STATISTICS – DRIVING SUCCESS OR BLOCKING THE ROAD?

Stephen A. Zayac
Ford Motor Company
USA

Yes, and yes. Success is dependent on developing conceptual understanding, easing interpretation, simplifying validation and facilitating corrective action. Focusing on statistical theory, data manipulation and increasing mathematical sophistication blocks the road to improvement. Lessons, learned over the past quarter century, in instructional strategies, in defining learning objectives and in using interactive examples, will be reviewed. Experience, demonstrating that developing EDA, measurement, DOE, prediction and control skills are critical, will be shared. Driven by the paradigm of statistical thinking and the concepts of quantitative literacy, compatible with the philosophies of Deming, Juran and Box, these approaches can ease implementation of ISO standards and accelerate the effectiveness of Six Sigma technologies.

BASIS

Worldwide, the number of people driving automobiles is increasing. Not all drive standard transmissions. Less can make more than minor repairs. Fewer still understand the thermodynamics of combustion. Nor is it necessary. Most don't even study their owner's manual. What are the lessons for statisticians?

W. A. Shewhart stated that "The long range contribution of statistics depends not so much upon getting a lot of highly trained statisticians into industry, as it does in creating a statistically minded generation of physicists, chemists, engineers, and others who will, in any way have a hand in developing and directing the production processes of tomorrow." Training needs to address developing appropriate quantitative skills in management, engineers and workers. Success or failure depends on an integrated approach that addresses:

- Need to Know – Direct Link to Job
- Simplified Step-by-Step Process to Guide Work & Assess Progress
- Technical Content Aimed at Facilitating Improvement
- Tools that Direct the Decision Process
- Effective Use of Educational Technologies

The following guidelines are drawn primarily from experiences over the past two decades within Ford Motor Company. Additional information sources and supporting studies will be referenced. Several graphical examples will accompany the talk. Let's address these issues one-by-one.

FOCUS

On-the-job training[1] must address clearly defined business needs if improvement in quality or productivity is desired. Local management must identify job-specific opportunities to be addressed prior to committing personnel to training. Linking individual experience and on-the-job examples bridges the training-application gap. Whether presenting advanced methodologies and core competencies, statistical education should aim to improve quantitative reasoning skills. To form the appropriate questions, recognize and collect relevant data, translate that data into information and answer the question is always the objective. Concepts of Type I and Type II error need to be tempered by consideration of Type III error[2] – answering the wrong question. Some basic learning objectives can be found in Appendix I.

PROCESS

Statistics implementation in industry often is a religious, rather than a profitable, experience (Figure 1). Looking beyond the sales hype technology differences are minimal. Statistics catalyzes improvement if focus moves beyond training and technology to integration into core business practices. Quality and productivity improves if the training addresses not only how to apply the statistical methods but also how the tools can be managed. Proforma, data collection protocols, step-by-step process documentation and review & revision procedures need to be addressed. Integration into the core business practices not only encourages use but also supports ISO9000 implementation.

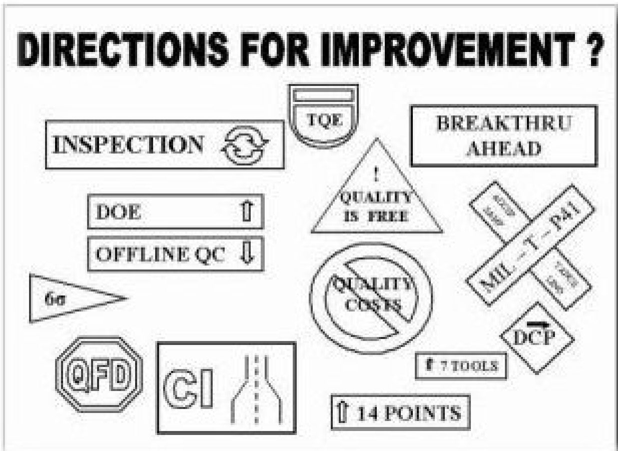

Figure 1. Using statistics to drive successful quality and productivity improvement efforts requires focusing on the objectives and not getting confused by slogans. All processes share the same conceptual bases. Use differences to enrich rather than to rebuild.

