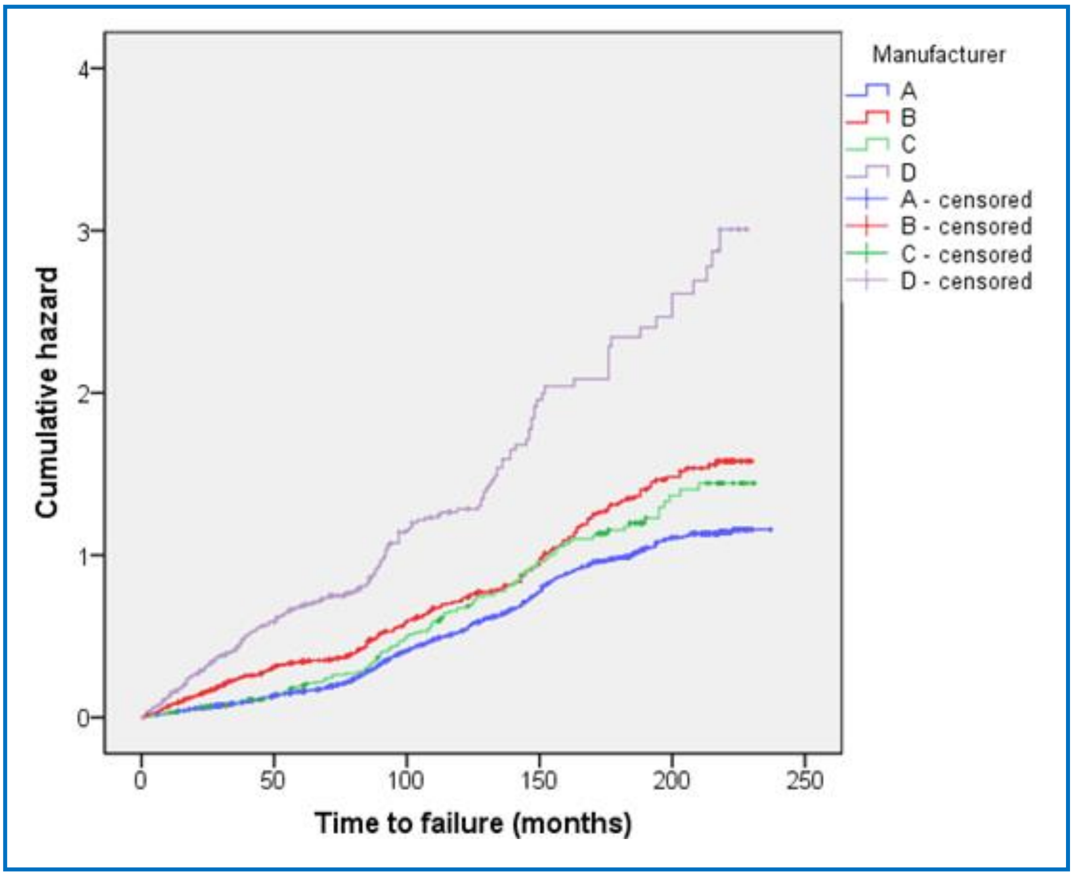


Output Files

The output is graphs and tables that are accessed from the module's visualisation component.

Figure 2 shows the cumulative hazard curves for 2,250 pumps in waste water pumping stations for four manufacturers in 800 locations based on 12 years of failure data. It consists of a series of discrete points where each point is an asset.

