Control-Chart Dashboards: Managing Your Numbers Instead of Your Numbers Managing You

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ABSTRACT

This paper, which documents Fluor Hanford’s application of Statistical Process Control (SPC) and Dashboards to support planning and decision making, is a sequel to “Leading with Leading Indicators” that was presented at WM ’05. This year’s paper provides more detail on management’s use of SPC and control charts and discusses their integration into an executive summary using the popular color-coded dashboard methodology.

Fluor Hanford has applied SPC in a non-traditional (that is non-manufacturing) manner. Dr. Shewhart’s 75-year-old control-chart methodologies have been updated to modern data processing, but are still founded on his sound, tried and true principles. These methods are playing a key role in safety and quality at what has been called the world’s largest environmental cleanup project. The U.S. Department of Energy’s (DOE’s) Hanford Site played a pivotal role in the nation’s defense, beginning in the 1940s when it was established as part of the Manhattan Project. After more than 50 years of producing nuclear weapons, Hanford – which covers 586 square miles in southeastern Washington state – is now focused on three outcomes:

1. Restoring the Columbia River corridor for multiple uses
2. Transitioning the central plateau to support long-term waste management
3. Putting DOE assets to work for the future.

The control-chart-based dashboard has been featured by several professional societies in their publications, most recently by the American Society of Safety Engineers. The case is provided for why one should consider switching from bar charts, moving averages, “rainbow charts,” and other non-statistical charting methods, and changing to control charts. Control charts have actually cost less to make than these other charts. Lessons learned from implementing the “FluorBoard” control-chart-based dashboards will be included. These tools, management theories and methods, coupled with involved leadership and employee efforts, will directly lead to significant improvements in worker safety and health, and environmental protection and restoration at nuclear cleanup sites.

INTRODUCTION

Leadership, Leading Indicators, statistical methodology, and worker-supervisor teaming continue to play a key role in safety and quality at what has been called the world’s largest environmental cleanup project. The U.S. Department of Energy’s (DOE’s) Hanford Site played a pivotal role in the nation’s defense beginning in the 1940s, when it was created as part of the Manhattan Project. After more than 50 years of producing material for nuclear weapons, Hanford, covering 586 square miles in southeastern Washington state, is now focused on three outcomes:

1. Restoring the Columbia River corridor for multiple uses
2. Transitioning the central plateau to support long-term waste management
3. Putting DOE assets to work for the future.

The current environmental cleanup mission faces challenges of overlapping technical, political, regulatory, environmental, and cultural interests. Fluor Hanford, a prime contractor for the DOE, has the ultimate responsibility for cleaning up a large portion of the site. The emphasis has to be on doing work safely, delivering quality work, controlling costs, and meeting deadlines.

Leading with Leading Indicators

The presentation “Leading with Leading Indicators” was developed for WM’05. Variations on this presentation have since been made at ICEM ’05, the American Society of Safety Engineers national conference in 2006, ORC Worldwide (Washington, D,C,), the 2006 Northwest Occupational Health Conference, and the 2006 Washington State Governor’s Safety Conference. The message has been received with great interest and success at these venues. The presentation has been invited to the 2007 Washington State Governor’s Safety Conference as a “blockbuster” presentation. This paper incorporates lessons from these presentations, and also shares experiences with the control-chart-based dashboard over the past two years.

The “FluorBoard”

The “FluorBoard” was developed to combine two performance-measurement methodologies: Statistical Process Control and color-coded “dashboards.” Statistical Process Control (SPC) was used as the technical basis for displaying and analyzing the subject data. The color coded “dashboard” was utilized to display an overview of the results in an “executive summary” format for managers. SPC has a long and successful history in manufacturing. It was originally developed by Dr. Shewhart [1] in the 1930s and further refined by Dr. Deming [2] [3] from World War II through the 1980s. SPC is a robust methodology that can be adapted for a wide variety of data sources and data distributions. Color-coded dashboards and “balanced scorecards” were proposed in the 1990s by Robert Kaplan and David Norton [4] to display performance results to managers quickly.

