Process Stability and Predictability for Non-Normal Response Data

By Forrest Breyfogle, III

Smarter Solutions, Inc.
Founder and CEO

The high level goal of business should be the creation of **M**ore **C**ustomers and **C**ash. An organization's **E**xistence and **E**xcellence depend upon it! Similar to Albert Einstein's famous equation we can express this business need as $E=MC^2$.

Management by hope does not lead to MC^2. To achieve MC^2, organizations need to orchestrate activities so that everybody is doing the right thing at the right time. If meaningful measures are not identified and monitored appropriately, management will not know if it is doing the right things correctly. Behavior is driven not only by what is measured but also by how the measurements are tracked and reported. Organizations need measurements that lead to the orchestration of activities that align with achieving MC^2.

The Smarter Six Sigma Solutions (S^4) or Integrated Enterprise Excellence (IEE) system described in this paper focuses on creating MC^2, which results when organization take Lean Six Sigma and the Balanced Scorecard to its next level. The illustrative example shows the application of S^4/IEE techniques to non-normal response data.

TRADITIONAL PERFORMANCE MEASURES

Have you seen charts like Figure 1? Most of us have. Consider what kind of presentation dialog typically accompanies this type of charting.

Performance Measure	FY 2001 Actual	FY 2002 Actual	FY 2003 Actual	FY 2003 Amended	FY 2004 Amended
Percentage of customers satisfied with dispatch staff	99.99%	100%	99.99%	98%	98%
Percentage of priority one calls dispatched to field crews within 30 minutes of receipt	99.99%	99%	99.99%	95%	95%
Labor cost per customer call taken in Dispatch Operations	$4.20	$5.31	$5.09	$4.88	$5.09
Number of calls taken through Dispatch Operations	62,054	59,828	63,046	60,000	60,000
Number of priority one calls dispatched to field crews	5,797	4,828	6,686	5,000	6,500
Number of work orders and component parts (segments) created in database	8,226	4,724	7,742	5,500	6,700

