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Barringer Process Reliability – "My factory on a page".

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Abstract

This paper describes the use of a Reliability Engineering process also known As **Barringer Process Reliability** (or BPR). It is a simple yet powerful method for senior leaders to assess and quantify the performance of their production plant with simple graphics and a few key performance numbers. It is "my factory on a single page" appropriate for busy managers in an organization. The underlying mathematical concept for BPR is the Weibull statistical distribution assuming that daily output in production plants all follow this distribution. BPR is not intended to go into the details of the losses or low production capabilities but rather remains at a high level (the 10,000ft view). However, it is still able to benchmark, quantify production losses as well as opportunities and measure quite precisely the variability in production output. This paper introduces the concept followed a variety of BPR applications in an operating environment.

1. Introduction

Barringer Process Reliability (BPR) is a process developed by Paul Barringer and is used to highlight problems in operations which, if not addressed and mitigated, could have significant revenue reduction -consequences Often the problems are identified with a root for obvious maintenance improvements and other times the problems have roots in how the asset is operated (less obvious). A BPR analysis uses the Weibull probability plot which happens to be a very well-known tool in the field of Reliability Engineering. The Weibull technique and graphics highlight important information useful to a plant operator attempting to quantify production losses and/or seeking to solve business problems. On one side of a sheet of paper only, the Weibull plot can tell the true "story" of the operation being analyzed. One-page summaries are very important for busy people—particularly senior leaders. Managers always look down on the process from a 10,000-foot level, and they see matters differently than the field worker who is at the 1-foot level. Field Workers always look up the process from a low altitude where the view can be overwhelming due to a maze of problems.

The hardest part, yet the most important part, of any reliability analysis is getting the data. However, BPR techniques use production data which is often readily available such as a refinery's daily crude input or refined products output. As it happens, production quantities are precursors for revenue, and thus restriction in output is critical for every profit driven operation. The Weibull technique aids in visualizing and quantifying business problems as the cost of unreliability of processes are important. In essence, BPR is about making businesses more efficient and more profitable.

This paper explains the concept of BPR starting with a simple sports-based example then moves into a more complex analysis of a production plant.

2. BPR simplified Example 1

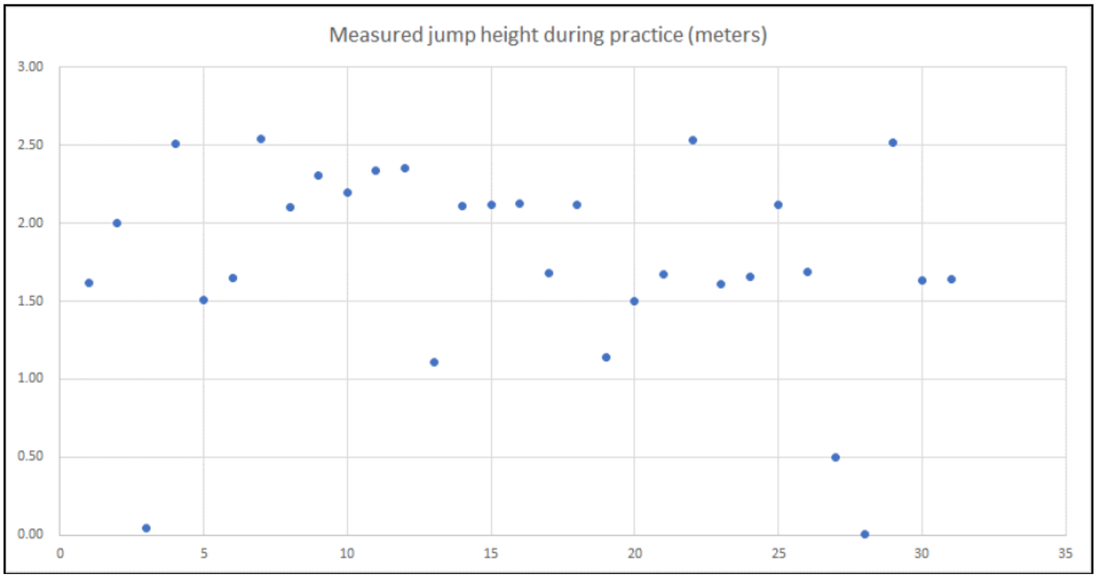
This simplified example helps illustrate the concept of Barringer Process Reliability. It relates to professional sports specifically high jump. High jump like every competitive sport, is aimed at pushing the boundaries of capability similarly to a production plant. But the athlete also must be consistent in his or her performance during practice sessions in the same way that an operation has to consistently deliver what customers need and expect.

Let us take the example of an athlete who has a jump record of 2.45m. This example assumes that the author is the athlete's coach, and that the athlete is practicing for a major competition. The athlete performs a chronological series of 31 jumps and a laser system measures a specific point on his body when he jumps. One-centimeter incremental measures are recorded at each jump as shown in the following Table 1.