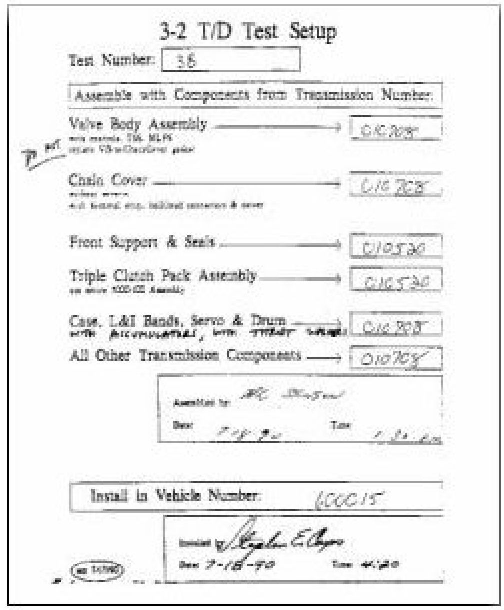

Figure 2. Test sheets must be specific & explicit!

The Six Sigma[3] process offers a comprehensive, if rather generic, example. At the core is a five-step quantification process – define, measure, analyze, improve, control. Unique are decision criteria that address moving from stage to stage and that emphasize targeted benefits. For example, in the problem definition stage, rather than focusing on overall process yield, "rolled throughput yield" – the product of the individual process yields – is emphasized. Although providing integrated case studies, simulations, statistical software, analysis formats and online reference guides, high level of local expertise is required for use.

Building improved business practices and simplifying use is the enabling step. Many of these processes are readily available. The Automotive Industry Action Group[4] provides both process and decision guidelines for quantifying and evaluating gage capability. Many, since Taguchi, offer user-friendly guides to planning experiments. Wu[5] enhances Taguchi's "linear graph" approach to two-level fractional factorial designs and Lorezen[6] provides a step-by-step guide to selecting multilevel orthogonal main effect designs. However, more is needed.

Sustaining productivity improvement[7] requires fool-proofing the process. Document the experimental plan. Be specific and take nothing for granted. Review procedures with personnel who will conduct the experiment. Identify all variables to be measured and those to be controlled. Describe measuring technique. Include recommended test points and the proposed test sequence. Specify checks, standards and calibrations. Provide detailed, step-by-step, instructions. Supply data collection sheets specific to the test (*e.g.* Figure 2). Allow for documentation and notification of changes in test personnel, equipment or procedures. Code experimental units to avoid biasing results. Color code and tag to minimize mix-up or loss. Use an experimental log and make clear all exceptions and outliers are to be thoroughly described and retained for analysis.

CONTENT & TOOLS

Content should not be divorced from the available tools. Statistical content[8] can be parsed into five areas: (1) theoretical derivation; (2) criteria for application; (3) numerical manipulation; (4) interpretation of results; and, (5) validation of assumptions. For our customer, tasked with process and product improvement, understanding the criteria for application, the interpretation of the analysis and its validation are most important. Theory and computation coverage should be limited to enabling effective method selection, interpretation and corroboration. Consider an example that models a pump's vacuum draw under various rpm, pressure and temperature conditions.

Fitting a functional model with "n" possible coefficients, there are 2^n-1 possible models. Using a second-order Taylor series approximation to estimate the functional fit, for "v" variables, there are v(v+3)/2 coefficients. Thus for this response with three possible predictors, nine coefficients require estimation. Thus, this "simple" model requires 2^9-1, or 511, alternatives to be evaluated. However, this modeling stage can be simplified by a three-step process: (1) Construct a conditional plots to visualize the response; (2) Use fitting functions to describe behavior, characterize variability and predict performance; and, if required, (3) Fit the functional form suggested by the prior steps.

First, construct a conditional plot. Figure 3 was generated using S-Plus[9] Trellis Graphics and its GUI interface tools. Within each plot vacuum is plotted against speed. Within each cell, the bars indicate the pressure and temperature. Pressure is constant within each column and increases from right to left. Temperature is constant within each row and increases from bottom to top. Examining this plot suggests a quadratic dependence on speed, a linear dependence on temperature and no dependence on pressure.

