Charting Safety Performance

Combining statistical tools provides quality data

By Steven S. Prevette

STATISTICS AND INJURY RATE CALCULATIONS can be the source of many problems. It is not usually the numbers that cause difficulties, but how those numbers are used. The first item on the agenda of a typical safety meeting is a laundry list of last month's injuries and everything being done to prevent their recurrence. The next month, the same things happen again and a completely new list of preventive strategies is generated. Each month managers and SH&E professionals react to the latest results, and incorporate new and ever-different fixes. In these situations, the numbers are driving the actions, rather than the actions driving the numbers. Wheeler refers to this behavior as "numerical illiteracy" (Wheeler).

This article describes how to make the numbers work for the company, instead of the company working for the numbers. To do this, one must look at the ways numbers have been commonly viewed, and contrast that view with an alternate, statistically credible way to look at numbers. Statistical process control (SPC) and control charts have long been used in industry for trending operational, quality and safety data. Color-coded dashboards have recently come into use for displaying information to management. This article discusses a method that combines the best of SPC techniques with the display methods found in "balanced scorecards" and dashboards.

This methodology has been used at Fluor Hanford, a contractor at the U.S. Department of Energy's (DOE) Hanford site in Washington. The massive project on the former nuclear materials production site is considered one of the largest environmental cleanup projects in the world. Fluor Hanford has achieved significant safety improvements—including more than an 80% reduction in OSHA cases per 200,000 hours worked over the last 9 years. These improvements were achieved by a committed partnering of workers, managers and statistical methodology.

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Safety achievements at the site have been due to a systematic approach to safety. This includes excellent cooperation between field workers, SH&E professionals and management through application of OSHA's Voluntary Protection Programs principles. The corporation's values are centered around safety, and Fluor Hanford has taken a rigorous approach to using its safety statistics, based on Shewhart's control charts, and Deming's management and quality methods (Shewhart; Deming).

An Example of Numerical Illiteracy

Typically, a company looks at numbers such as injury rates by comparing this month to last month, or by comparing this month to a numerical goal. This is a simple, yet damaging approach. Assume that the past 25 months of data looked like those in Figure 1. Calendar year 2005 began well, with 8 injuries in January and only 3 injuries in February. Notice the fine decreasing trend from July 2004 through February 2005. The organization cashes in its safety recognition money and throws a party.

Following the success in February, something went wrong in March. The numbers jumped from 3 injuries in February to 13 for March—an increase of more than 400%. April and May recover somewhat, but not by much.

Moving Averages

Next, let's try a 12-month moving average. This is a tool used by many companies, and it is regularly included in M.B.A. quantitative methods courses (Anderson, et al). The moving average in Figure 2 has smoothed out the data. Safety performance is improving after all. A similar result occurs if one adds a "trend line" using a least-squares fit (or, more properly, linear regression). These statistical methods show that there is an improving trend.

Color Coding

At this point, management is confused. Conflicting analyses have been presented. Something seems to be amiss and management believes the current performance is not acceptable. Wanting improve-

ment, management directs the use of the latest tool—the color-coded dashboard (Palady). Any month with fewer than 5 cases will be green, and months with more than 10 will be red. Months where the number of cases falls between 5 and 10 will be yellow. This will be used in an overall presentation for company leaders so they can quickly see how the company is doing, without the dueling statistics (Figure 3).

February is green—an exemplary month. But the group became complacent and the rate went red in March. Corrective actions followed, which reduced the injuries to the yellow band. May is heading back toward the red zone, as everyone tries to figure out what it will take to get back to February's level.

Conflicting Interpretations of the Data

Focusing on last month's number, making comparisons from month to month, and making comparisons to the goal. Does this sound familiar? How is it working? Likely not well, because the numbers in this example did not come from any real injury rate. They came from a random number generator of average 12 and standard deviation 3.46 (which is the square root of 12, simulating a Poisson distribution standard deviation). Every reaction described was actually a reaction to random noise in the data.

Statistical Process Control & Control Charts

Shewhart developed SPC more than 75 years ago. SPC is a graphic analysis method that separates signal from noise in operational data. The chart used is called a control chart. These charts have the advantage of being both very visual and straightforward, yet manage to statistically separate trends from random noise (Shewhart).

Since those unfamiliar with these charts may resist their use, a hands-on experience called the "Red Bead Experiment" can be useful. Deming used this training exercise as part of his 4-day seminars that were held across the country in the 1980s. The experiment is documented in *The New Economics* (Deming).