Jump #	Measured jump height during practice (meters)		Jump #	Measured jump height during practice (meters)
1	1.62		17	1.68
2	2.00		18	2.12
3	0.04		19	1.14
4	2.51		20	1.50
5	1.51		21	1.67
6	1.65		22	2.53
7	2.54		23	1.61
8	2.10		24	1.66
9	2.31		25	2.12
10	2.20		26	1.69
11	2.34		27	0.50
12	2.35		28	0.00
13	1.11		29	2.52
14	2.11		30	1.63
15	2.12		31	1.64
16	2.13			

Table 1 – Practice jump records for high jump athlete (chronological)

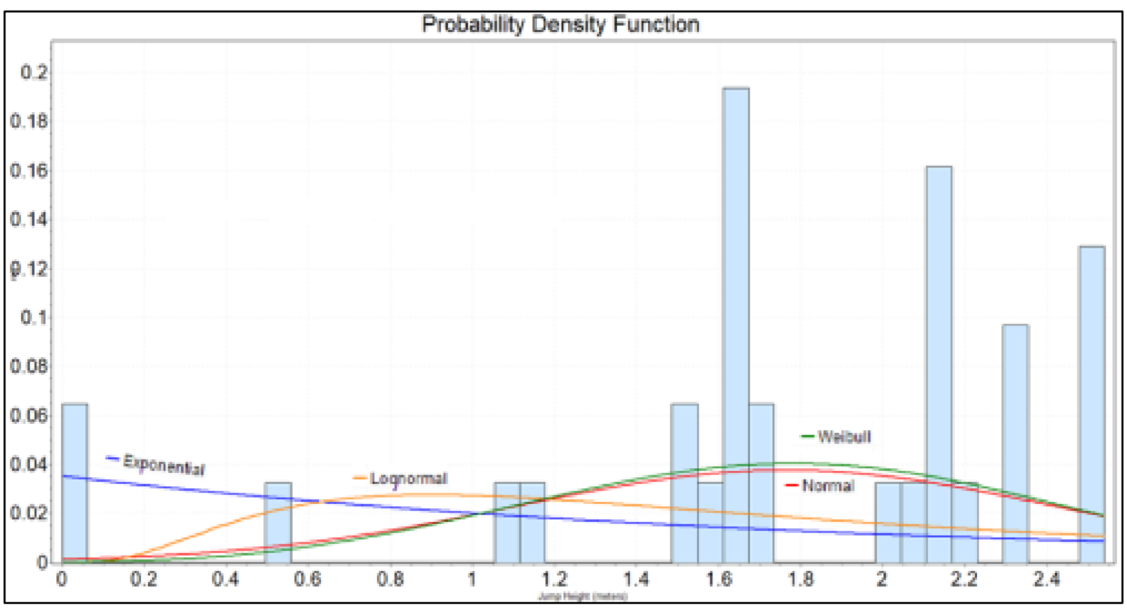
The successive jump heights are plotted in Graph 1. This graph is called a "Rainplot" graph and is handy to visualize the output of a process without initially going into complex statistics. One can observe that there is a certain amount of variability (point scatter) in successive jump heights including failed jumps. For example, jump #28 is one where the athlete might have tripped just before the bar. However, all the performance numbers good or bad, are crucial for the analysis.



Graph 1 – Practice jump Rainplot for the athlete

If the 31 points above were plotted in 4 statistical distributions commonly used in Reliability Engineering, one would obtain the Probability Density Function (PDF) graphs in Graph 2 below. PDF graphs are normalized frequency graphs. One can see visually that the Lognormal and Exponential distributions do not fit the peaks properly so are eliminated. The Weibull and Normal distributions are better fits. However, the normal distribution would provide negative values which is non-sensical in terms of jump height. In essence, the Weibull 2 Parameter distribution is chosen as the best fit for the following reasons

1. There are no negative values
2. There is a clear limit in high values which corresponds to jump height data. The athlete cannot physically jump beyond a certain limit



Graph 2 – Comparing different statistical distributions plotted with jump records for the athlete

Additionally, in terms of goodness of fit calculations, the Weibull 2P is also a better fit than the Normal distribution.

Obviously, there could be better distributions than a Weibull distribution that fit the data, but the particular advantage of this specific distribution is the ability to obtain straight lines hence simplifying the visualization of the data in a classical Cumulative Density Function (CDF) plot as shown in Diagram 1. The CDF is the integration of the PDF highlighted in Graph 2 and provides users with the probability of failure or the reliability functions. The equations related to the mathematical transformation of the Weibull CDF is provided below where Beta is the shape parameter and Eta the scale parameter in a 2 parameter Weibull distribution defined for a variable “x”.