Each method has its strengths and weaknesses. SPC is perhaps the simplest statistical methodology for separating trends from random noise. However, reviewing hundreds of SPC charts can be time consuming. Color-coded dashboards, on the other hand, provide a quick overview of hundreds of indicators on a single piece of paper. The disadvantage of most dashboard systems, however, is they react to random noise, unable to separate a trend from a signal.

STATISTICAL PROCESS CONTROL

There are several requirements within the DOE's rules and orders that call for trending operational data. Over the years, this trending has been done by a variety of methods at a number of sites. Fluor Hanford has chosen to utilize one standardized methodology for its quality and safety trending – Statistical Process Control (SPC) and control charts.

Figure 1 is an example of a control chart showing the OSHA Recordable Case Rate for Fluor Hanford and its subcontractors. Each month, similar charts are made for each of the major projects within Fluor Hanford and displayed on the "FluorBoard." Overall, there has been an 85% reduction in the OSHA recordable injury rate in the past 10 years.

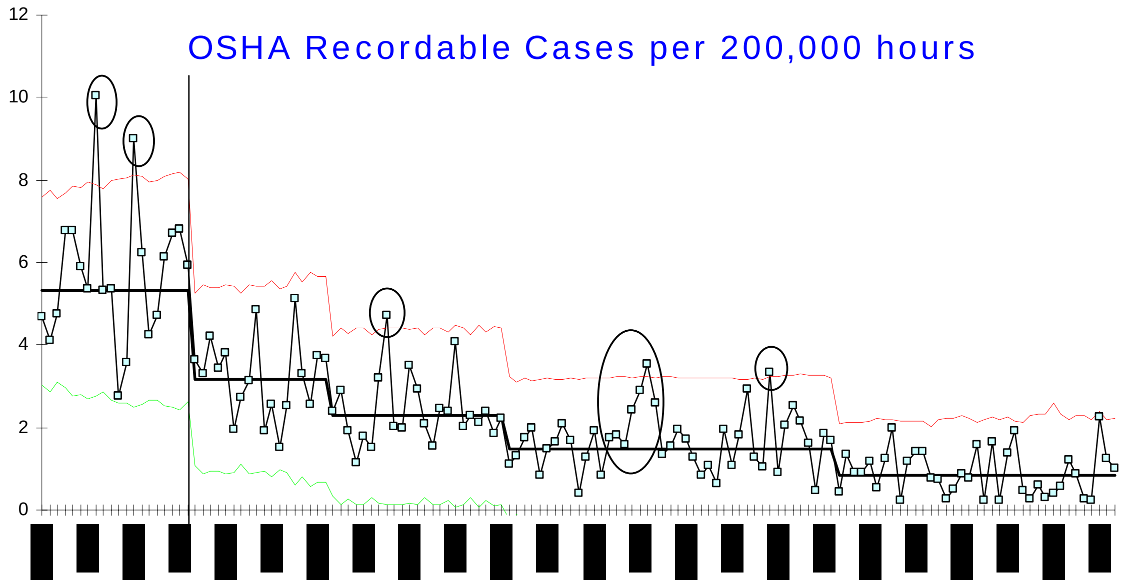

Fig. 1. Fluor Hanford's OSHA Recordable Case Rate (including subcontractors)

In the control chart, the data are plotted, and baseline averages (the heavy black line) are established for stable time intervals. A Lower Control Limit and an Upper Control Limit are plotted, representing the expected range of variation in the data. Variation outside this range is circled, and the average baseline is shifted upon a permanent change in the data. For more details on the techniques used, please refer to the "Hanford Trending Primer" at http://www.hanford.gov/safety/vpp/trend.htm.

Why Statistical Process Control?

Several options have been used in business for performance-measurement analysis in the past. These range from the simple — bar charts, cumulative year-to-date, moving averages — to the complex, Analysis of Variance (ANOVA), regression (non linear and multiple variables), and Design of Experiments. While the simpler tools fall victim to over reaction to random noise, the more complex versions also have an inherent flaw — they can't easily be used by non-statisticians.