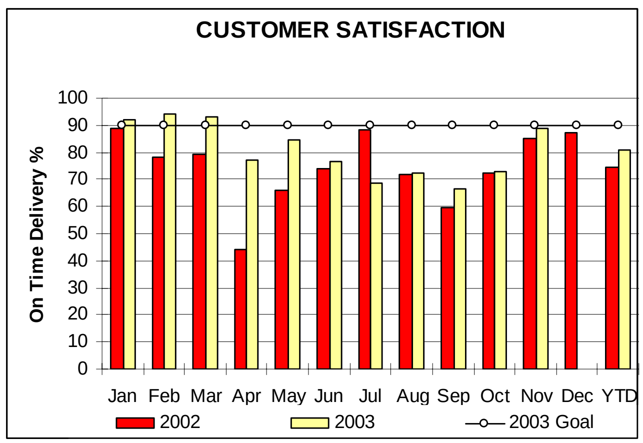
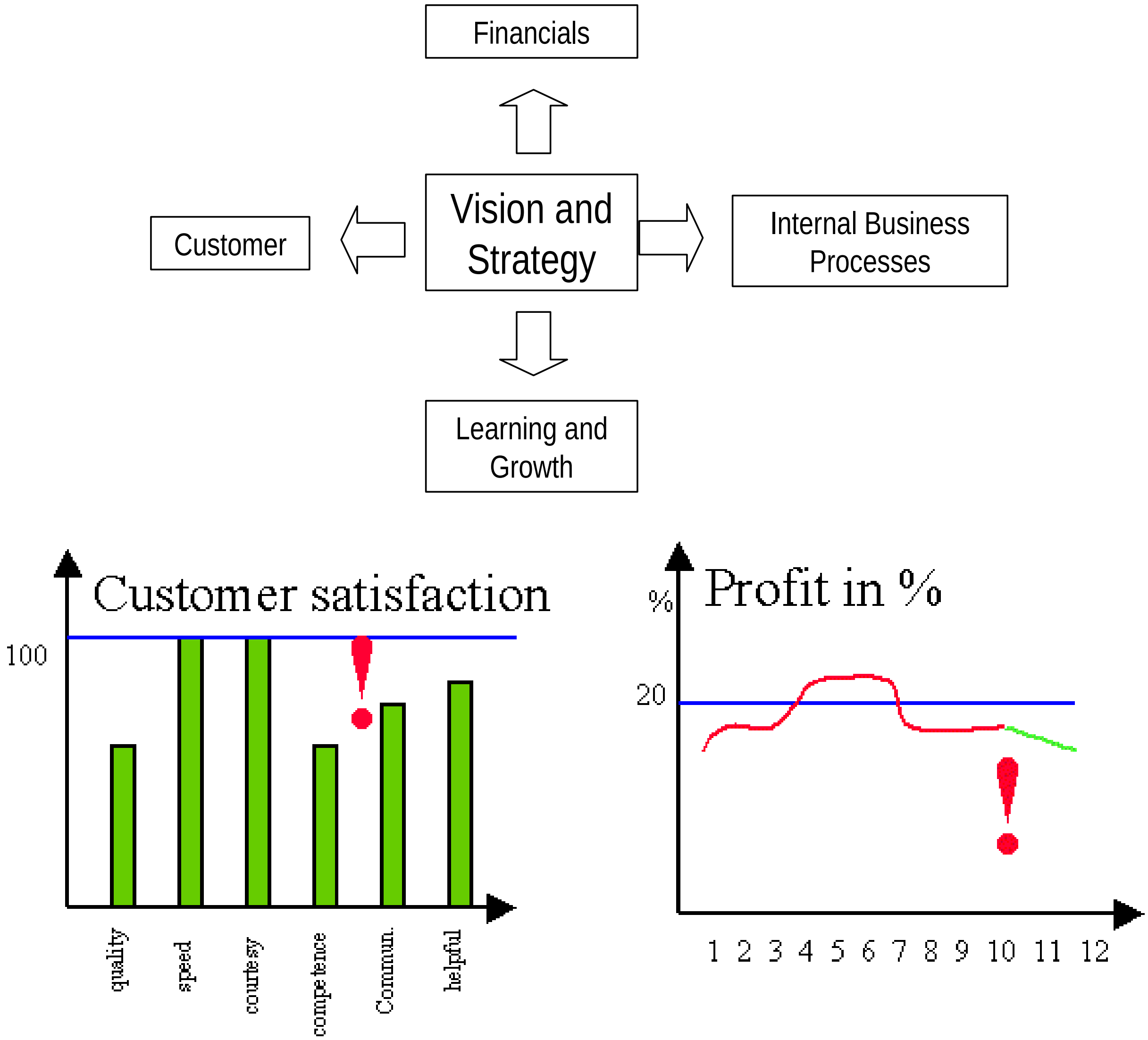


Figure 1

It is a good bet that the presentation of the charts in Figure 1 would lead to stories describing what caused up and down chart movements.

Another common approach to management and improvement is to create a balanced scorecard[1], as illustrated in Figure 2.



Reference (2004): http://www.emeraldhillsstrategy.com/dashboard.html

Figure 2

In the balanced scorecard approach, metrics are aligned with the organization's vision and mission and have balance across the areas of financials, customer, internal business processes, and learning and growth. For this approach, each metric category must have objectives, measures, targets, and initiatives. When targets are not met, a red flag (exclamation points in the figure) triggers action toward bring the metric back on target.

If we view a process as having an output, Y, which is a function of x; i.e. Y=f(x), we can say that a balanced scorecard approach manages the business through the Ys of processes.

The drive to meet Y objectives throughout the organization can create unintended issues, such as process sub-optimization at the detriment of long-term enterprise health. For example, Krispy Kreme shipped donuts that the company knew would be returned in order to meet short-term financial objectives. Another illustration is Enron, which ended up doing things that had severe legal issues when it managed solely to achieve its "Y" objectives.

Often traditional performance metrics:

- Reflect only fiscal quarterly/yearly metrics
- Don't have a procedure for improving the process so that gains occur and are maintained in the future
- Make current metric response comparisons to a point estimate from a previous month or year
- Attempt to manage the business through the "Ys" of the business, as opposed to striving for long-lasting improvements that are a result of making fundamental changes to the key "xs" that drive the business

These traditional methods do not view the enterprise as a system of processes filled with variability. Performance metrics are a result of these processes, along with the variability that occurs within these processes. Long-lasting, positive change results only from systematic improvement in these processes.

SEPARATING SPECIAL CAUSE FROM COMMON CAUSE

Walter Shewhart's traditional control charting techniques focus on the identification of assignable causes. However, Edwards Deming notes:[2] "We shall speak of faults of the system as common causes of trouble, and faults from fleeting events as special causes."