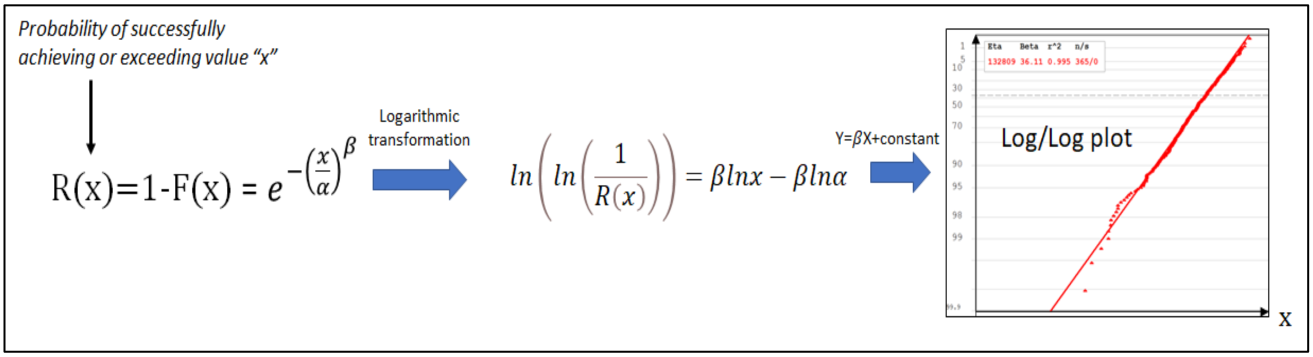
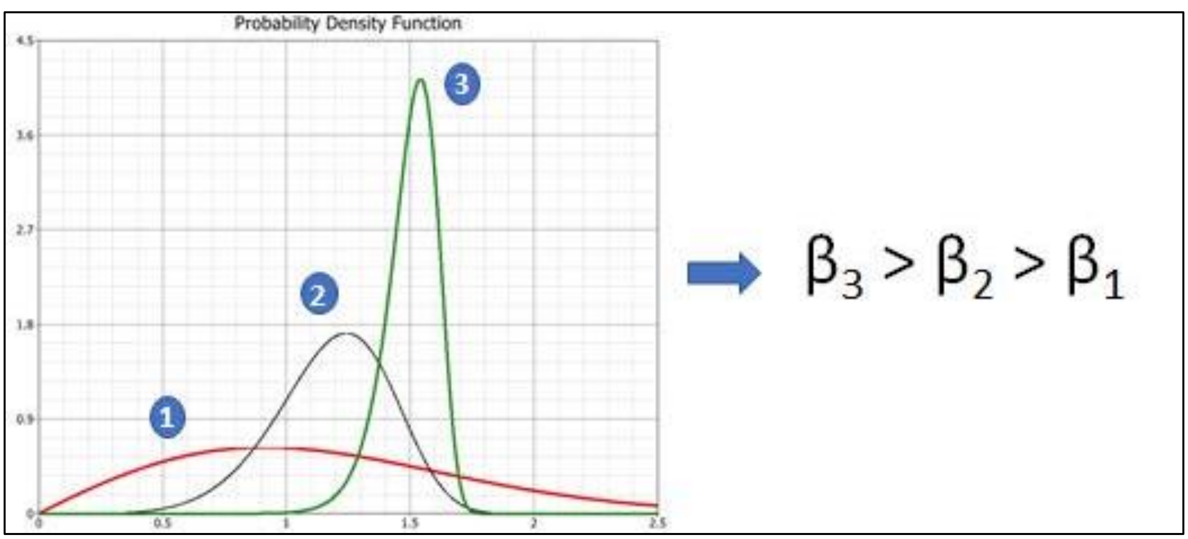


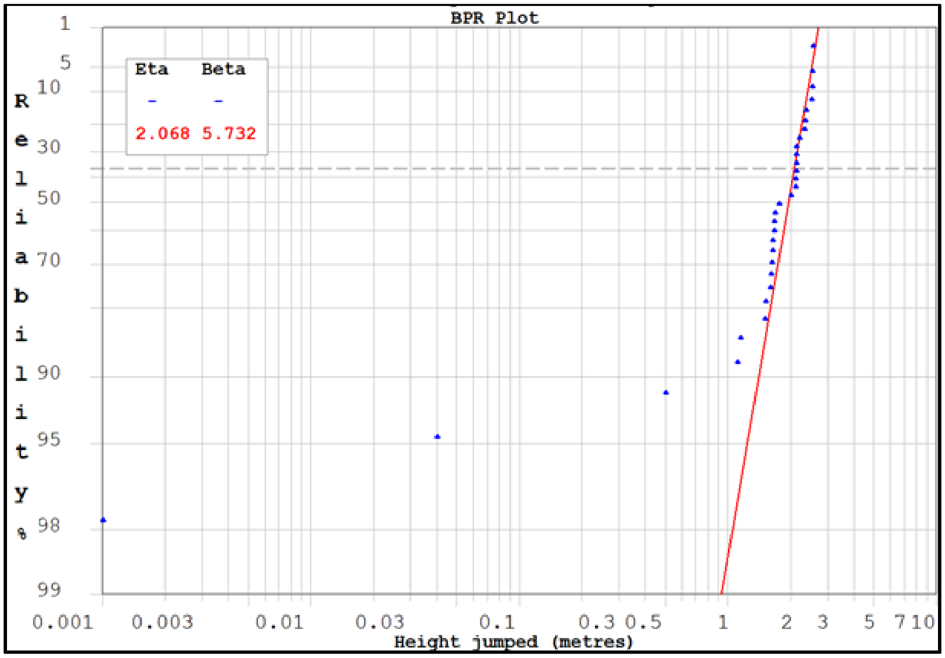
Diagram 1 – Mathematical illustration showing how to obtain a “straight line” BPR plot from the CDF Weibull function using the logarithmic transformation

Hence the CDF plot above is in a straight line, has a slope of Beta and a Characteristic Value Eta. In any Weibull distribution, for x=Eta, R(x)=36.2% hence the qualifier of characteristic value. In practical high jumps terms, Eta is the height that is achieved or exceeded 36.2% of the time by the athlete. Depending on the values of Beta, the point scatter or variability changes; the higher the beta value, the lower the variability and inversely as shown in the following Graph 3 below.