The experiment has been used at the Hanford site for a hands-on training session in how this principle works. Instead of a computer random number generator, a bucket of beads of two colors are used. Red beads are "bad." White beads are "good." The number of beads of each color remains the same throughout the experiment.

Although the red beads are randomly mixed throughout the supply, some worker always has the least red beads and some worker always has the most. Half of the workers will get worse from one try to the next, half will get better. Workers receive praise and correction depending on whether they are better or worse than their peers, or based on comparison to their previous attempts. Numerical targets are set for reduced numbers of red beads. Cash incentives are offered for meeting targets (which never seem to be met).

The experiment is a powerful experience. One hour with the red beads have transformed SH&E

Figure 1

Injuries per Month

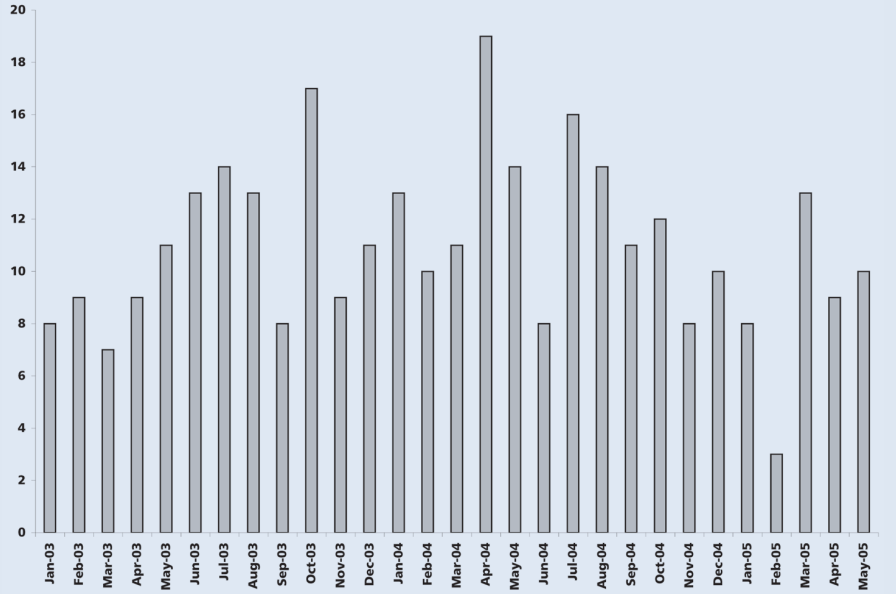


Figure 2

Injuries per Month, Moving Average

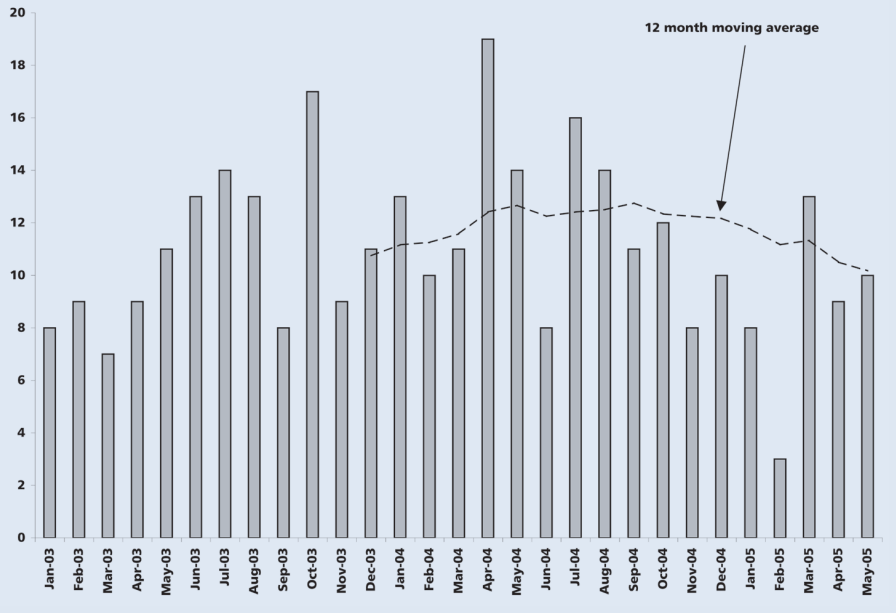


Figure 3

Injuries per Month, by Color

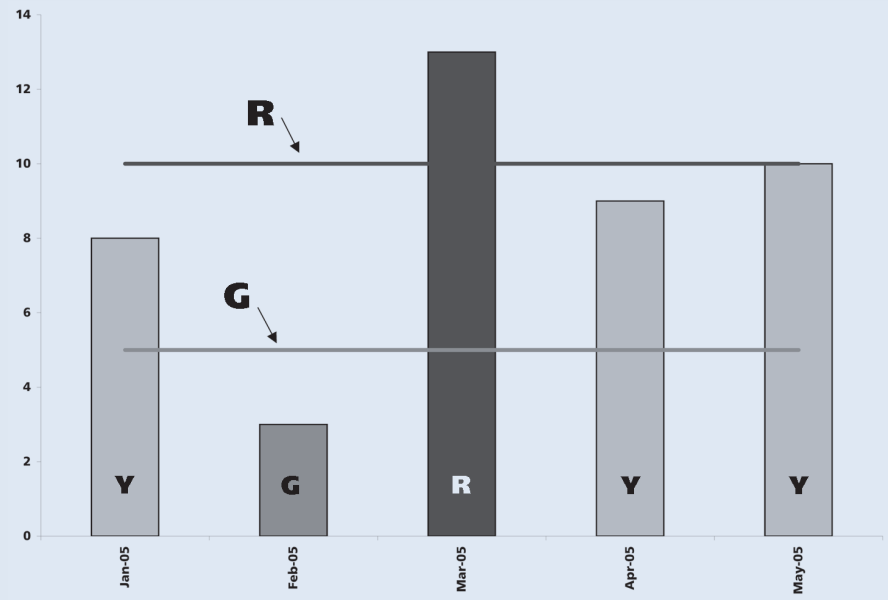
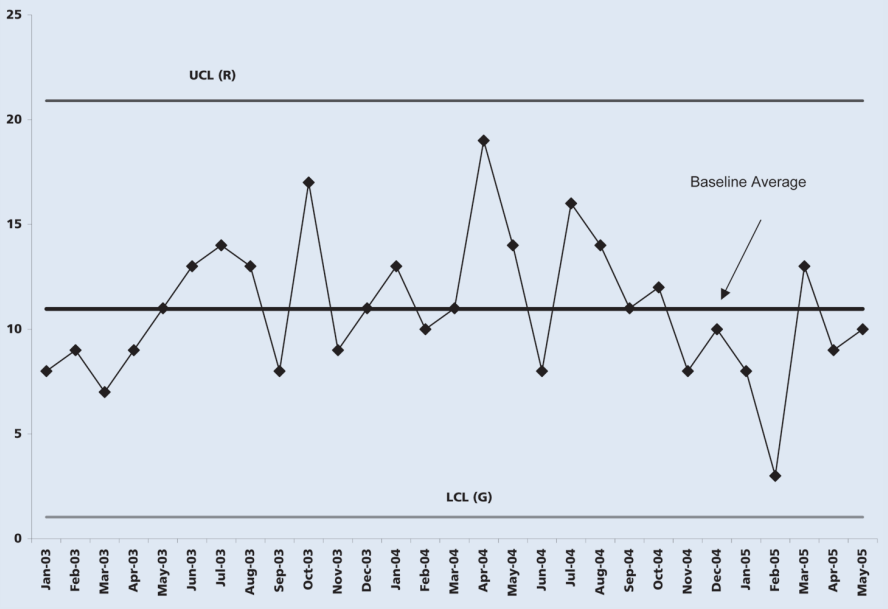


Figure 4

Injuries per Month, Control Chart



professionals (or at least started the transformation) from setting targets and following the numbers to understanding what the numbers are telling them. During the session, one can observe—based on audience reaction—this transformation. The experience at first appears humorous, but as participants recognize the common factors with their actual work, they begin to realize that a new method for responding to data is needed.

Feedback from the experiment has always been very positive. A session was recently performed (including a translation into Spanish) in Juarez, Mexico, during an international quality conference. Comments were as favorable as any other session performed, with the most common statement being "we wish our managers were here to see this also."

Appropriate Reaction to Random Noise

The control chart becomes the new method, the new lens for looking at safety data. A control chart has a center line representing the average of the data, and control limits at three standard deviations from the average line. In Figure 4, the average line is a heavy black line, the upper control limit (UCL) is red and the lower control limit (LCL) is green. When seen through this new lens, the example data look as they do in Figure 4.

As one would expect, these data are statistically stable. Nothing was done differently to get the result of 3 injuries in February 2005 as was done to get the result of 16 injuries in July 2004. It is only the result of a random number generator. There must always be a highest value and a lowest value. Supposing that there must be a signal, that there must be something which can be acted on in the recent results, becomes a source of frustration and represents "numerical illiteracy."