From these authoritative descriptions, we could paraphrase their conclusions as:

- Shewhart: A special cause is an assignable cause that could be internal or external to the system.
- Deming: A special cause is a fleeting event experienced by the system

There is a fundamental difference between "assignable causes" and "fleeting events." Because of this, the control charting terms "common cause" and "special cause" variability can lead to different interpretations and action plans. The S^4/IEE system creates control charts that identify special cause conditions, which are consistent with Deming's description.

Within S^4/IEE, the implementation of Deming's common/special-cause identification system is accomplished using an infrequent subgrouping/sampling plan. With this approach, a subgrouping interval is chosen so that the normal variability from input variables that could affect the response will occur between subgroupings. For example, any differences between working shifts, raw material lots, departments, and/or machines that affect our output variable level would be considered as originating from common cause variability. This list of variables might lead us to a daily subgrouping interval, where the data within each subgroup interval would be a randomly-selected datum point or a compilation of data. We then need to create a control chart strategy so that the magnitude of the between-subgroup variability affects the lower control limit (LCL) and upper control limit (UCL) calculations.

The individuals chart (X) is a very useful tool to accomplish this. Unlike an $\bar{x}$ and R chart, an individuals chart (X) has control limits that are a function of between subgroup variability[7]. For X charts, UCL and LCL are usually calculated from the relationships

$$\text{UCL} = \bar{x} + 2.66(\overline{\text{MR}}) \qquad \text{LCL} = \bar{x} - 2.66(\overline{\text{MR}})$$

where $\overline{MR}$ is the average moving range between adjacent subgroups.

The individuals chart works well when the underlying distribution from which the sample is taken is normal; however, the individuals chart is not robust to non-normality[6]. In the real world, non-normal conditions occur frequently. One example of a non-normal condition is when there is, or tends to be, a natural boundary condition; e.g., zero or some boundary close to zero. For this situation, an untransformed data control chart can cause false signals, and common-cause variability can appear as special cause. When this occurs, we can circumvent this charting limitation by transforming the data.

HIGH-LEVEL 30,000-FOOT-LEVEL METRIC

The 30,000-foot-level control chart is a S^4/IEE methodology that quantifies what the customer of a process is experiencing. This control chart tracks the output of a process at a high level and is not intended to be used to determine if and when timely process input adjustments should be made.

For example, a 30,000-foot-level metric might address the overall customer experience of time spent during checkout at a grocery store. A store would use a more frequent tracking and adjustment mechanism in order to adjust checker coverage during natural peak and valley demand periods. How well this input adjustment is managed can dramatically impact both the customer experience and the company's profitability. The 30,000-foot-level chart tracks the impact that this and other process inputs have on a response output.

For a 30,000-foot-level control chart, we do not simply monitor data over an arbitrary recent period of time; e.g., last 3 months, 6 months, 12 months, etc. We would like to present data on the control chart for a period at least since the process' last shift, which could extend for several years. When 30,000-foot-level control chart is in control or stable, we can say that the process is predictable. This prediction statement could be for the complete time period of the control chart or the last 6 weeks, if that is when a process shift was demonstrated.

If the process is predictable, a process prediction statement can be made based on the assumption that nothing changes, either positively or negatively, in the system. Within S^4/IEE, this prediction statement is in a straight forward, easily understood format. We should note that if the prediction statement ends up being undesirable, we then work to shift the process to the better by creating an S^4/IEE project. This strategy uses a 30,000-foot-level metric to pull (a Lean term) a project into creation.

In references 3, 4, and 5, I describe a traditional and a 30,000-foot-level procedure for creating control charts and making process capability/performance assessments for a continuous, pass/fail, and count data. In this article, I will extend the 30,000-foot-level control charting and process capability/performance assessment to non-normal data that has a sub-grouping size of one.

EXAMPLE: DAYS SALES OUTSTANDING

The prompt payment of invoices is important to a company. Consider that the days sales outstanding (DSO) metric, which tracks prompt invoice payment for this company, follows the underlying distribution shown in Figure 1.