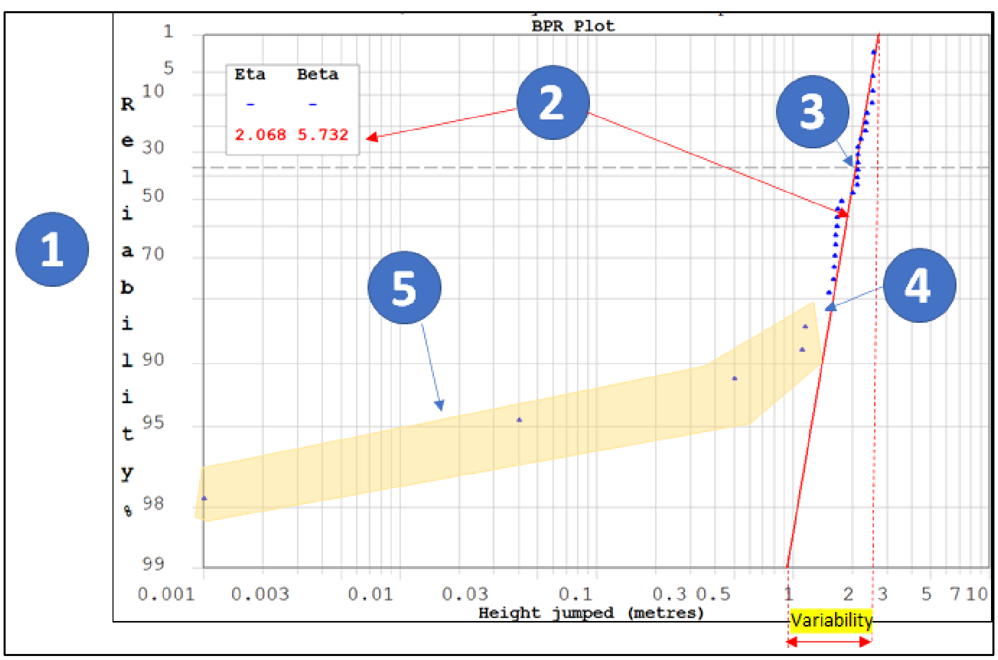
Graph 3 – Illustration of increasing Beta values and corresponding decrease in variability for Weibull distribution data sets

In the case of the athlete's jump heights, we have a BPR plot as defined below. The Supersmith-Weibull ™ software[2,3] is used for the BPR analysis. The BPR plot removes the data chronology; it sorts the 31 points from the lowest jump value (bottom left corner) to the highest value (top right corner).



Graph 4 - BPR Plot with Practice jump records for the athlete - (software Supersmith-Weibull ™)

The above graph and the information it provides, is further detailed in the following Graph 5 and subsequent paragraphs



Graph 5 - BPR Plot with practice jump records for the athlete – with highlighted section explained further below (software Supersmith-Weibull ™)

- Item 1 – this is the Reliability axis, i.e. the probability of achieving or exceeding a certain jump height.
- Item 2 – this is the line defined by a Weibull distribution (with associated Weibull distribution parameters on top left) illustrating the demonstrated capability of the jumper or the normal jump height when "all is well". However, there is some variability in this line (illustrated in yellow) which shows the range of performance. In the BPR[1] jargon, this line (Item 2) is known as the "Demonstrated Production Line".
- Item 3 – This point is the jumper's characteristic performance value based on his demonstrated capability. It corresponds to a Reliability value of 36.2% and can be used as a reference point or a benchmark. This value for the athlete's 31 jumps is 2.068m.
- Item 4 – this is the Reliability value at which the jumper's performance deviates into "poor" performance; things are not "all well" anymore. The athlete has a 84% chance of being on his demonstrated capability mode ("all well") and therefore 16% in a low performance mode. The other way to read this point is: the athlete has an 84% probability of jumping at or above a height of 1.54 meters (same as Item 1 above). In the BPR[1] jargon this line is known as the "Process Reliability" value.
- Item 5 – these are all the points where the jumper has underperformed. They stand out in the graph as moving away for the Demonstrated Capability Line (Item 2). This section is also called the "Crash and Burn" or "Reliability Loss" section[1].

Hence, using the BPR analysis, the athlete's coach can make the following deductions about his current and future performance:

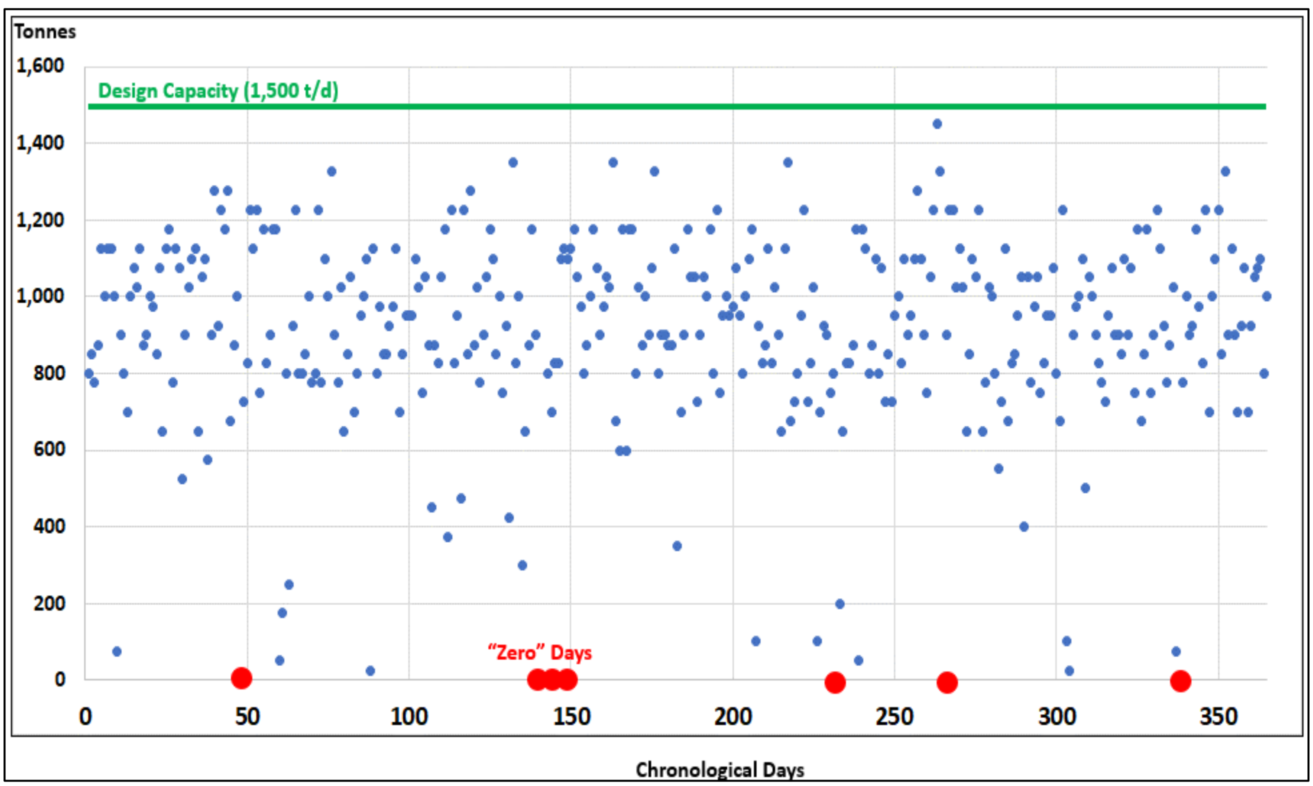
1. 84% of the time, he follows his "demonstrated" or "typical" capability.
2. 16% of the time (i.e. 100%-84% relating to section 5 above), his performance is poor; he is "unreliable" and deviates from his demonstrated capabilities. This is an area where one could consider improvements.
3. In his demonstrated capability mode, his variability can be defined with a number; Beta value = 5.732 (Graph 5 Item 2). The jump height value oscillates between 0.9 to 2.6 meters which is a rather large range.
4. His "expected" or characteristic jump height is 2.068m. This is also a benchmark metric with which other jumpers can measure themselves against the athlete.
5. The probability of the athlete breaking his own performance record of 2.45m in a competition is 7% based on his Demonstrated Capability obtained during practice jumps. This 7% is the vertical axis reliability value for x=2.45m.

The above analysis will allow the coach to understand and measure the athlete's performance as well as establish any improvement strategies. Those strategies would include:

- Investigating the cause of bad jumps and mitigating those through a Root Cause Analysis process
- Reduce variability by increasing the beta value and the slope of the Capability Line. This could be achieved through a Six Sigma Project such as reducing energy losses during the running stage (technique improvement), having improved warming up sessions or having better shoes[1]
- Increase his expected jump height by pushing the Demonstrated Capability Line to the right (e.g. Six Sigma Project in order to develop more muscular body mass)[1]