THE HAZARDS OF RANDOM NOISE

Each month, whatever quantity one is measuring as a performance measure, will change in value. Last month there were four injuries; 20 work packages completed; and 2,376 hours worked. This month there were five injuries; 27 work packages completed; and 2,189 hours worked. The numbers change from month to month. If they did not vary, one would likely begin to believe someone is falsifying the data. How likely is it to have three injuries every month, month after month, for ten years? The following statistical rule appears to apply – "given two numbers, they will be different."

Many corporations present point-to-point comparisons (month-to-month, quarter-to-quarter, this month to the same month last year) in tables. Percentage changes are calculated, and then these changes are used to make management decisions. Yet, how do they know that the change from four injuries last month to five injuries this month had a specific cause that calls for taking action? Should an increase from 20 work packages to 27 work packages in a month be celebrated?

An even stronger reaction to random noise can occur with color-coded performance systems. Generally, arbitrary thresholds are used to characterize the performance measure results as "red," "yellow" or "green." Four injuries in a month may represent "green" performance, but five may cross the threshold into "yellow." This would demand management attention and action. However, if the threshold did not happen to be between four and five, no action would be required.

Dr. Deming [3] told the story of a sugar refinery in his book Out of the Crisis. The plant's objective was to reduce the consumption of seawater to 3.5 tons per ton of end product. To accomplish their objective, they posted a colored slat at the end of each day's production. A red slat was posted if the 3.5-ton goal was exceeded. A green slat posted, if it were achieved. A red slat sent the workers huddling to try to discover what went wrong the previous day. If the next day turned green, they celebrated. All sorts of explanations and attempts to take corrective action were made. All were wrong. An endless series of emotional highs and lows prevailed, with no improvement in the results. A better plan would have been to accumulate the results over many days, study the process with knowledge of chemistry and processing, and establish a good experimental design to determine the capabilities of the process. An analysis of the results over the long term would have been much more fruitful than the day-to-day reactions to short-term results.

Type I Error - False Alarms

Reacting to random noise as if it were a signal worthy of action has been referred to by Dr. Wheeler [5] as "numerical illiteracy." There are heavy losses from over adjusting a process due to random noise. Machinery will actually create product that is less consistent (more variable) if it is adjusted as a result of each item made. People will become withdrawn and frustrated if corrected daily for variation in results over which they have no control. Acting on the most recent result, as if something had changed to create this result, when in reality, nothing had changed is referred to in statistics as a "Type I" error. Most people have experience in flipping coins. If the reasonable person flipped two "heads" in a row, and then followed with a "tail," they would most likely not assume anything had changed. This was simply the random result of the coin flip. Yet, the same person when faced with a drop in a performance measure to below average following two months of above-average stats will feel compelled to take action.

Regression ("least-squares fit," or "trend lines" in an Excel spreadsheet) charts tend to lead to Type I errors. No matter what the data, it is highly unlikely that the slope of a fitted line (or curve) will be exactly zero. Thus, some form of trend or pattern will always be declared. Some statistical courses teach the R-squared value, but it is very difficult and unreliable to interpret. The math for plotting confidence and prediction intervals is very complex and rarely taught. The effect is that most users of regression fits will overreact to random noise.

Human Performance

Many DOE sites are implementing "Human Performance" initiatives. DOE training materials [6] state, "To explain failure, do not try to find where people went wrong. Instead, find how people's assessments and actions made sense at the time, given the circumstances that surround them." This view fits well with the statistical view of avoiding Type I errors. Instead of blaming the worker — reacting to the latest event — a systems view is applied. One asks if any worker could have caused the event, given the state of the process and the workers' training and knowledge. The fact that a given worker at a given time had a given event is put in context with the systems and processes, including the "error precursors" and "error-likely situations." A series of apparently random results is indicative of results from a stable process with some amount of random variation overlaid.

TYPE II ERROR - FAILURES TO DETECT

Type II error is the failure to detect a changing condition, the failure to detect a trend. Decision makers generally have a great fear of being judged — with 20-20 hindsight following an event — of failing to have detected the changes leading to the event. This fear tends to amplify results to all events, leading to more Type I errors.