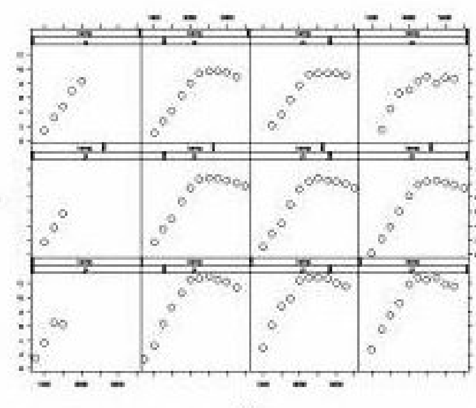

Figure 3. Conditional plot of pump vacuum (v) modelled by pump speed (rpm) given pressure (pr) and temperature (temp)

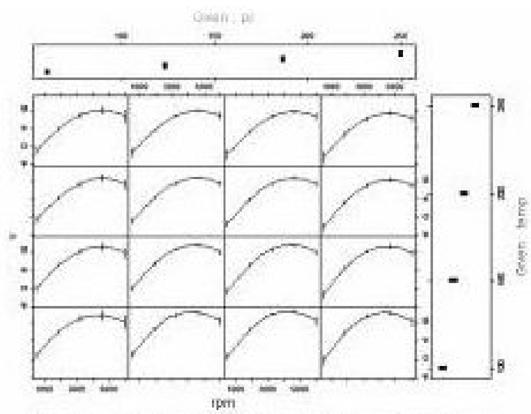

Figure 4. Conditional plots of loess predictions with 99% CI. Each cell plots vacuum vs. speed. The fixed values of pressure and temperature are given in the margins

Second, use a fitting function. Here, loess (locally weighted regression) models vacuum using speed, pressure and temperature. This "non-parametric" smoothing technique yields an average standard error of 0.48 and a multiple R^2 of 99% but requires the equivalent of 17 terms for the fit. This non-parametric model can be used for prediction. Figures 4, 5 and 6 display the

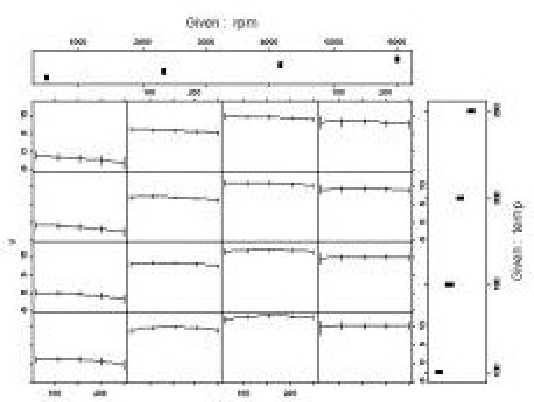

Figure 5. Conditional plots of loess predictions with 99% CI. Each cell plots vacuum vs. pressure. The fixed values of speed and temperature are given in the margins

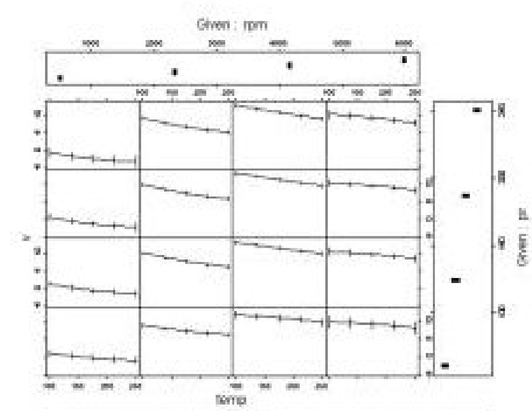

Figure 6. Conditional plots of loess predictions with 99% CI. Each cell plots vacuum vs. temperature. The fixed values of speed and pressure are given in the margins

predicted vacuum using sets of 4-by-4 conditioning plots. The vertical bars are 99% confidence limit for the fit. The vacuum *vs.* speed plots (Figure 4), indicates quadratic dependence, a linear term (*i.e.*

the maximum is not centered at zero speed) and an intercept near the origin. The vacuum *vs*. pressure plots (Figure 5), indicates vacuum dependence on pressure is negligible. Finally, the vacuum *vs.* temperature plots (Figure 6), suggests linear temperature dependence - constant slope with intercept dependent only on speed. If the task is prediction, further analysis is not required.