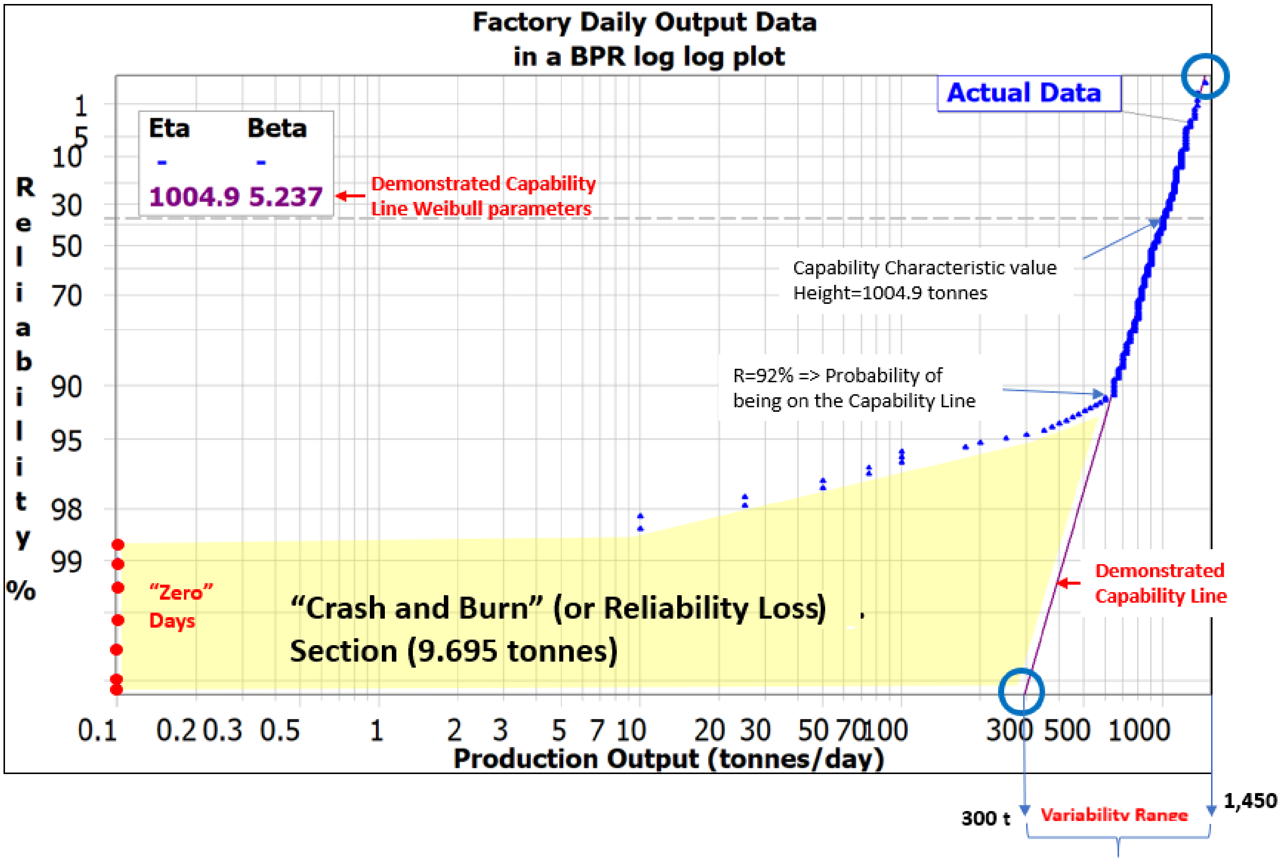
2 Factory Production Example 2

This second example is based on a factory producing mineral ore. The factory was designed to output 1,500 tonnes of ore per day. This is what is expected by the shareholders, management, and the general workforce. However, the reality for a year's production is different as shown in the Rainplot Graph 6 below. There are 7 days where production is nil ("zero days") highlighted in red in Graph 6 and based on the actual daily output scatter (blue dots) we can observe high variability in output. Ultimately, the design capacity goal is practically never achieved.



Graph 6 – Rainplot graph for factory daily chronological ore production output over 365 days (including design rates and "zero" days)

The next step is to perform a BPR analysis which will provide us with a detailed performance assessment on the factory's output in a visual and condensed (i.e. one page) format. To perform this, the 365 actual daily production data is entered in the Supersmith-Weibull ™ software leading to the visual output on Graph 7 below.



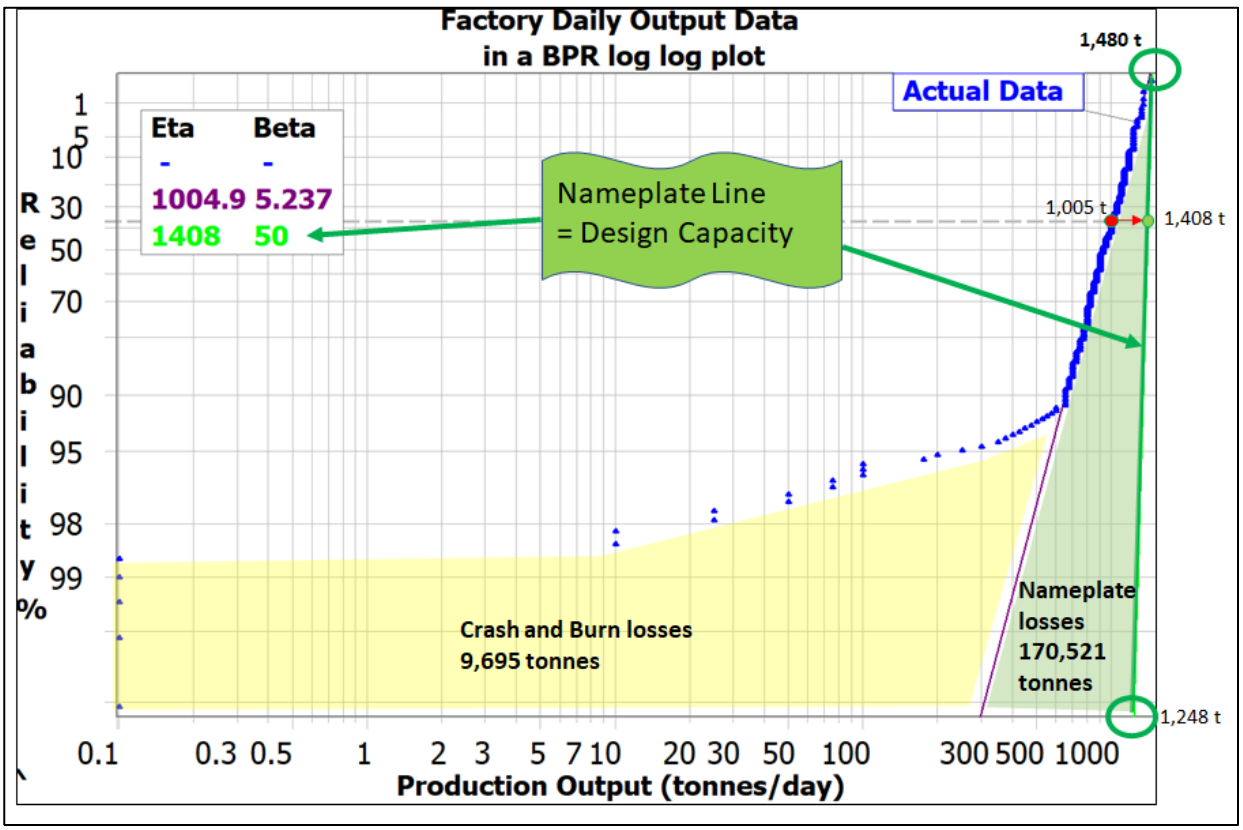
Graph 7 - BPR Plots for factory ore production output over 365 days - (software Supersmith-Weibull ™)

The Graph 7 BPR analysis provides the following information on the factory performance:

- The Characteristic capability value (Eta) is 1004.9 tonnes/day. This value 33% below the Design Rate of 1,500 tonnes/day.
- As seen in Graph 6, output variability is high corresponding to a low beta value (5.237). Low variability output in world class operations would see a beta value closer to 100. The variability range is highlighted at the bottom right and varies between 300 and 1,450 tonnes/day.
- 92% of time, the factory operates on the Capability Line.
- The Crash and Burn or Reliability Losses measured against the Capability Line, is costing this factory 9,695 tonnes for this 365-day period. This figure is obtained by performing a graphical integration in the yellow section in Graph 7. If the revenue collected from a ton of ore was \$100 then the lost revenue would be around \$1M per year.
- Zero days increase Crash and Burn losses significantly as they increase the area of the yellow section.