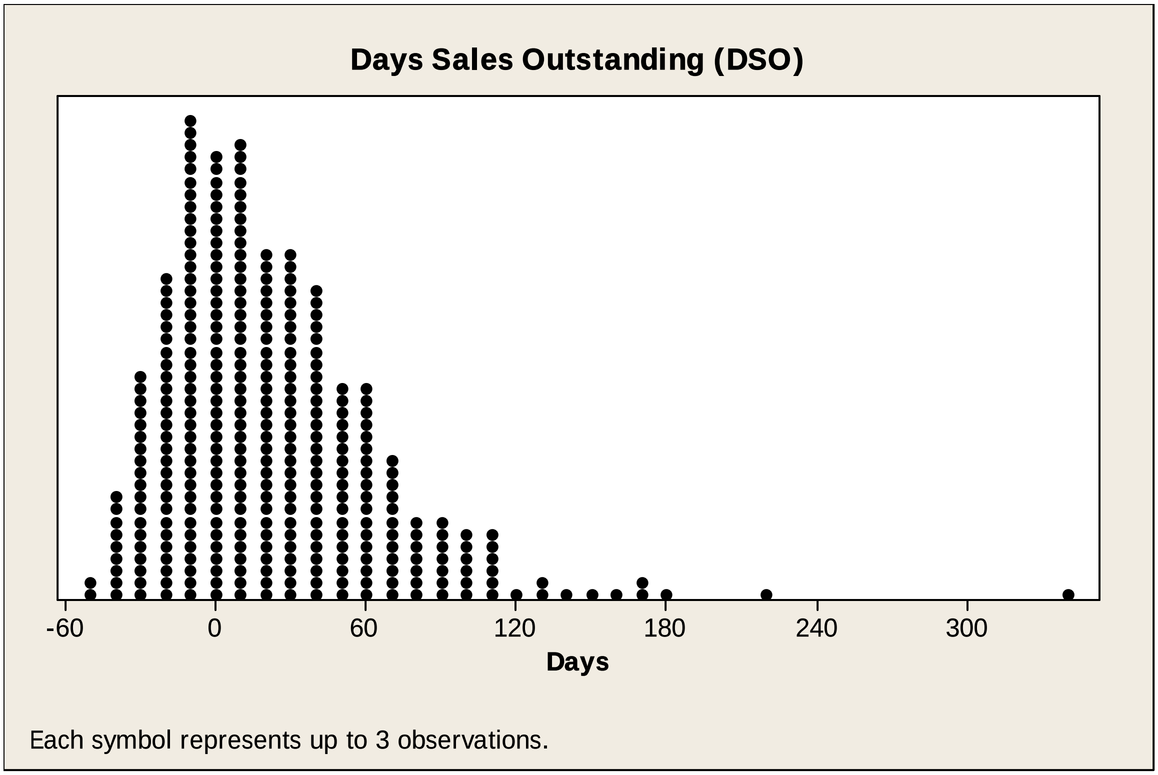


Figure 1

This randomly generated data from a 3-parameter log-normal distribution is to simulate a real situation, where 0 days represent the situation where a payment was received precisely on its due date. By simple observation, we note that this distribution does not have a bell-shaped curve appearance where tails extend equally on both sides of its median value and approach a theoretically infinite value. This distribution has a long tail to the right.

The difference in invoice payment durations, which affects the spread of this distribution, could originate from differences in payment practices between the companies invoiced, invoice amounts (larger invoice amounts may take longer to get paid), day of the week invoiced, invoicing department, etc. With the S^4/IEE methodology, any impact by these input variables on payment duration is considered a source for common cause variability.

Consider that over time nothing has changed within this process. We want next to simulate what might be expected if we were to track a process sample over time. In reference 3, I considered multiple subgroup continuous-response samples. For this paper, we will simulate what might be expected if only one paid invoice were randomly selected weekly; i.e., consider that only one sample per subgroup was collected, since it is hard to collect the data. Relative to the decision for weekly versus more frequent sub-grouping, we decided not to have a daily sub-grouping since we thought that there might be a difference by day of the week; hence, the decision to select weekly sub-grouping. An individuals control chart plot of one randomly selected weekly payment duration is shown in Figure 2.

Since these data are randomly selected, we would expect that the control chart would have a random scatter within the upper and lower control chart boundaries. This chart doesn't have this appearance. The data in this chart seem to exhibit a lower boundary condition about -25 days. In addition, although through chance we could experience an out-of-control condition for this random data, we would not expect to experience this with only 35 tracked sub-groupings.