A good physical example is the smoke detector in a building. At a certain level of particulates and/or carbon monoxide in the atmosphere, it will alarm. Upon hearing the alarm, the residents are expected to take action — to evacuate. Let us assume the owner of the building is fearful of missing a fire condition. In a desire to be safer, the owner changes the alarm set point to a lower threshold. Thus, the chance of a Type II error (failure to detect a fire) is decreased. However, what is the actual result? The residents are now less safe. Perhaps on a daily basis fire alarms go off as a result of the smallest amount of dust in the air (or even burnt toast). The residents quickly learn to ignore the fire alarm, or at least are hesitant in responding to it. Then one day, a real fire occurs.

The residents fail to react to the alarm, and have a much more difficult time avoiding injury or death. The owner's desire to be safer led to a less safe condition.

Detecting Change Effectively

Just as the household smoke detector detects a change (an unusual level of particulate or carbon monoxide) and alarms, business systems need a change detector and alarm. When a business condition changes, leaders need to detect the change, determine its effect, formulate a response, and implement the response. The challenge comes in separating the routine variation in the periodic performance measure results from the signal that something has changed. Dr. Deming referred to the routine variation as "common cause" variation, and the signal as "special cause" variation. Failure to detect a negative change can cause it to grow in scope, and become a serious, difficult problem to solve.

At Fluor Hanford, a facility had suffered a failure of automated handling equipment, and shifted to using manual tools. After making a control chart similar to Figure 1, it could be seen that the injury rate had spiked above the upper control limit. There were ergonomic issues associated with the manual tools that were leading to muscular skeletal injuries, resulting in a significant increase in shoulder-strain injuries. Unfortunately, corrective actions were delayed because the facility in question was using moving-average charts to plot their injuries. It took much longer for the moving average to react than the control chart built with the same data. Similar problems exist with bar charts, pie charts, and cumulative year-to-date charts. These methods contain no alarm criteria for detecting a significant change. The alarm function of the smoke detector is missing, and instead, the decision as to whether or not a change has occurred is left is up to the personal judgment of the individual(s) using the chart. Note that failure to detect an improving condition can also be harmful. If an action has been taken that has caused a significant improvement in performance, but it is not detected, then there can be no reinforcement of the action. The action may be ceased as not being effective. Worse, lessons from the improvement cannot be applied to other similar processes and systems.

STATISTICAL PROCESS CONTROL

Statistical Process Control is an integral part of Fluor Hanford's performance-indicator system. Many times, performance-indicator systems fail due to the inability of actually using the performance information, or worse, misusing the information. There are overreactions to the current month's result, and lack of reaction to significant trends. Table I below summarizes the errors commonly made when SPC is not used.

Table I. Performance Indicator Errors

Common Error	Basis	Effect of Error	A Better Idea
Reaction to the most recent results, reacting to each up and down	**Point to point comparison with previous month, or to an average, or to**	**"Tampering" with the process. Knee-jerk actions taken to address symptoms**	**Use SPC to discover the process is stable. Work on**

in the data.	**similar month in previous year. Color coding based upon most recent result.**	**with little long term effect, except frustration.**	**underlying causes and the system over the long run.**
Failure to detect a significant adverse trend.	**Bar charts, Pie Charts and moving averages have no specific criteria to separate random noise from signal. They have no alarm system.**	**No corrective actions taken, the trend continues and the molehill grows into a mountain.**	**Use SPC trend rules detect change. Allows for timely corrective actions to arrest the trend.**

A simple control chart is shown in Figure 2. The data are plotted as they occur in each time interval. Each time interval is independent from the others; there is no averaging or running total of the data.