The variability range highlighted above (300-1,450 tonnes/day) illustrates the ability to turn a single digit performance goal into a range. Arguably this is a poor performing plant indicated by this large range of performance. This is a particular feature of BPR which provides flexibility to the operator of the plant; in other words he can operate within a range of values rather than a single binary "hit or miss" number.

Apart from highlighting the design output earlier, we have not really applied the 1,500 tonnes/day value in the BPR plot. This is done by inserting another Weibull distribution or line called, in the BPR jargon, the Nameplate Line[1]. Because this line would also be a range of numbers, we would have to define it so that it incorporates the 1,500 tonnes/day value knowing that 1,500 tonnes/day is the maximum value. On top of achieving this value, the key stakeholders running the factory would assume that variability at the desired high performance level is lower hence beta higher and closer to 100 (100 being world class). In this case as shown in Graph 8 below, the Reliability Engineer and Management choose a Nameplate Line closely representing production expectations and having the following parameters: Beta = 50 and Eta=1,408 tonnes/day.



Graph 8 - BPR Plots for factory ore production output over 365 days with Nameplate Line - (software Supersmith-Weibull ™)

The Graph 8 BPR analysis provides the following information on the factory performance listed as follows:

- The Nameplate Line (or design goal) is as mentioned, drawn to accommodate the 1,500 tonnes/day marker or close enough. As shown in Graph 8, it ranges from 1,248 to 1,480 tonnes/day. Notice that this range is much narrower than the Capability Line range.

- Lining up with the previous comment, the Nameplate Variability factor is 10 times higher (50)
- The Nameplate Characteristic value advances by ~40% (from 1,005 to 1,408 tonnes/day).
- In terms of losses, the Nameplate losses amount to 170,521 tonnes for the 365 days. This is the graphical integration or the area between the Capability Line and the Nameplate Line (green in Graph 8). It is a very high number indicating the stretch required to get to the design goal from where we stand with the current Capability Line. It is a large number to recover and might not be realistic in one go.
- Nameplate losses are much higher than Crash and Burn Losses; about 17 times higher; it is the dominant loss category.

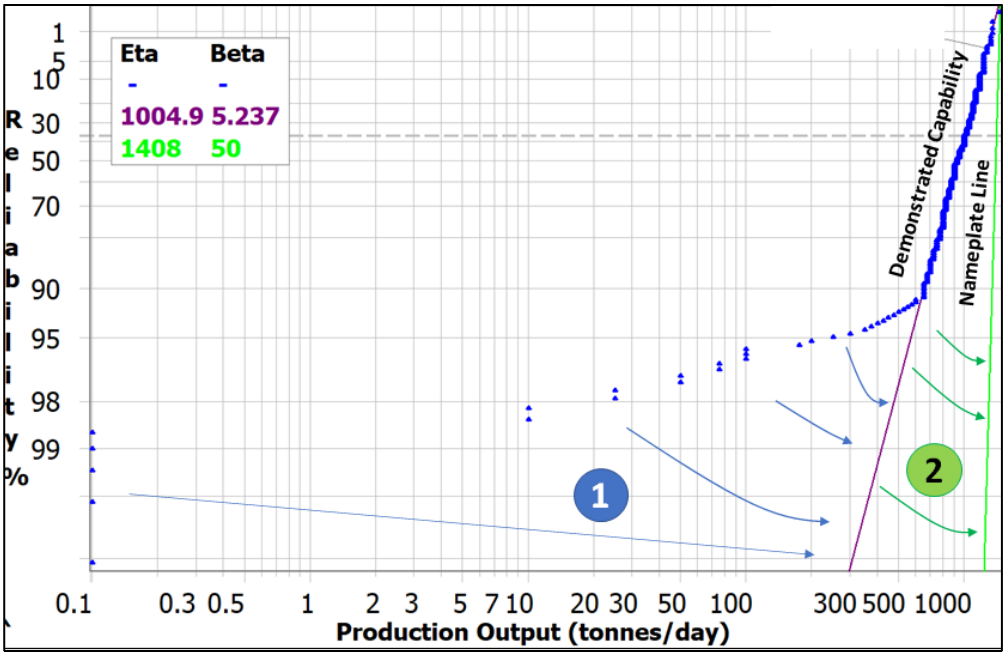
As now shown in Graph 8, BPR allows us to highlight two types of losses: Crash and Burn losses related to the Demonstrated Capability Line and what is known as “Efficiency and Utilization” losses in the BPR jargon[1], related to the Nameplate Line. A non exhaustive set of examples highlighting these types of losses are characterized as follows:

- Crash and Burn losses:
  - Equipment or instrumentation failures leading to long maintenance downtime.
  - High impact events such as fires, explosions or power failures.

The Crash and Burn losses are addressed through Root Cause Analysis exercises and correction of identified issues.