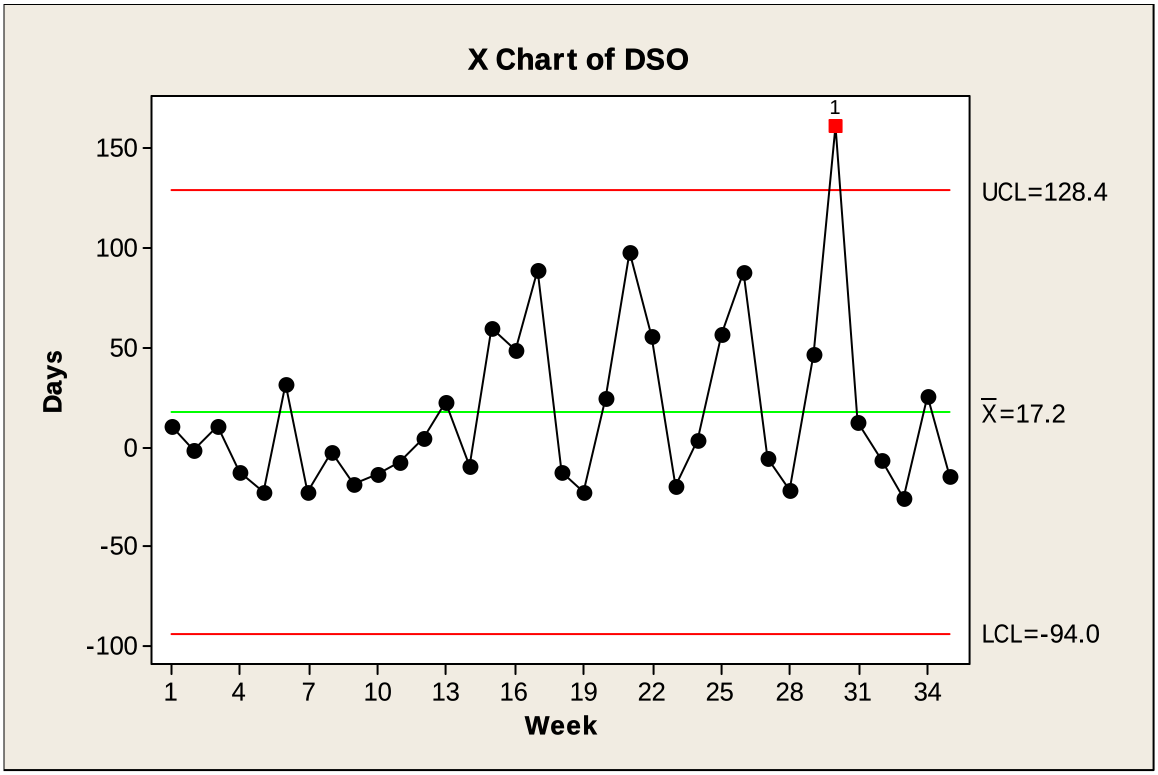


Figure 2

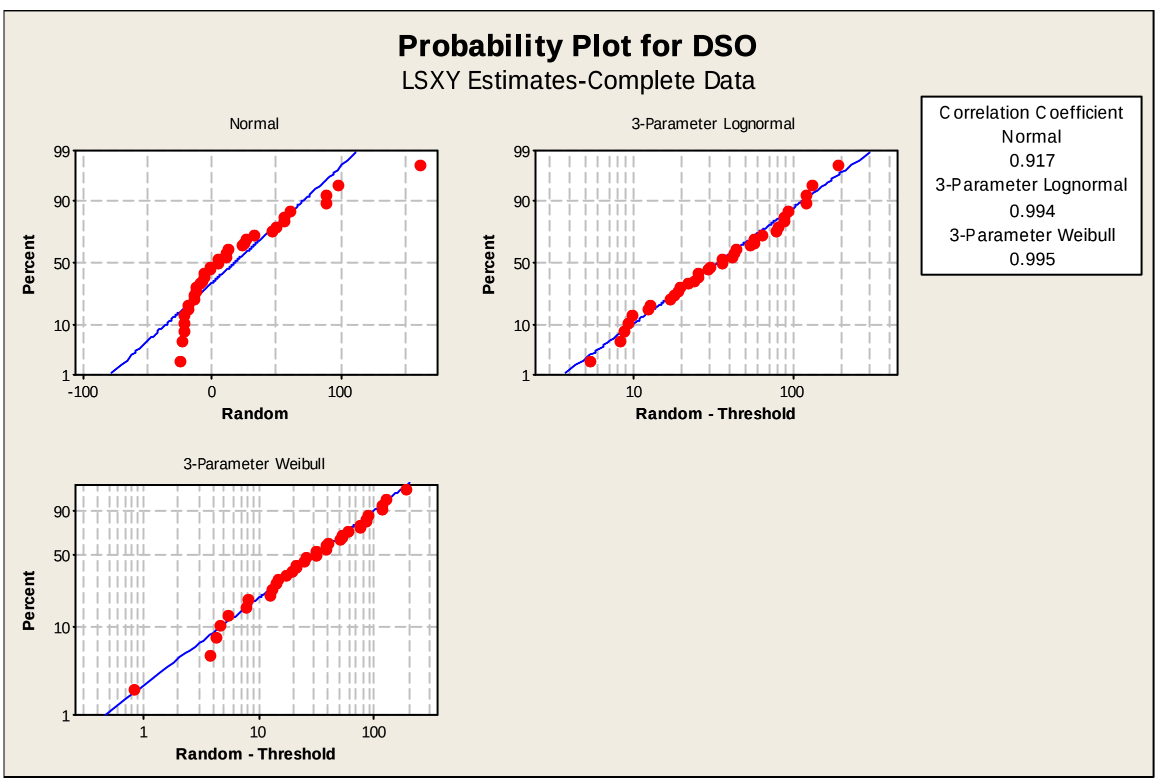


Figure 3

The X chart is not robust to non-normal data[6]; therefore, for some situations such as this one, data need to be transformed when creating the control chart.

As we can see in Figure 3, the normal distribution does not fit well. Both the 3-parameter Weibull and 3-parameter lognormal distribution fit well, where the 2-parameter lognormal and Weibull distributions could not be considered since these distributions cannot accept negative values.