Figure 2



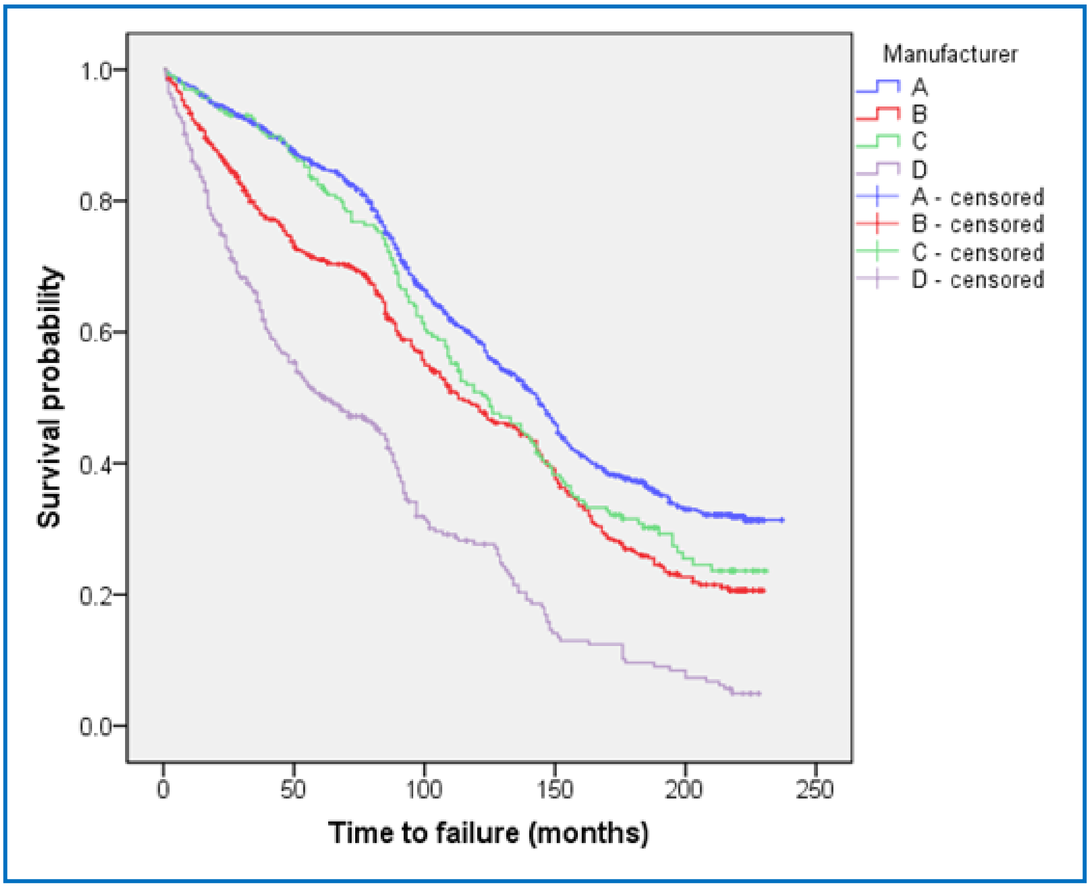
At all times pumps from manufacturer D had the highest cumulative hazards and pumps from manufacturer A had the lowest cumulative hazards, and so pumps from manufacturer A had the lowest maintenance costs. After ten years, the risk of failure of pumps from manufacturer D is about 3.25 times that of pumps from manufacturer A (1.3/0.4).

As shown in the legend, the small crosses on the graphs are censored pumps. Censored pumps are pumps that had not failed by the end of the study, and are discussed with the concept of risk sets in the appendix in *Introduction to PAM* in PAM Introduction.

In general, if first asset failures are being analysed, the time to failure is the age of the asset.

Figure 3 shows the survival probability curves for the same data.

Figure 3



At all times pumps from manufacturer D had the lowest survival probabilities and pumps from manufacturer A had the highest survival probabilities. Since survival probability and cumulative hazard are related, Figures 2 and 3 provide the same information and conclusions. Figure 3 shows that after ten years the ratio of the survival probabilities of pumps from manufacturers A and D is *not* 3.25 (the ratio of the cumulative hazards) but about 2.25 (0.63/0.28).

At very long times to failure when there are relatively few observations the cumulative hazard and survival probability plots must be interpreted with caution.

In addition to graphs of the cumulative and survival function, tables with the pumps' failure statistics and survival time statistics are produced. Table 1 shows the number of manufacturers of each type (*Total N*), the number of failures (*N of Events*) and the number of censored events (*Censored, N*).

Table 1

Manufacturer	Total N	N of Events	Censored	
			N	Percent
A	174	97	77	44.3%
B	69	42	27	39.1%
C	1352	709	643	47.6%
D	561	331	230	41.0%
E	232	144	88	37.9%
F	164	100	64	39.0%
G	352	264	88	25.0%
H	2967	1775	1192	40.2%
I	51	21	30	58.8%
J	387	279	108	27.9%
K	46	27	19	41.3%
L	56	37	19	33.9%
Overall	6411	3826	2585	40.3%

Table 2 shows the mean and median survival times and their 95 percent confidence intervals for each manufacturer.

Table 2

Means and Medians for Survival Time

Manufacturer	Mean[a]				Median			
	Estimate	Std. Error	95% Confidence Interval		Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound			Lower Bound	Upper Bound
A	136.881	5.905	125.307	148.454	130.000	7.720	114.868	145.132
B	108.105	10.685	87.163	129.047	83.000	9.816	63.761	102.239
C	146.037	2.260	141.608	150.466	143.000	3.372	136.391	149.609
D	120.385	3.593	113.343	127.427	113.000	8.223	96.882	129.118
E	133.241	5.007	123.429	143.054	124.000	8.830	106.693	141.307
F	112.145	6.572	99.263	125.027	115.000	10.250	94.910	135.090
G	124.980	3.598	117.928	132.033	116.000	6.029	104.183	127.817
H	139.375	1.425	136.581	142.169	131.000	2.569	125.965	136.035
I	160.110	15.141	130.434	189.786	163.000	49.643	65.701	260.299
J	79.504	3.745	72.163	86.845	62.000	8.381	45.573	78.427
K	153.589	9.794	134.392	172.786	152.000	13.228	126.073	177.927
L	132.074	10.031	112.414	151.735	112.000	19.616	73.553	150.447
Overall	138.193	1.239	135.766	140.621	126.000	1.728	122.614	129.386

a. Estimation is limited to the largest survival time if it is censored.