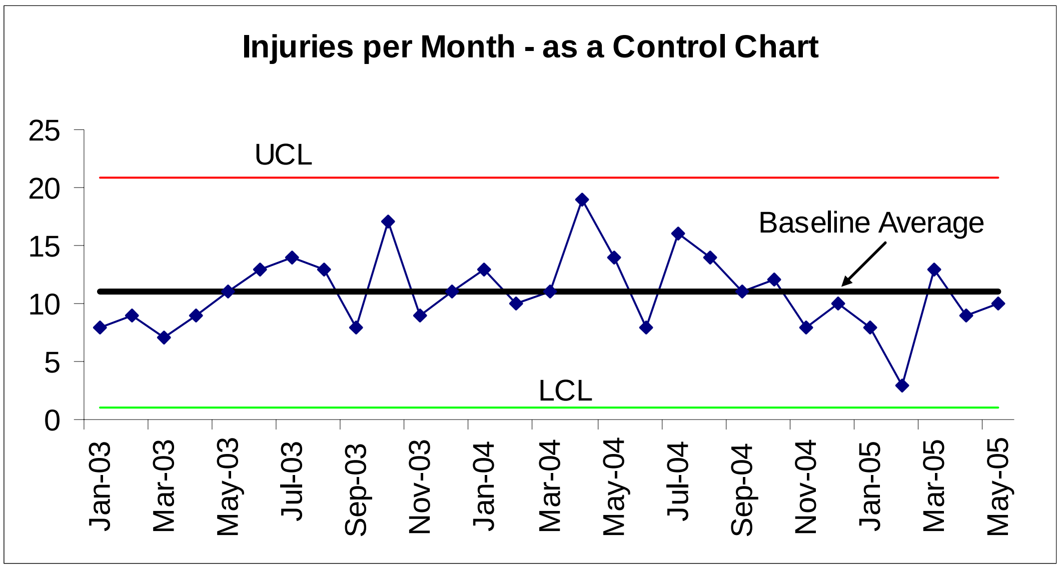

Fig 2. An example control chart

The baseline average is the average (mean) of the data on the chart. It is the "center line" for the chart. The UCL is the Upper Control Limit. It is plotted at the average plus three times the standard deviation of the data. The LCL is the Lower Control Limit. It is plotted at the average minus three times the standard deviation of the data. The average and control limits become the prediction of future performance. As long as nothing changes with the process, then future results will be between the values of the UCL and the LCL, and center about the average. Since the average and control limits are a prediction, one does not change their values as further data are plotted, the average and control limits are left locked in place until a statistically significant change occurs.

Detecting a Change

Specific rules are applied to detect a statistically significant change. Some rules detect a short term, but large deviation change. Other rules detect more subtle changes, but they must be in effect for a longer period of time. Rules do vary slightly from author to author. Fluor Hanford uses the rules in Table II for its control charts.

Table II. Rules for Detecting Trends on a Control Chart

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

The trending rules are used as feedback to the workers. A trend in an adverse direction is used as a trigger to investigate and implement corrective action. A trend in the improving direction provides feedback that previous interventions have taken effect. If the trend permanently shifts performance, a new baseline average and new control limits are established. For more detailed information on SPC, trend rules, and control charts, please see the *Hanford Trending Primer* at http://www.hanford.gov/safety/vpp/trend.htm.

COLOR-CODED SPC-BASED DASHBOARD

A challenge with performance measurement lies in the presentation of the indicators to the leaders. In October 2006, the author created 3,000 charts and data reports for Fluor Hanford. This volume of information could be overwhelming if not organized into executive overviews and the SPC color-coded dashboard. Our version of the SPC Based Dashboard has been locally referred to as the "FluorBoard."

The Fluor Hanford performance indicators are presented in a manner similar to Table III. There is no attempt to roll the data into a single index or aggregate. Leading indicators are accumulated in a grouping; lagging indicators, in another group. Fluor keeps the individual indicator charts separated. This has not been a burden on management decision making, as the consistent, quick to interpret SPC format is utilized in a standard presentation format on all charts.

