On the Importance of Statistical Science in Transportation

J. STUART HUNTER AND OLGA J. PENDLETON

Sound statistical science must be combined with modern technology if the United States is to meet its transportation quality objectives. Success will require standardized measurements, the collection of information-laden data, resourceful data analysis, and the planning for new data. These quantitative arts must be combined with methods for problem solving and decision making under uncertainty. Statistical science thus joins the engineering sciences in the never-ending pursuit of transportation quality.

Total quality management (TQM) in transportation can be viewed as the concurrent application of engineering, economics, organizational behavior, and public service. Providing TQM in transportation is complicated by the myriad political constituencies, vast geography, and the many facets of transportation—highway, rail, water, and air—in the United States. Nevertheless, certain persistent strands of TQM can be identified whatever the arena of application. Transportation executives lead and incorporate quality values into everyday management; vendors and builders work to provide products that go beyond the mere meeting of specifications. Never-ending improvement coupled with customer satisfaction is the leading objective of TQM for manager and vendor alike (*1,2*). But like the warp and woof of a fine fabric, these interpersonal and human behavior strands must be coupled with the strong cords of technology. Quality transportation *technology* must accompany quality transportation *management*.

The 71st Annual Meeting of the Transportation Research Board reflected the vast range of competencies that together define "transportation technology." One important technical competence is statistical science, its applications often so ubiquitous that many technologists and managers seem almost unaware of its existence. The days wherein transportation leadership can assume this casual attitude toward the art of good statistical practice must pass. Too much is at stake.

To elucidate the importance of modern statistics on behalf of transportation technology, we can begin with the problems of simply recording data. After all, being a good number librarian is a commonplace view of a statistician. Certainly it is important to count and record special occurrences, be they home runs or traffic fatalities. And it is similarly wise to have someone record continuous measurements such as the axle weight of trucks or the compaction of bituminous concrete. Of course, a good number librarian will keep neat files and will be thorough and quick to provide data on demand. But one observes that it is a rare computer software program that cannot meet these humble requirements. The science of statistics on behalf of transportation technology goes far beyond number librarianship.

Statistical science influences data recording by noting that information and data are not identical. A nonstatistical mind confuses the two. What is not realized is that information lies within data, much as ore within a matrix of rock. The statistical art is to create and record *information-laden* data. Attention turns now to what is being monitored or measured, how the data are being collected and recorded, and the purpose of the entire exercise. Furthermore, data are rarely cheap. Statistical problems abound.

Consider the problems of measurements, the "coins," the items of value, regularly interchanged by scientists and engineers (and politicians too). As an example, consider measuring pavement thickness. How much faith can one place in this simple evaluation? Much depends on the completeness of the definition of what is meant by "pavement," a description of how thickness will be measured, with what instruments, where on the pavement, and how many samples across what time and space. Thickness measurements may ultimately be used to estimate pavement stiffness, a subject of much concern in the current Strategic Highway Research Program (SHRP). Unfortunately, in today's world of transportation technology, different groups often hew to different measurement standards. Further, even when a single national transportation measurement standard exists, little or no surveillance or traceability mechanism is available. Frankly, a measure of pavement stiffness made in Boston would not be trusted in Seattle. And if the measurement were not trusted, how would one then make valid comparisons between suggested pavement improvement methods made in the two areas?

It is not reasonable to ask that every measurement made at every time and place have the same integrity as those guaranteed by the National Institute of Standards and Technology (NIST). But it is reasonable to ask those responsible for spending large sums on transportation projects to become more aware of the value of good measurement. Regrettably, most of the measurement systems mandated by the various U.S. transportation agencies are inadequately controlled. The societal costs of these poor measurements are huge (*3*).

The great engineering effort called the Tower of Babel came to a gradual halt when the builders found that they could no longer communicate. The present great engineering accomplishments of modern transportation are there for all to see. Unfortunately, symptoms of faulty technical communication (poor data) dim their present health and future growth. Defining transportation measurement processes, writing product and performance specifications, and setting up proper acceptance procedures require a common technical language.

J. S. Hunter, 503 Lake Drive, Princeton, N.J. 08540-5639. O. J. Pendleton, Texas A&M University, College Station, Tex. 77843-3135.

When one is dealing with data and its associated activities, statistics is the lingua franca.