Third, if a parametric model is required, Step 1 and Step 2 ease the selection process. In this case, exploratory data analysis (Step 1) and generalized additive modeling (Step 2) suggest that vacuum may be adequately modeled by three terms - one linear in speed, one quadratic in speed and one linear in temperature. Indeed the linear model yields a fit with an average prediction error of 0.66 and a multiple R^2 of 99%.

Finally, selecting between the fitting function (Step 2) and the functional fit (Step 3) amounts to an empirical tradeoff between reducing fitting error and simplicity. Parsimony - the KISS (keep it simple statistician) principle - favors the linear model (Step 3). The admonition, “All models are wrong, but some are useful”, cautions against blind simplicity. Understanding the “physics” of the system should dictate choice. Extrapolation should be avoided in either case.

Summarizing, training needs to provide strategies and tools that address the client's business objectives. Purely quantitative methods can bog down the search for robust performance in a quagmire of analysis. Using scientific visualization and computer-intensive algorithms can speed assessment. To ”do more, do it quicker, do it better and do it with less” is the task.

PEDAGOGY

To obtain success, learning objectives must be measurably defined for each course and applications identified that connect with each student's needs. Our experience reveals participants appreciate and value the identification and delivery of predefined skills in each session. Using modular units with adequate session spacing sessions facilitates[10] application and aids retention. Providing guides for practice problems develops a systematic approach to quantitative issues. Individual consulting, in-class presentations and periodic management reviews drives use. Meetings with management also provide the opportunity to reinforce their ability to understand, initiate and interrogate statistical use.

Development of quantitative literacy requires both manipulative and reasoning skills. Myriad instructional technologies[11] should be matched to the task. Our experience confirms that direct group contact is hard to replace. Group sessions[12] provide the opportunity to discuss problem formulation, to explore alternative analytical approaches and to address quantification issues, individual analyses and assessments. Handouts minimize transcription and allow for more thoughtful assessment. Using graphical approaches and simulations broadens discussion, clarifies summarizing statistics and often simplifies interpretation. Group activities, interactive demonstrations and simulations can soften resistance to new approaches. Introducing improved methodologies with examples outside the participants' expertise allows incorporation without embarrassment.

Computer use and web accessibility can enrich the students' experience and ease the instructor's workload. Our experience shows introducing graphical and computing tools in class saves much aggravation but skill development can be enhanced[13] via web or CD based reinforcement. Most successful, mastery-level learning (providing permuted problems until satisfactory competency in demonstrated) aids understanding the basic facts, clarifies conceptual definitions and develops "computational" skill. Use the web to provide schedules, assignments and class notes. Adding an online discussion forum fosters discussion beyond the classroom and office hours.

NEW IDEAS?

In 1891Truman Henry Safford[14] noted, *"…six rules for teaching arithmetic badly…*

First. Divide your hours for arithmetic into theory, mental arithmetic, and written. In each division pay no attention to either of the others.

Second. In theory, proceed from abstract ideas; use foreign and high-sounding words; spend the most time on what is of no practical use; give a detailed theory of proportion.

Third. Arrange your mental arithmetic so that the children shall not employ any processes of their own; make it as much an arithmetic of figures as possible; if the scholar is to divide mentally, accustom him to write the dividend and divisor in the air with his finger.

Fourth. Have some special devices in mental arithmetic to throw dust in the eyes of the public.

Fifth. In written arithmetic, let each child do the sums from a book, imitating a process which has been shown him, but not explained. Let every one go on for himself; if he gets the right answer (by the key, which you keep), say Right! if not, say Wrong! and leave him to find out for himself how to get a better result. This we may call training in independence.

Sixth. An especial means of hindering all progress in arithmetic lies in the examples. Large numbers, unintelligible denominations, matters which the children do not understand, all these should be thoroughly employed.

By these six rules you will be pretty sure to attain your object of teaching without any result."

