Mini Paper

A PRIMER FOR ENUMERATIVE VS. ANALYTIC STUDIES: USING CAUTION IN STATISTICAL INFERENCES

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Preamble: Statistical Inferences

In 1986, I attended a six-week class on “Enumerative and Analytical Studies” presented by Dr. W. E. Deming. Although my formal education in statistics and my applications of statistics in industry were well formed by then, Dr. Deming presented a different perspective. He presented an issue that was unknown to me; the controversy on statistical tests of hypotheses and the limitation of statistical inferences. I had many years to reflect, argue, debate, and finally understand thanks to Dr. Deming’s tutoring.

In April 1990, the seed of this paper was formed after attending (again) Dr. Deming’s four-day seminar in Cincinnati. It occurred to Marilyn and me that there needed to be more discussion of this topic. We wanted to present what we had discovered through our own experiences based on the theory of knowledge from Dr. Deming.

In the summer of 1990, Dr. Deming edited the paper with me. He was very excited and wanted it presented at his yearly conference in New York. We decided the timing was too soon for us. However, I believe the time is right to begin a dialogue within the ASQC membership on this topic. For some members, this entire topic will be new and will take some thought to understand the distinction between the two types of studies. For other members, this may be a chance to revisit and consider another perspective.

Eileen J. Beachell

Introduction

Increasing numbers of businesses are becoming convinced that quality in manufacturing is a key ingredient in successful global competition, increased returns to stockholders, product improvement, and increased productivity. When this conviction leads to action, it often results in the use of statistical methods, including industrial statistics such as tests of hypotheses and design of experiments. Due to the increase in the use of statistical methods, particularly design of experiments, in quality improvement, questions have been asked regarding the validity of statistical inferences drawn from these applications.

Dr. W. E. Deming (1) warns against the use of statistical methods for prediction in numerous papers and lectures:

“If statisticians understood a system, and if they understood some theory and knowledge and something about psychology, they could no longer teach tests of significance, test of hypothesis, chi square... Statistical theory, used cautiously, with the help of the theory of knowledge, can be useful in the interpretation of the results of tests and experiments.”

Examples are presented to illustrate when the industrial user of statistics should apply and interpret statistical results with conviction, caution, or not at all.

Enumerative and Analytic Studies

Critical to understanding the applications of statistical analyses in industry is the distinction between an enumerative study and an analytic study. An enumerative study is an analysis collected on data from a study on a limited group or frame. A decision will be made to accept or reject (to buy or not buy) or to act on the group or frame studied.

<u>An Example of an Enumerative Study</u>

A new supplier has sent a batch of parts to a plant. The manager must decide to accept (to buy) or reject (not buy) this single shipment of parts (the material). She has specifications for the diameter of these parts and she cannot spend time measuring every part. In this example statistical sampling and analyses are used correctly to study the shipment (the material). Sample statistics—e.g., comparing a sample of randomly selected parts to the blueprint tolerances for process location and spread—will allow the manager to make a decision about whether to buy the entire shipment.

Most parametric statistics require the use of a random sample of the material to describe the shipment in a valid manner. This example meets this important assumption. Therefore, most statistical analyses will allow for prediction of material characteristics from the sample. The sample could be used to predict and analyze the distribution of the material, conduct a capability study or calculate confidence intervals on the mean and variance. The statistical inferences made on the material(or frame) will help to make a decision on whether to accept the shipment or reject it.

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The Analytic Study

An analytic study is an analysis aimed at answering questions about future material not yet made. The analytic study is not interested in making a decision on the shipment but on the supplier. In the analytic study, a decision will be made on the cause system generating the material.

An Example of an Analytic Study

Continuing the part example, suppose that this time the manager must decide whether to accept the new supplier as a source. She still has the specifications and the random sample of parts from the one shipment of parts (the material) to help make her decision. It is the manager's plan to use the statistics from the sample to predict the supplier's parts over many shipments (the universe or the system). If the sample passes statistical evaluations comparing its location and spread to the blueprint specifications she plans to accept the supplier as a source. Although this may seem like a legitimate use of the sample, this strategy can lead to non-valid statistical results. In other words, the conclusion drawn from the sample statistics may not be confirmed when future shipments of the part are examined. In fact, it is often inappropriate to use enumerative statistics to answer analytic questions.

In the enumerative study the manager was able to use statistics calculated from the sample to describe the material because the sample represented that material (Recall, the sample was randomly drawn from the material it was to describe.) Similarly, to use the same sample to answer questions about future material we must have reason to believe that our random sample represents all of the supplier's future shipments. If we do not have convincing evidence of this, then sample statistics such as t-tests, ANOVA, and distributional analysis cannot predict the part diameters in the future.

Key Differences Between Enumerative and Analytic Studies.

Table 1 defines the key considerations made for each type of study.

TABLE 1. Differences between Enumerative and Analytic Studies

ENUMERATIVE	ANALYTIC
Interest is in studying the group (material) the samples were taken from.	A prediction will be made about the process that produces the material.
No predictions are made about future materials.	A decision will be made to change or not change the process that will produce the material in the future
The sample was chosen randomly from the material.	Special members were chosen for the sample.
A decision will be made only on the material studied.	The process will be worked on.
Most statistical analyses are valid for inferences on the material under study.	Statistical methods of inferences (DOE, t-tests, etc.) are not meaningful for prediction. If the conditions of the study are repeatable in the future, then statistical inference may be valid.
No decision will be made based on the process that generated the material studied.	Document the statistical control of the variables.