Alert engineers and managers also recognize that an intrinsic variability, *noise*, accompanies all physical measurements. The variance of measurements (or equivalently its positive square root, the standard deviation) measures data noise and should accompany every reported statistic or set of data. The enhancement of quality requires the ability to detect signals in the presence of noise. For example, statistical quality control is the science of making decisions under uncertainty (accepting or rejecting products) using noisy data. As noted by Afferton et al. in another paper in this Record, successful statistical quality assurance (SQA) programs require carefully written protocols along with estimates of measurement and sampling variance, the statistician's technical term for noise. Awareness of statistical science begins with the knowledge that data variance is a natural phenomenon that is measurable and an essential component of decision making.

But the real leap to a consciousness of the importance of statistical science comes after data are in hand. Data analysis begins. Are patterns evident in the historical record that graphical displays might expose? What descriptive statistics (averages, percentages, ratios, physical measures) should one construct from the data? How might the data be partitioned to display differences or similarities? Using graphical techniques, much statistical analysis can be performed quite simply (*4,5*). Transportation managers should be alert to, and insist upon, informative graphics and learn the pitfalls of graphical misrepresentation (*6–8*).

Analysis then turns to inference. The key question becomes, "What can be inferred in the dark of these data?" What associations exist between the observed variables? What forecasts are reasonable? Are there mathematical or physical models evident, or partially discernible, that might serve to increase one's basic knowledge? How well are the parameters of interest estimated (in statistical terms, what are the standard errors of the estimates)? And finally, what about measures of uncertainty itself?

Concerning the fitting of models, some caution should be exercised when models are constructed from data using only statistical principles. Most statistical models relating cause-and-effect variables are *empirical*, often mere polynomial relationships between x's and y's. Fitting "regression" models is easy in these days of modern computers and statistical software. But the world of transportation science often employs mathematical models that go far beyond these simple statistical constructions—models that entrain the laws of engineering and physics, nonlinear in their parameters and often dynamic. Successful inference requires a blending of engineering knowledge and statistical practice. Enlightened empiricism accompanies good science.

We come finally to the creation of new data, information-laden data to provide answers to questions. A sampling program may be needed to determine the acceptability of purchased materials or the completion of a contract. A survey may be required to measure the public's concern over a proposed project. Special information may be needed in a laboratory or field test to compare different construction methods or items. Statistical science has made profoundly important contributions to the art of planning for data (*9*). Good data speed understanding; poor data become the pollutants to rational planning and decision making.

On reflection, one discovers that the science called "statistics" is the formalization of the scientific method; it is the use of data within the learning process applied to problem solving. Statistical science begins with the arts of amassing data, provides methods for data analysis leading in turn to inferences elucidating fundamental principles, and finally forecasts future performance, requiring confirmation and the need for new data. This learning process repeats the cycle of data gathering, analysis, inference, and forecasting until a state of knowledge is acquired sufficient to solve the problem at hand. Deming's insistence on "never ending improvement" reflects the essential need to increase knowledge on behalf of quality, to *learn*.

Managers and engineers in transportation and in all the applied sciences employ data daily to solve problems and thus daily "do statistics." What is generally lacking is an awareness that methods for problem solving and decision making under uncertainty are themselves a science. Its name is "statistics." Someone once said that problems are most quickly solved using the highest level of language possible (*10*). The challenge then is to make the scientific method, the learning process, the logic and language of statistics more apparent and less subliminal. This will only be accomplished by education. A good place to begin would be with the simple art of statistics.

REFERENCES

1. W. E. Deming. *Out of the Crisis*. MIT Press, Cambridge, Mass., 1986.
2. J. M. Juran. *Juran on Leadership for Quality*. The Free Press, Macmillan, New York, 1989.
3. J. S. Hunter. The National System of Scientific Measurement. *Science*, Vol. 210, 1980, pp. 869–874.
4. J. W. Tukey. *Exploratory Data Analysis*. Addison-Wesley, Reading, Mass., 1977.
5. J. M. Chambers, W. S. Cleveland, B. Kleiner, and P. A. Tukey. *Graphical Methods for Data Analysis*. Wadsworth, Belmont, Calif., 1983.
6. E. R. Tufte. *The Visual Display of Quantitative Information*. Graphics Press, Cheshire, Conn., 1983.
7. E. R. Tufte. *Envisioning Information*. Graphics Press, Cheshire, Conn., 1990.
8. H. Wainer. How to Display Data Badly. *American Statistician*, Vol. 38, No. 2, 1984, pp. 137–147.
9. G. E. P. Box, W. G. Hunter, and J. S. Hunter. *Statistics for Experimenters*. Wiley, New York, 1978.
10. C. H. Kepner and B. B. Tregoe. *The New Rational Manager*. Princeton Research Press, Princeton, N.J., 1981.