Manufacturer I has the highest mean and median survival times, and manufacturer J has the lowest mean and median survival times by a significant margin.

Failure (Hazard) Rate Curve

The literature has many studies on how the failure (hazard) rate of assets changes as assets are used. A plot of the failure rate against time is the asset deterioration curve. A common form of the curve is the well known bathtub curve, as shown in Figure 4. Its name derives from the shape of the observed failure rate curve (the blue line). Failure rate is explained in the appendix in *Introduction to PAM* in PAM Introduction (the term ‘hazard rate’ rather than ‘failure rate’ is used in the document).

Figure 4

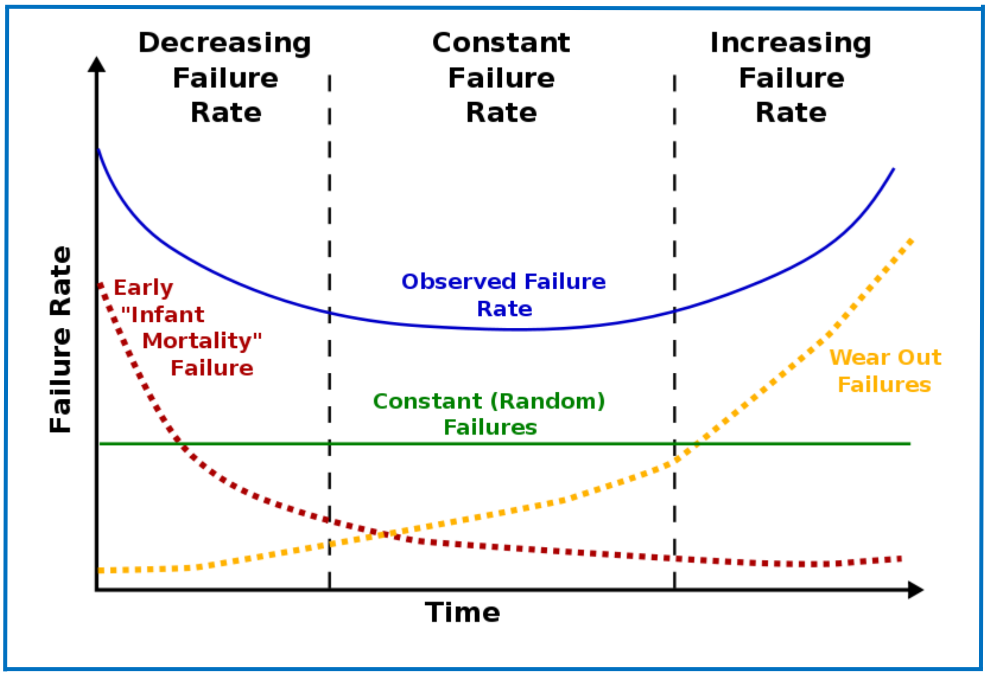


Figure 4 shows that the failure rate curve has three asset life stages (early (infant) mortality failure, constant (random) failure rate, and wear out failures) and Table 3 summarises their main features.

Table 3

Asset Life Stage	Failure Rate Characteristic	Cause
Start-up/commissioning	Decreasing	Early (infant) mortality
Normal operation (*most of the asset’s life*)	Pseudo constant	Normal operation
End of life	Increasing	Wear out

Since the failure rate curve in Figure 4 does not assume a model (distribution), it is non-parametric and derived by empirical analysis of the data. One curve is calculated for each defined group of assets, for example pumps with the same specification operating in the same environment. The profiles of different groups can then be compared to see how they perform in each life stage.

The curves assume that the assets were not maintained after installation and commissioning. If some assets were maintained to reduce their failure rates and extend their lifetimes, the curve can be generated but it cannot be interpreted meaningfully because it was formed using data from assets that were maintained and assets that were not maintained. Furthermore, the assets that were maintained were most likely maintained in different ways and at different times. In summary, it is not possible to draw valid conclusions from deterioration curves formed using data from assets operating under different conditions.