This new way of looking at data offers a new way of reacting to data as well—although it is not really so new, given that Shewhart developed the methodology in 1930. If the new month's datum is within the control limits and no other rules for a "trend" are triggered, then nothing will be gained from further examination of this month's injuries. If the injury rate needs to be improved, then the red beads—the sources of injuries—need to be removed from the system.

Following is a set of rules for detecting trends on a control chart:

- One point outside the control limits.
- Two of three points two standard deviations above/below average.
- Four of five points one standard deviation above/below average.
- Seven points in a row all above/below average.
- Ten of 11 points in a row all above/below average.
- Seven points in a row all increasing/decreasing.

(Variations on this list do exist. The key is to select one set of rules that is reasonable and stick to it.)

Look across all of the months of data for further information. Perhaps back injuries are the leading body part, while strains and sprains are the leading

injury types. This implies one should work on actions needed to reduce back injuries overall, not just last month's back injuries. (Pierce's article, "Variation and Acceptable Risk" further elaborates on these principles.)

Examples of Common Causes versus Special Causes

Experience at Fluor Hanford has shown that it is important to understand when the process is stable and when it is changing. During times of stability, SH&E professionals reviewed the long-term injury record for the period of stability. A significant reduction in injuries occurred after one such review where the most commonly injured occupations were identified and the most common types of injuries were identified for those groups. At that time, the common injury type was back injuries due to overexertion.

Policy and work practices were changed to encourage proper lifting techniques and the use of materials handling equipment over manual lifting. This is an example of analyzing "common cause" variation to determine actions to provide improvement. As the actions took effect, a decreasing trend was noticed that provided validation of the efforts.

Another example involves a group whose injury rate spiked above the UCL on its injury charts. Some automated processing equipment had failed and the work had shifted to manual backup equipment. That equipment posed some ergonomic issues which were leading to musculoskeletal injuries. This is an example of detecting and correcting for "special cause" variation. Interestingly, actions were delayed because the workgroup had been using moving average charts to plot its injuries; it took much longer for the moving average to react than the SPC chart with the same data.

The Need for a Transformation

The Red Bead Experiment will provide a good theoretical basis to help an organization transform from reacting to last month's injuries to understanding variation. Making charts similar to that depicted in Figure 4, using actual local data, will provide a practical basis for the transformation.

Thinking must also be transformed, particularly about how data are handled. Hanford site management went through many phases of "simple and flashy" charts, including three-dimensional bar charts, colors based on numerical targets and moving averages, before the worth of control charts was truly proven. Control charts allow managers and SH&E professionals to make decisions based on data—and more importantly, decisions based on variation in the data.

Table 1

Typical Trending Errors

Error	Typical Behavior	Reaction (when not using SPC)	Action (when using SPC)
Reacting to ups and downs (false alarms)	Comparisons point to point, to average, to last year	Tampering and knee-jerk reactions, overreaction to all small problems, frustration	When stable, work on long-term history, fix the system
Failure to detect trend	No criteria to separate trend from noise	Small problem which could have been corrected while a small problem grows into a big problem	Use SPC to detect trends accurately and in time

Table 2

SPC Dashboard Theory

Control Chart Result	Leadership Decision	Color Assignment	Leadership Action
Stable	Level is acceptable	Green	Stay the course
	Level is not acceptable	Yellow	Improve the system
Trend	Adverse	Red	Take corrective action
	Improving	Green	Reinforce—Stay the course, apply to similar systems

Parent company Fluor Corp. has watched the progress at Hanford with great interest and has started to roll out this approach at other projects as well.

Converting Trends to Action

When a trend is detected according to the trending rules, the source of the trend should be determined. Trends in the positive direction should be reinforced and lessons gained for application in similar areas. Trends in the negative direction should be corrected. Deming referred to such trends as "special cause" variation (Deming). However, it is likely that most charts made will be statistically stable.

When a process is stable and the variation in the data appear to be random, then reaction to the most recent datum will likely cause problems. "Feel good" actions will be taken, but no real change is likely. These situations exhibit "common cause" variation. The process is stable and predictable (within the bounds of the control limits). No amount of root-cause analysis or corrective actions that only focus on the most recent event will have an effect. When the process data are stable, one needs to change the process. Any root-cause analyses or Pareto analyses need to encompass a long-term set of data, reflecting the time period for which the control chart has been stable.