I prefer the Weibull distribution, in general, for reliability analyses and the lognormal for transactional situations. Because of this, I will use the lognormal distribution for the further computations. Using the estimated parameters of a 3-parameter lognormal distribution, a data transformation plot yielded the individuals chart shown in Figure 4.

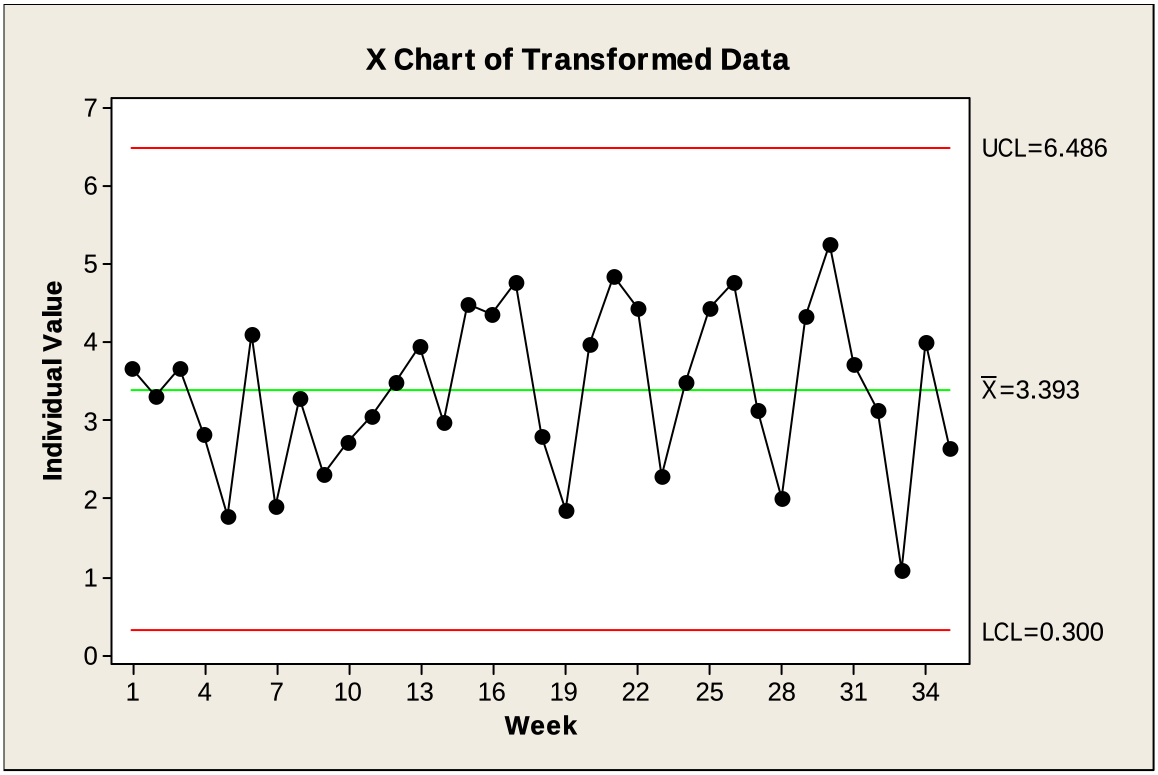


Figure 4

This transformed individuals plot indicates that the process is predictable. The next appropriate question to answer is: What is predicted?