- Efficiency and Utilization losses:
  - Efficiency losses such as bottlenecks, late starts, set up time, inefficient work practices, low quality products.
  - Utilization Losses such as lack of feedstock, chronic short trips requiring resets.

Efficiency and Utilization losses manifest as more subtle and chronic events hence are more difficult to fix as compared to Crash and Burn losses. Those losses are best addressed though Six Sigma[1] projects. It is suggested to start fixing relatively easier Crash and Burn losses first followed by more complex Efficiency and Utilization losses; a bit like “eating the elephant in small bits” approach. This stepwise approach is illustrated in Graph 9 below where in the first step we try and “align” as much as possible the Crash and Burn points onto the Demonstrated Capability Line.

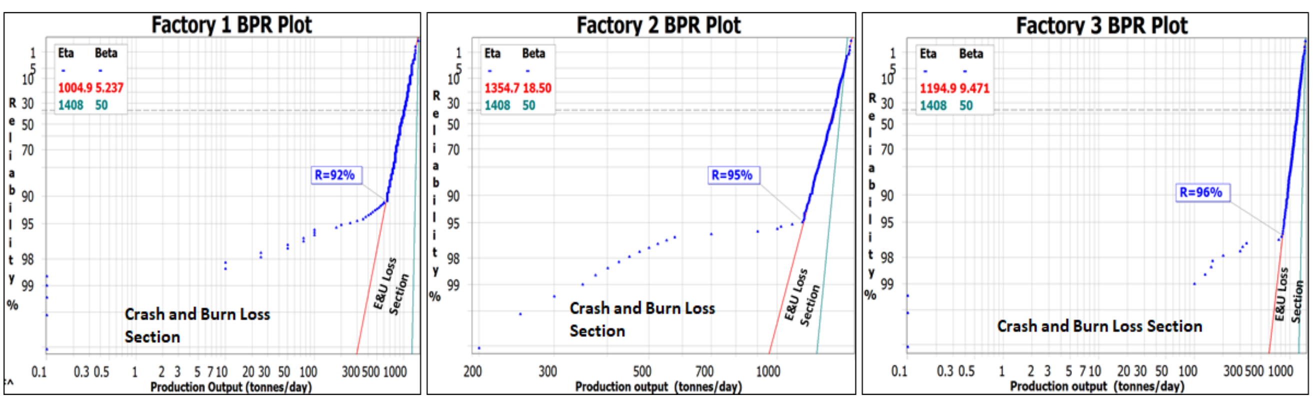


Graph 9 - BPR Plots illustrating the recommended the 2 successive step approach to addressing the Crash and Burn and Efficiency and Utilization losses - (software Supersmith-Weibull ™)

Examples of Six Sigma approaches to solving Efficiency and Utilization losses would be Production Debottlenecking, Lean Manufacturing, or Kaizen iterative approaches.

3 Example 3 – Benchmarking identical factories

This example looks at comparing 3 identical factories in the ore producing corporation which happen to have different output performance results. Factory #1 is the same one highlighted in Example 2. Each individual BPR analysis for the 3 factories is provided in Graph 10 below.



Graph 10 – Comparative BPR plots for the 3-factory output (software Supersmith-Weibull ™)

The BPR analytical output values are summarized in Table 2 below. It appears that Factory 2 has the best performance amongst the 3 showing lower losses and lower variability. However, Factory 2's performance is still far from the nameplate values. Nevertheless, since all the factories are identical, the other two factories could use the learnings from Factory 2 to enhance their capabilities. In other words, Factory 2 could be an intermediate benchmark for the two others. If Factory 1 and 3 can match the performance of Factory 2, this could lead to a $20M annual revenue increase for the corporation. Alternatively, Factory 2's Demonstrated Capability could be an intermediate Nameplate goal for all three factories.

BPR Output	Factory 1	Factory 2	Factory 3
Capability Line Beta	5.24	18.50	9.47
Capability Line Eta (tonnes/day)	1,004.90	1,354.70	1,194.90
Nameplate Line Beta	50.00		
NameplateLine Eta (tonnes/day)	1408.00		
C&B losses (tonnes)	9,695.00	9,761.00	6,688.00
E&U Losses (tonnes)	170,521.00	27,776.00	94,202.00
Total Losses (tonnes)	180,216.00	37,537.00	100,890.00
Total loss revenue at $100 per ton	$ 18,021,600	$ 3,753,700	$ 10,089,000

Table 2 – Comparative BPR output summary for the 3 factories

Conclusion

Paul Barringer quoted the following: "The ultimate aim of a business is satisfying customers with on time deliveries of quality products whilst producing satisfactory long term returns for the shareholders." His BPR process is a robust tool that allows reliability professionals to analyze, quantify and benchmark the performance of an operation at a high level using readily available production output data. From it, KPIs, such as Capability or Variability, can better reflect the nature of a production output, and lead to more efficient application of resolution methods such as RCAs or Six Sigma. Visualizations of performance are concise and provide meaningful insights to allow senior leaders to sponsor improvement in their production that ultimately drives the shareholder value Paul Barringer spoke of.

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APPENDIX DOCUMENTS

Acknowledgement

H.Paul Barringer P.E. (1936-2016)

The BPR process was created and proliferated in industry by Paul Barringer. Paul stands amongst the greatest Reliability Engineers and has contributed immensely to advancement of this science let alone teaching and mentoring countless practicing Reliability Engineers such as the author of this paper.

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3 – Supersmith Weibull software screenshot