Figure 5

May 2005 FluorBoard

Fluor Hanford Dashboard: Safety and Health - OS&H

Indicator (with link to definition)	FH Overall	PFP	K Basins	FFTF	WS&D	SW/GWVZ + WSCF	CP D&D & RCC	CS&I
LEADING INJURY INDICATORS	**W**	**W**	**G**	**G**	**W**	**W**	**W**	**W**
First-Aid Case Rate	Y	W	G	W	Y	Y	R	W
ORPS	Y	W	G	Y	W	W	W	Y
Near Misses	G	G	G	G	G	G	G	G
No. Safety Inspections	G	W	G	G	G	G	G	G
Safety Inspection Scores	G	G	G	G	G	W	G	G
HGET Survey	G	Y	G	G	R	G	W	R
Safety Related Employee Concerns	W	W	W	W	Y	W	G	W
LAGGING INJURY INDICATORS	**W**	**W**	**G**	**G**	**G**	**W**	**W**	**Y**
OSHA Case Rate	W	Y	G	G	W	Y	Y	Y
DAFW Case Rate	W	G	G	G	G	G	G	Y
DART Case Rate	G	G	G	G	W	G	W	Y
Severity Rate	G	G	G	G	G	G	G	G

Green = Improving Trend or Superior Performance, White = Acceptable, Yellow = Stable, needs improvement or potential Non-Improving Trend, Red = Unacceptable Level or Non-Improving Trend

Reporting Period - May 2005

Leading indicators:

- *First-aid case rate*
- *ORPS (Occurrence Reporting and Processing System)—event reports*
- *Near misses*
- *Number of safety inspections*
- *Safety inspection scores*
- *HGET (Hanford general employee training) worker survey—taken once a year by each employee*
- *Safety-related employee concerns*

Lagging indicators:

- *OSHA case rate (OSHA recordable cases per 200,000 hours)*
- *DAFW case rate (days away from work cases per 200,000 hours)*
- *DART case rate (days away, restricted or terminated/transferred cases per 200,000 hours)*
- *Severity rate (number of days away or restricted work activity days per 200,000 hours)*

This separation of special cause variation from common cause variation is a cornerstone of Deming's management philosophy. It has proven effective for the Hanford site, which has seen its OSHA recordable case rate drop by more than 80% over the past 9 years.

Application of These Methodologies

The author was hired at the Hanford site in 1993 as a maintenance supervisor. After 6 months on site, his role changed to performance indicator analysis because of his background in operations research and Deming's methodologies. Originally, SPC was implemented in maintenance work package cycle times. An employee suggestion (through the company safety council) asked for SPC to be implemented in safety charting as well. The stage was set for a transformation in thinking that took place over many years. The use of SPC continued at Hanford when Fluor Hanford became a contractor in 1997. [Early use of SPC at the site is documented in Prevette(a). Further information is available in the Hanford Trending Primer, which can be accessed at www.hanford.gov/safety/vpp/trend.htm.]

Fluor Hanford safety charts are produced through customized Visual Basic programs. These programs access the source data files, build a working copy of each database with the necessary trending information, then create all data tables and reports necessary to support the corporation and its 4,000 workers. An average of 1,600 routine charts and reports are generated within the first 7 working days of each month. That figure includes charts for safety and health, as well as for operations, maintenance, quality assurance and corrective action management. All of the charts are either SPC control charts, or supporting Pareto and histogram charts.

Data quality is controlled through a software quality policy and routine assessments comparing the chart data to the source data. Injury data are collected from the same software that supports the company's OSHA 300 log database. Other performance indicators were developed from existing databases on the site maintained by various organizations. In the case of a new safety inspection program, the author receives safety inspections from the field and enters the results into a Micosoft Access database for analysis in the dashboard and other performance charts.

Managing Data Overload through Dashboard Colors

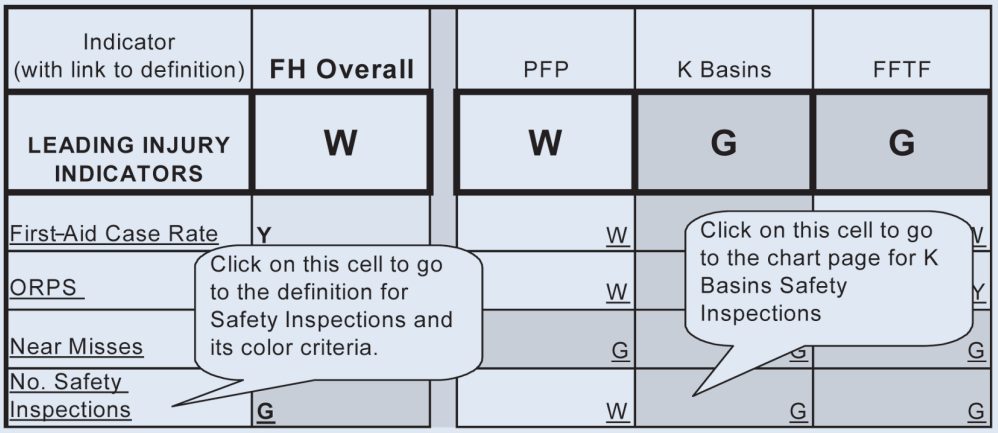
Data overload is a common concern. As noted, hundreds of charts are generated each month and no one person receives all of the routine and nonroutine charts made each month. However, this sheer volume of information can be overwhelming. Computers and analysts can easily flood managers with reports and data.