Table III. The Safety and Health "FluorBoard" Page for September 2006

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

Table IV provides the logic used to create the color assignments. The color "white" was added due to lessons from using only red, yellow and green. First, there tends to be a desire to set up criteria that allows almost everyone being green. Adding white as a neutral band is useful as it provides an incentive to move to a superior level of performance, without being seen as "penalizing" reasonable performance by making it "yellow." Also, a "one point away" rule has been added. Experience found that managers were troubled that a stable "green" process could shift in the next update to red (adverse trend) with no warning or "yellow" value. To counteract this concern, charts that are one month away from developing an adverse trend are color coded yellow. As an example, if there have been six months in a row on the adverse side of the average line, the chart will be made "yellow" as a warning. If the seventh month is also on the adverse side of the average line, the chart is made "red." The "white" values may be ignored if the reader views it as unduly complicating the system.

Table IV. Control-Chart-Based Dashboard Rules

Control Chart Result	**Decision**	**Color**	**Leadership Action Needed**
Stable (common cause variation)	Level is superior	GREEN	Stay the course
	Level is acceptable	WHITE	May continue at this level, or decide to improve

	Level is not acceptable	YELLOW	Improve the system
Trend (special cause variation)	Trend is in adverse direction	RED	Correct for the problem
	One point away from an adverse trend	YELLOW	Warning that next result may be red
	Trend is in improving direction	GREEN	Keep the trend going
	One point away from an improving trend	WHITE (if chart would have otherwise been red or yellow)	Preliminary feedback that a improvement may be developing

The decision as to whether a stable chart is acceptable or unacceptable is owned by management. Managers must determine if improvement is needed or not. Analysts can help managers in making this decision by gathering benchmark data, performing cost-benefit and risk analyses, and conducting customer interviews and surveys. Managers may choose to execute a policy of continual improvement, and always pick a small number of stable systems for improvement, do the improvement, and then move on to others. Note that it is not necessary to make a new decision on each update as to whether or not a stable system is "yellow," "white," or "green." This is a one-time decision, which remains in effect until a trend occurs, or other priorities change and necessitate a reevaluation of the color with respect to other stable systems.

AN IMPROVEMENT CYCLE

The "FluorBoard" has a built-in improvement cycle. Let us assume a performance measure starts at a stable, but not acceptable level. The measure is made "yellow," and the cue is provided to the employees that the current process is not capable of producing an acceptable level. Histograms and Pareto charts (see the *Hanford Trending Primer*) are useful for slicing the long-term performance problem sources from most common to least common. "Low-hanging fruit" are identified for attention. Procedures are changed, and workers are trained to the new processes. As the changes take effect, a trend develops and is identified using the rules of Table II. The performance measure is coded "green" for an improving trend. Eventually, the trend ends, and performance steadies out at a new level. A new baseline average is calculated and control limits determined. This new level is evaluated to see if it is "acceptable." If this new performance level is acceptable, the chart remains "green." If it is not, the chart is reset to "yellow" and the cycle begins afresh.

LESSONS LEARNED

The author has documented the "FluorBoard" system in articles for two professional societies [7] and [8]; feedback from both has been positive. The Environmental Management leadership of the DOE has taken a strong interest in the American Society of Safety Engineers' article [8]. The readers and audiences appear most interested in the discussion of Type I errors — minimizing ineffective "knee jerk" reactions to the latest events.

Trends versus Levels

One characteristic of this process that became apparent during use is that the "FluorBoard" reacts stronger to changes in performance than to the level of the performance. This situation has caused some consternation with managers comparing their results against other managers. For example, there may be one project with a stable and predictable injury rate that is simply not acceptable. Perhaps they have 2.5 OSHA recordable cases per 200,000 hours worked. This project would be made "yellow" on the "FluorBoard" and expected to review their processes and systems to determine what improving actions to take. However, because the results are stable, no amount of review of or action will likely cause improvement.

In comparison, we may have a project that was previously stable "green" at 0.5 cases per 200,000 hours. Unfortunately, this month they exceeded their Upper Control Limit. As a result, this indicator is assigned a "red" color. The overall injury rate for the year to date may only be 0.7 for the group. The manager of the group asks — how is it "fair" that their good record of 0.7 is made "red" while the 2.5 group is "yellow"? The answer is that the "red" should not be seen as "worse" than the "yellow," only that the red is providing the signal that something has changed. The "red" is similar to a blinking red on a traffic light. The driver should stop, assess the conditions, and proceed when safe to do so. The "red" alerts the manager to a changing condition. Indeed, one should stop and assess the situation, and determine what corrective action is needed. Why would the manager want to wait until the safety problem becomes so protracted that the year-to-date injury rate is impacted? Early action will arrest the trend, and also minimize the cumulative effects of strain and sprain on the human body, if the injuries are strain/sprain related.