Traditional six sigma process capability units such as C_p, C_{pk}, P_p, P_{pk} and sigma quality level require the input of a specification, which often does not exist in most transactional environments. In addition, these units can cause much confusion even if a specification does exist. I prefer to answer this prediction question in terms that everybody understands. I reference this form of reporting as "process capability/performance metric[7]."

We could simply estimate from a probability plot the reported percentage that is not paid on time or beyond a certain number of days late. However, this form of reporting does not give us a picture of the amount of variability that exists within the current process. A median response value with an 80% frequency of occurrence gives us a much more descriptive picture of the expectations from our process, which is easy to understand from the CEO to the line operator level.

From Figure 5 we note that the 3-parameter lognormal distribution fits well. From Figure 6, which does not consider the 3-parameter threshold adjustment, we estimate the process capability/performance metric to be a median of 0.7 days with an 80% frequency of occurrence of -20.9 days to 78.8 days.

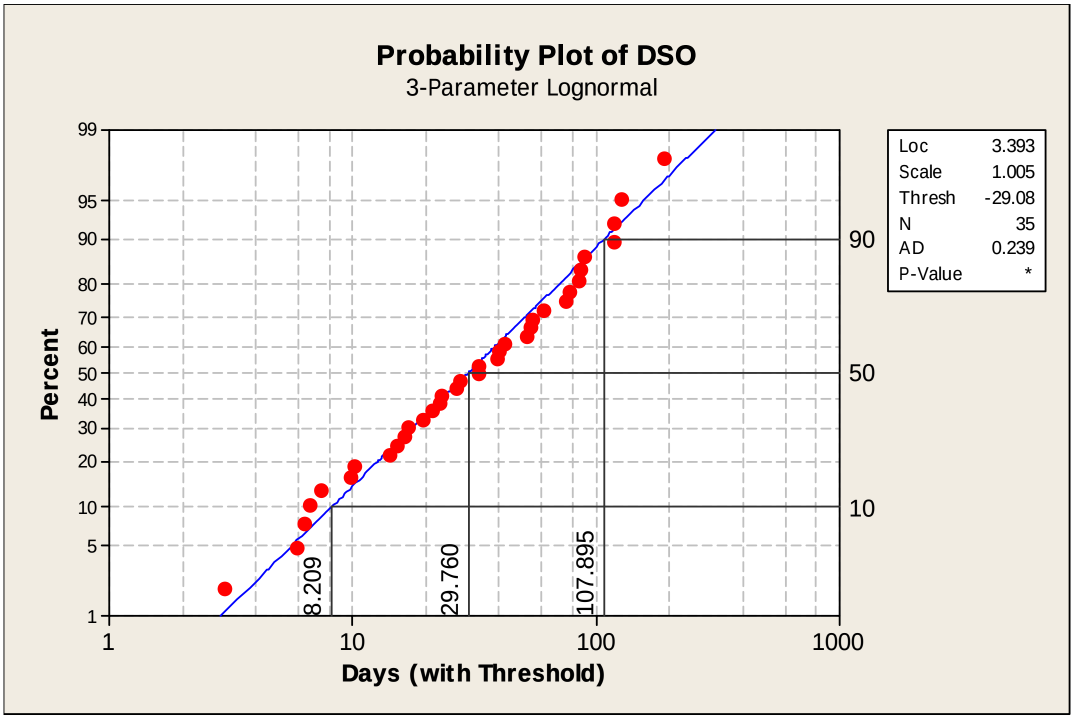


Figure 5

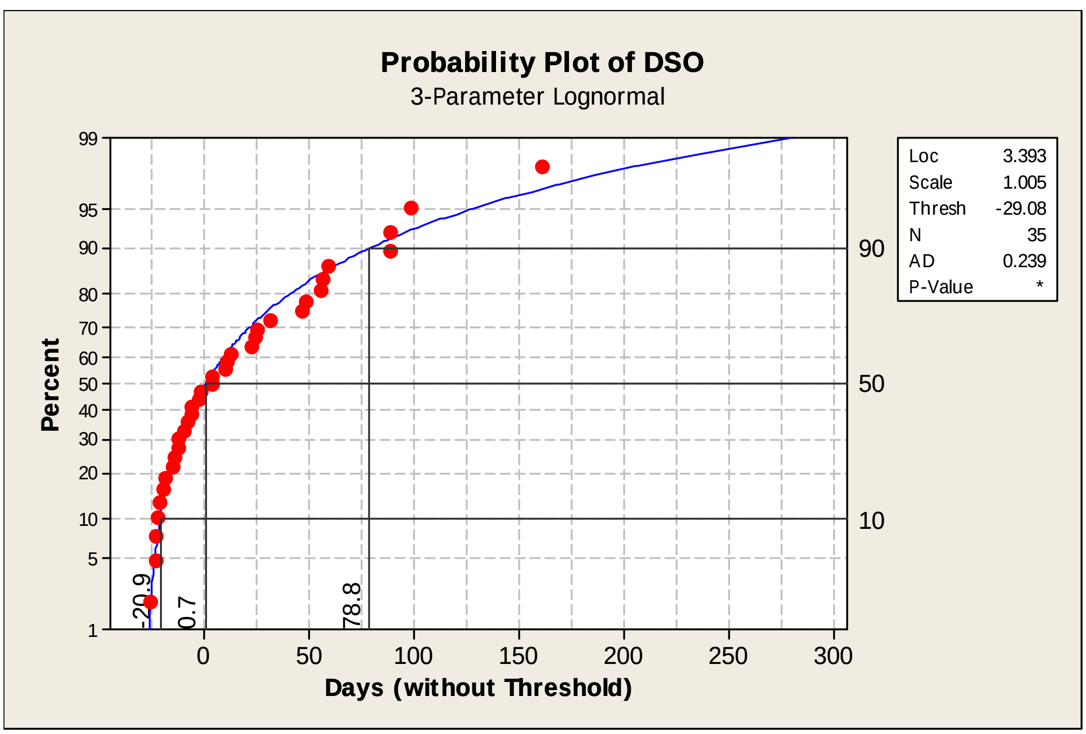


Figure 6

S^4/IEE PROJECT SELECTION

Typically, organizations evaluate the success of their Six Sigma deployment as the collective financial benefit from project completions, where projects are “pushed” for creation; e.g., brainstorm for projects and rank these projects to see which projects to work on first. However, when we step back to the collective enterprise view, we do not often see the benefits of these project financial benefits within the overall organization’s ROI or profit margins. With a Six Sigma push-for-project-creation system, organizations could even be sub-optimizing processes to the detriment of the overall enterprise[8].