One potential solution is to color-code results and roll these results into one scorecard or dashboard. The red, yellow and green colors from traffic lights are typically used. Green usually implies okay, yellow means caution and red means stop, there is a problem. DOE began calling for the use of color-

coded "dashboard" performance indicator charts in 2001 through the Energy Facility Contractors Group (EFCOG). Traditionally, the chart colors are set by comparing results against a set of thresholds. Figure 3 is an example of such charts. Colors from the various individual charts are then rolled into a single-page overview. The locations of red and yellow colors are intended to provide a quick indication of areas needing attention.

Figure 6

A Portion of the Dashboard Page



Instruction for establishing hyperlinks in Excel:
Right-click on the cell
Select "Hyperlink"
Browse through files until you get to the desired file
Select "OK"

Now, whenever someone left clicks on the cell, the linked file will open. Do the same for chart definitions. Each cell with a color uses "Conditional Formatting" to change color depending on the letter value (R, Y, W or G) in the cell. The cell letter value is linked by formula to the caption under the related chart.

A Dashboard Driven by SPC: The FluorBoard

As demonstrated in Figure 3, the traditional method of color-coding results by comparing the current result to numerical thresholds can cause an overreaction to random noise. The charts can also be very insensitive to slow, long-term trends. One answer is the "FluorBoard," which combines the best features of control charts with the best features of color-coding.

A set of SPC-based color-coded charts was established at Fluor Hanford in 2003 [as discussed in Prevette(b)]. Just after completion of the draft article, management decided to shift to the "traditional" dashboard. This lasted for 1 year. Then, accumulation of the problems predicted in the article (overreaction to random noise, overlooking of significant changing conditions) caused a change in direction back to SPC.

Table 1 (pg. 37) highlights typical errors that tend to be made when not using control charts. The first type of error (reacting to random noise) was illustrated in the scenario at the beginning of this article. The second type of error, failure to detect a trend, is a fear that tends to cause many false alarms. The lessons from this table are applied to the FluorBoard (Table 2, pg. 37). Table 2 includes the control chart result, stable or trend, as determined by the analyst. The second column contains the decisions needed from leaders, which puts the control chart in context. The third and fourth columns contain the resulting color, and the recommended leadership actions.

In the traditional dashboard method, the threshold values are established arbitrarily. In the SPC method, a decision must be made: If the process is currently stable, does it need to be improved? The methodology integrates well with Deming's 14 points in understanding the variation in the data, and also avoidance of numerical targets (Deming).

Managers and the safety councils review stable systems to determine whether improvement is needed. A baseline in effect at some time in the past may be a useful threshold. For example, after launching a formal safety inspection program, it was decided that a higher number of inspections would be worthwhile. The initial baseline average was used to determine colors: 1) green if a new baseline had been established at a better level than original; 2) white if it had not changed; and 3) yellow if a new baseline that was lower was established.