ADMONITION

Our experience demonstrates that statistics can drive continuous improvement. The job is simple. Help the client[15] to use what they know, preserve what they learn and use the scientific method for improvement.

REFERENCES

1. Hogg, R.V. (1985). Statistical education for engineers: An initial task force report. *The American Statistician, 30(1),* 168-175.
2. Deming, W.E. (1985). *Quality, productivity and competitive position*. Cambridge: MIT Press.
3. Harry, M., & Schroeder, R. (1999). *Six Sigma – The BREAKTHROUGH management strategy revolutionizing the world's top corporations.* NYC: Doubleday. http://6-sigma.com/
4. Automotive Industry Action Group (1995). *MSA-2 measurement systems analysis* (2nd edn). http://www.aiag.org/publications/quality/mas2.html
5. Wu, C.F.J., & Chen, Y. (1992). A graph-aided method for planning two-level experiments. *Technometrics, 34.* 162-175
6. Lorenzen, T.J. (1993). Making orthogonal main effect designs useful. *GMR-8025.* General Motors Research and Development Center, Warren, MI.
7. Zayac, S.A. (1985). Training for productivity – an engineer's perspective. *Statistical Education Proceedings of Joint Statistical Meetings, 8/85.*
8. Venables, W.N., & Ripley, B.D. (1999). *Modern applied statistics with S-PLUS* (3rd edn). New York: Springer. http://www.insightful.com
9. Zayac, S.A. (1997). Simpson's paradox - looking beyond the obvious. *ATEO Team Review - Statistically Speaking, 5/97.*
10. Mariana, L. (2001). Teaching the *modular* way? *Learning Paths (Common European Framework of Reference) 10/01.* http://www.learningpaths.cjb.net
11. Wegman, E. (2001). The HyperLearning Center. http://cne.gmu.edu
12. Lenth, R. (2001). Comments on Web-based instruction. *Joint Statistical Meetings, 8/01.*
    Lane, D. (2001). The quality issue – have we degraded statistical education? *Ibid. 176.*
13. Davis, R., Miller, .S (2001). Teaching statistics on line-on-and-off campus. *Joint Statistical Meeting, 22T, 8/01.* http://webct.pct.edu:3000/NTH16090/course/index.htm
14. Safford, T. H. (1891). Modern teaching of arithmetic. *The Atlantic Monthly*, *67(403),* 674-675. http://memory.loc.gov/ammem/ammemhome.html
15. Bennett, C. L. (1986). How to run a process plant. *Chemtech, 11/86.* 672-675.

APPENDIX I. SAMPLE OBJECTIVES FOR AN ENGINEERING DATA ANALYSIS CLASS

Problem Posing

- Use graphics & statistics to clarify operational definitions.
- Use categorical classification & sequential stratification to identify sources of variability.
- Pareto-ize factors to catalyze improvement.
- Quantify variability with smoothing functions, distributional models & simulation

Firefighting
- Quantify whether observed differences are real.
- Use expertise to improve test precision.
- Identify direct, conditional, or quantile relationships.
- Use of fitting functions & functional fits to picture & quantify relationships.

Process Improvement
- Determine if data is valid for prediction & whether all its information has been uncovered.
- Identify whether direct or team action is needed for improvement.
- Use of graphical & quantitative methods to quantify time dependencies.
- Use data to assess process capability.

Reliability
- Identify types, limits and predictability of reliability data.
- Classify quality, overload & wearout failures.
- Use simulation & modeling to predict system reliability & incidents of failure.
- Recognize need for upfront indicators of product performance.

Efficient Testing
- Recognize if the testing of many factors can be simplified.
- Structure test plans to be as dependable and illuminating as possible.
- Use computer-aided analysis to identify & quantify statistical significance & practical impact.
- Separate quality & productivity factors.

Robust Performance
- Use of sequential strategies to optimize response & minimize variability.
- Use replicate testing to improve robust performance.
- Simplify prediction through metric selection & data transformation.
- Exploit differences between design & noise factors in active experimentation

Prevention
- Recognize importance of combining graphical & quantitative analyses in decision.
- Estimate gage capability & understand its product implications.
- Identify & use predictive statistical models.
- Understand the extent, limits & potential of online automated data analysis on informed observation.