Within S^4/IEE, the collective examination of responses from an organization’s 30,000-foot-level metrics, along with an enterprise analysis, can provide insight into which metrics need improvement. This approach best ensures that the overall enterprise ROI and profit margins benefit from project completion. That is, enterprise metric improvement needs provide a pull system for S^4/IEE project creation.

SUMMARY

Business existence and excellence (E) depend on more customers and cash (MC^2). The previously described S^4/IEE system focuses on $E = MC^2$ for enterprise management and project selection, including the tracking of 30,000-foot-level metrics that are not normally distributed with negative response data.

Within S^4/IEE, operational high level metrics at the enterprise level pull (used as a lean term) for the creation of projects. These projects can then follow a refined define-measure-analyze-improve-control (DMAIC) roadmap[7] that includes lean tools for process improvement or a define-measure-analyze-design-verify (DMADV) roadmap for product or process design needs.

REFERENCES

Minitab 14 was used for all statistical analyses.

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AUTHOR

Forrest Breyfogle III is founder and CEO of Smarter Solutions Inc. (www.SmarterSolutions.com) in Austin, TX. He earned a master's degree in mechanical engineering from the University of Texas-Austin. Breyfogle is the author of *Implementing Six Sigma*, co-author of *Managing Six Sigma*, and the author/co-author of five other books on topics that take Lean Six Sigma and the Balanced Scorecard to its next level. Breyfogle received the 2004 Crosby Medal for his book, *Implementing Six Sigma*, and is an ASQ fellow.