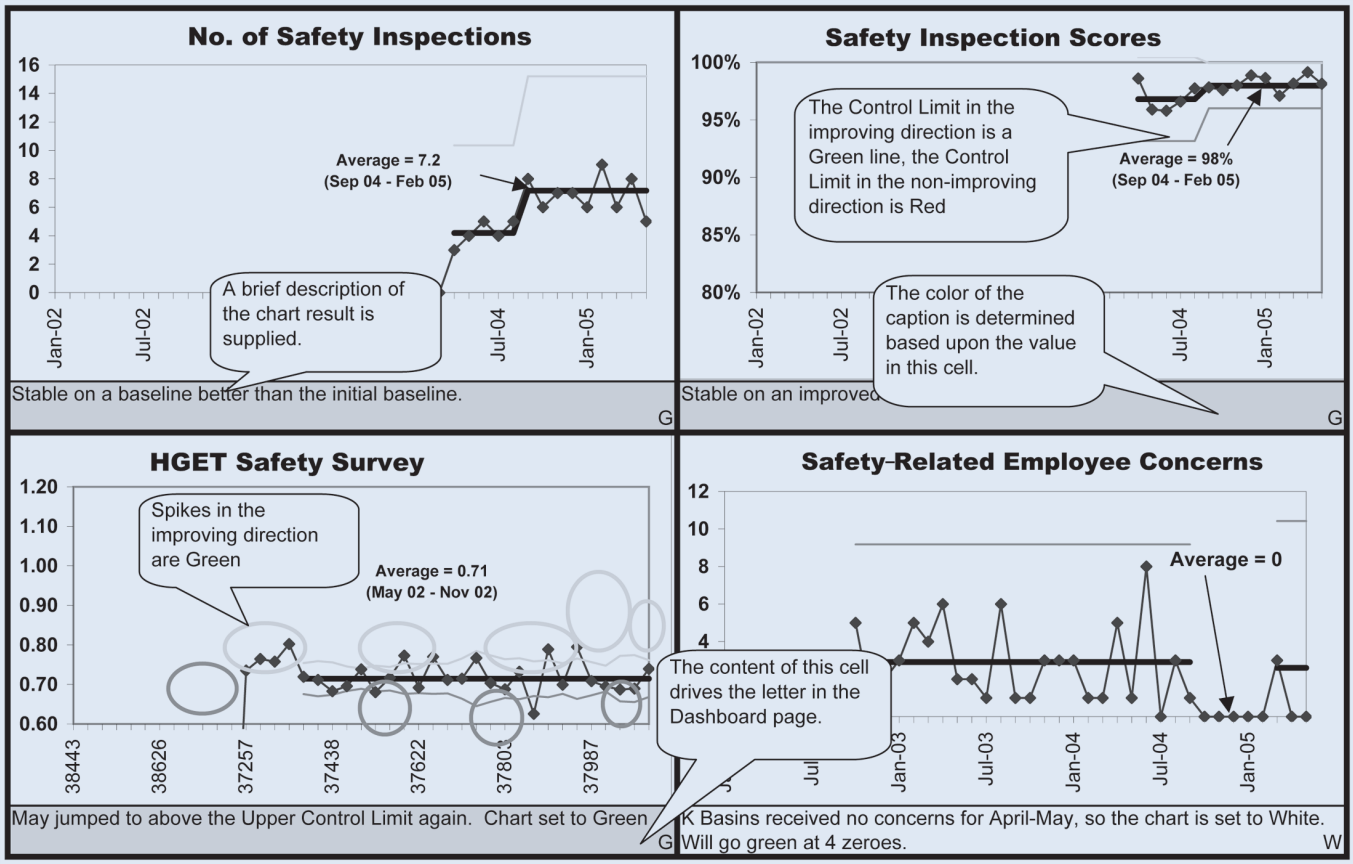
In other cases, numerical targets had been applied from outside the corporation. Negotiations with the government led to a base goal of 1.0 OSHA recordable case per 200,000 hours, and a "stretch" goal of 0.75. Thus, any organization stable less than 0.75 was green, stable between 0.75 and 1.0 was white, and yellow if greater than 1.0. Note in all cases that the baseline average is the basis for the color when there are no trends. Also, the baseline average only changes if a statistically significant change (per the rules described earlier) had occurred previously.

Lessons from the First Implementation

Two primary difficulties arose from the first year of using the SPC-based dashboard. The first was an interpretation issue with the expectation that "all charts should be green." If a yellow or red appeared, the reaction was viewed as punitive. Some managers became more concerned with how to change the color to green by changing the definition of the indicator or other manipulations, rather than with improving the process in order to achieve a green result. The SPC approach highlights trends moreso than levels, and is less sensitive to random results. Managers were upset when their overall levels appeared to be good, but a trend had developed and the color was now red. The

Figure 7

Chart Page from the "K Basins" Project



second issue was that a chart could be stable green one month, but if the next month exceeded a set rule, the chart immediately shifted to red without passing through yellow.

The following year, the company used the traditional dashboard approach. As noted, this caused overreaction to random noise, and manipulation with threshold levels led to even greater frustration throughout the year. The stage was set for another attempt at SPC. The managers involved became open to suggestions and mentoring. This time, when presented with a SPC prototype and training, the combination clicked.

A new color was added—white. It was used for stable systems that were okay but not excellent. The color white acknowledged that there was room for improvement without ringing the yellow or red alarm. White was also used as a transition for charts currently at yellow or red, but one month away from hitting a trend rule. For example, a yellow chart with six points in a row on the side of the average in the improving direction would be set to white, in anticipation of going green in the following update.