Meanwhile, the "yellow" group should continue to assess its long-term performance and sources of injuries, and work to change the system. Interestingly, a work "pause" or "stoppage" will likely help the "red" group determine what changed and to correct for it. A work "pause" or "stoppage" will likely not help the stable "yellow" group.

Judgment versus Learning

Much of the success of this method, and even performance measures in general, depends on how managers use the results. The "FluorBoard" is most effective when the reds and yellows (and even the green improving trends) are used as learning opportunities. The trends detected cue managers to ask "what happened," to determine what has changed and to take appropriate actions. Stable systems with poor performance need to be studied and changed.

The "FluorBoard" loses its effectiveness when the managers involved view the colors as judgments upon their performance or effectiveness. If reds and yellows are seen as "bad", as "punishment", then less is likely to be learned, and performance is not likely to improve. Yes, the workers and managers should be accountable for their performance, and a long term inability to improve should be questioned. But, treating each new yellow and red as "bad" will diminish the effectiveness of the corporation.

Summer Cycles

Fluor Hanford has faced a challenge over the past three years of spikes in the OSHA recordable case rate during the summer. These spikes may be seen in Figure 1. It is probable this seasonal cycle occurred before 2002, but was relatively "buried" by an overall stable rate through each year.

In 2006, Fluor Hanford recognized the hazard of the summer cycles. Warnings were made at safety councils in the March timeframe. Warning signals did develop in the leading indicators in April and May, especially in Occurrence Reports, an employee survey, and First-Aid Cases. Utilizing this information did minimize the summer spike, May and June remained very low. Unfortunately, July and August spiked higher than desired.

One interesting leading indicator that did not predict the summer increase was Employee Concerns. Previously, Employee Concerns and the OSHA recordable case rate were very tightly linked (see the 2005 version of this paper). Employee Concerns did not increase before or during the summer. This may indicate that a new leading indicator should be found, and Fluor Hanford is currently implementing a Human Performance Initiative that will likely include new leading indicators based on observing work in progress.

Radioactive Waste Characterization

Paper 7285, "Using Statistical Process Control to Monitor Radioactive Waste Characterization at a Radioactive Facility" at this conference details the use of Statistical Process Control for monitoring and decision making.

Data Analysis Working Group

One emerging use of SPC at Fluor Hanford is its Data Analysis Working Group (DAWG). This effort looks at many performance measures across the company, cross cutting many functions, including Quality, Safety, Corrective Action Management, and Environmental. Originally, the group attempted to assign score values to each datum reviewed, and total up those points by subject areas. A difficulty that ensued was a "piling on" effect. If an assessment were performed in a given area, it would generate Corrective Action Management reports. The DAWG would then see this influx of reports, and identify the subject as a "problem area" and call for more assessments to be performed. A never-ending cycle of assessments and corrective actions could then develop. During the fourth review cycle, the DAWG shifted to the use of statistical process control to discover emerging trends. Trends were color coded as red or green, with yellow signifying "one point away" from trends. These trends are then risk-ranked using a facilitated group discussion method to assign a risk score to the subject area. The group assigns values to five different probability factors and four different severity factors to generate an overall risk score. The trend results themselves do affect one of the probability scores in the model. The subject scores are then ranked and reported to management of Fluor Hanford for suggested actions and further review and assessments.

CONCLUSION

There are a number of tools and methodologies available to assist with safety leadership. Dashboards, driven by Statistical Process Control, as documented in this paper, can provide insight into the actions leaders need to take to achieve superior safety performance. Managers, workers, and safety professionals work towards one future, and build the corporate culture. The use of the "FluorBoard" assists the team in responding appropriately the wealth of performance data collected at a typical corporation.

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