The definition of yellow was modified so that it would be used as a transition from green to red. If a green stable chart is one point away from shift in the wrong direction, the chart is set to yellow. These actions, plus the experience with the traditional approach, have made this third version of the company dashboard acceptable and useful.

The thinking about the color red also underwent a change. Managers became willing to treat red as an information color, rather than as a punitive color. This improved insight allowed for appropriate and timely management actions to be taken.

Impacts on Management, Workers & SH&E Professionals

The vice president of safety and health for Fluor Hanford has found this way of viewing safety data to be extremely beneficial. As a senior manager, his time is limited. He receives a consistent set of charts on a weekly and monthly basis, all of which have a similar control chart construction so it is easy to scan across them. The dashboard colors are readily available via a link on his office computer.

The company's other vice presidents and CEO also have access to these charts. More importantly, they review them. The red and yellow colors allow them to quickly notice areas where conditions are changing—or where conditions need to be changed. The color white allows managers to see where there

may be opportunities for continual improvement. The FluorBoard also includes charts at the project level within the corporation. Project managers and SH&E professionals use these charts to target improvement efforts and to provide feedback about ongoing safety efforts. Each project has a safety council (Employee Zero Accident Council) made up of managers, union representatives and SH&E professionals who meet monthly. The results of the FluorBoard are reviewed at these meetings. Also, many control charts of safety and performance data are provided to organizations below the project level. These charts are available to all employees through bulletin boards and web pages. The charts help focus efforts toward consolidated companywide success.

Leading indicators have been established in parallel with the standard injury rates. The leading indicator results are also assigned colors using the SPC dashboard method and are given visibility. These leading indicators provide the ability to not only predict the future, but also to change the future. Examples of leading indicators and of the lagging indicators they can affect include:

- first-aid case rate (lagging indicator = OSHA recordable case rate);
- observations of work in progress checking for usefulness of the procedures (procedure error events);
- observations of worker body positions and tool ergonomics during routine work (body motion strain/sprain injuries);
- safety inspection scores for uneven surfaces, tripping hazards (fall/trip/slip injuries).

Mechanics of the FluorBoard

The FluorBoard was created with Microsoft Excel. No special software is needed and files can be set up by anyone with reasonable familiarity with spreadsheet tools. The dashboard itself has been set up with hyperlinks to the files containing the chart definitions, as well as the charts themselves. When the title of the chart is clicked on, a text file with the technical information on the chart is opened.

Figure 5 shows the overall FluorBoard for safety and health for May 2005. Each column is a project organization within Fluor Hanford. Each row is a specific performance indicator. The leading indicators are all rolled into one color by column as are the lagging indicators.

The leading indicators are first-aid case rate; occurrence reporting and processing system (ORPS) event reports; near-misses; number of safety inspections; safety inspection scores; Hanford general employee training (HGET) worker survey (taken once a year by each employee); and safety-related employee concerns.

The lagging indicators are OSHA case rate (OSHA recordable cases per 200,000 hours); DAFW case rate (days-away-from-work cases per 200,000 hours); DART case rate (days away, restricted or terminated/transferred cases per 200,000 hours); and severity rate (number of days away or restricted work activity days per 200,000 hours).

Links from the Dashboard to Charts

Figure 6 depicts a portion of the FluorBoard. Two indicators, first-aid cases and ORPS are shown, along with three project organizations.

Traditional dashboards provide one chart per page, complete with all definitions of data sources and color criteria. This makes for a very thick package. What has worked well in this case has been to provide one linked page for each chart definition. With the administrative definitions taken care of elsewhere, four charts can easily fit each page.

The safety-related employee concerns are currently white. This is due to the effect of the spike of three that occurred in March 2005. The chart will reset to green after 4 months of zeroes following the spike. If more concerns are received, a new baseline average and control limits will be developed, and this baseline will be reviewed against the color criteria for the chart.

This new way of looking at data offers a new way of reacting to data as well. If the new month's datum is within the control limits and no other rules for a "trend" are triggered, then nothing will be gained from further examination of this month's injuries. If the injury rate needs to be improved, then the sources of injuries need to be removed from the system.

Conclusion

The FluorBoard has been very successful at Fluor Hanford, and the effort to apply it across the corporation has begun. This methodology combines the best technical features of SPC with the best presentation features of color-coded dashboards. SH&E professionals and managers can now quickly make rational use of their data in order to make informed decisions. The effect of these decisions will also be determined in a credible, rigorous manner through the SPC trend rules. ■

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