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Dr. Deming stated that knowledge is the key information needed for analytic studies over enumerative studies[1]. This knowledge may come from control charts or from an expert in the subject-matter who can look at the data analysis on the frame and try to determine future events. The expert in the subject-matter should determine if the study conducted under one set of conditions gives any credence under other, future conditions. A control chart can assist in this assessment. If the variable of interest is in a state of statistical control over many conditions the expert may infer that the material sampled today will represent material made tomorrow. It is important to recognize that the validity of an enumerative study aimed at answering analytic questions can never be known until we can study the variable of interest under many conditions. The correct number of conditions that must be studied before the validity of the study is known is also decided by experts in the subject matter.

Examples of Applications of Enumerative Statistics in Analytic Studies

1. A division manager wishes to increase the yield of one of his manufacturing processes. The process is sensitive to ambient temperature and humidity. These conditions cannot be manipulated and are, seasonally, in a stable state of control. An experiment is conducted. The results suggest that the process yield will be best if certain critical process variables are set at recommended targets. The results of this experiment may only be valid under the original temperature and humidity conditions. In fact, Dr. Deming states that “The exact environmental conditions for any experiment will never be seen again.” [2]

   For this application this means that if the experiment is conducted in the spring, it’s results may not be valid in the summer, fall, or winter. Future prediction of the process yields might be verified if the temperature and humidity conditions were statistically stable throughout all seasons at the original experimental levels.

2. A company purchases a new gauge to evaluate a critical process variable on the production floor. The quality manager assesses the measurement variation and stability of the gauge in a climate-controlled environment using a standard short term gage study. The variation of the gauge when used on the production floor in ambient condition will most likely be quite different from that seen in the controlled study.

   A control chart will be necessary to assess the measurement device under the majority of conditions that it will experience day-to-day. This analytic study could not predict future measurement variation using confidence intervals, t-tests, or other statistical tests. Given the knowledge from the controlled study, a metrologist (subject matter-expert) could be asked to help predict the behavior of the gage under all (unstudied) conditions that the company might expect in the future (i.e., temperature range (40 degrees Fahrenheit to 110 degrees Fahrenheit) or humidity (50% to 100%)).

3. The operator on injection molder no. 3 has been recording a control chart on the weights of the pieces coming off on his shift. The weight chart is showing many special causes and the process engineers cannot identify the sources. An experiment is conducted to identify the special causes.

   There is no justification from the statistics that the special causes identified in the experiment will effect the process in the future. It could be misleading to apply the experimental results gleaned from a sample effected by a special cause to a future, hopefully stable process. The design of experiment is solely an enumerative study. No valid statistical inferences can be made. Any information gathered from this experiment must be evaluated and confirmed by experts in the subject matter and additional studies should be performed to confirm results as the process becomes stable.

4. A design engineer is evaluating a new component. She runs some statistical tests to compare the first group of working components to the blueprint specifications.

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The use of these early experiments as conclusive information would be premature. The results could reflect the special conditions under which the prototypes were produced. The sources of variation seen in the prototype lab could be completely different from those sources of variation effecting the production line. Any information gathered from this experiment must be evaluated by the design engineer and confirmed by additional studies as the part goes into production.

5. A statistical facilitator has determined the thickness of a plate coating is in a state of statistical control, but with an unacceptable level of variation. An experiment was conducted in order to assess the causes of that common cause variation. Statistical information, even when the underlying variable is statistically stable, should never be considered without the insight of a subject matter expert.

   Changes which reduce variation in one variable could increase variation on another. The statistical facilitator verifies the rationale of the results with the design and process engineers before recommending or implementing any changes aimed at reducing thickness variability.

Summary/Conclusions

The examples provided in this paper were aimed at assisting the industrial user who wishes to apply enumerative statistical analyses to analytic questions.

Table 2 summarizes the Issues and Considerations highlighted by these examples.

Table 2.
A Summary of Issues and Considerations in the use of Enumerative Statistics to Answer Analytic Questions.

ISSUES	CONSIDERATIONS
Experimentation without consideration of the uncontrolled conditions surrounding the experiment.	Gain knowledge before implementing any recommendations. Repeat the experiment under different uncontrolled conditions.
Study conducted in controlled ambient conditions when the results are to be used in uncontrolled ambient conditions.	Use a control chart to assess the stability of the uncontrolled conditions over all of the time periods of the implementation's scope.
Study conducted on an unstable process and application of the results to an unstable or stable process.	Consult an expert in the subject matter as to the sensitivity of the process being studied to the uncontrolled conditions.
Study conducted on a new process, in non-production facilities and application of the results to the process as it will run on the production floor.	Include experts in the subject matter in all phases of the statistical work.
Analyze and implement the results of a study without the evaluation of the appropriate experts and users of the information.	Understand clearly the limitations of a study or experiment.

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The major issue raised by these examples is that enumerative statistical tests are by themselves inadequate to answer analytic questions. These methods alone cannot be used for prediction. Iterative studies, expertise in the subject matter, knowledge of the state of control of influencing variables are some examples of the additional knowledge required.

Dr. Deming's concern regarding the teaching and application of statistical tests is well founded. The cost to companies who conduct experimental designs under one set of conditions and than implement the results under another set of conditions are high. Consider the dollars invested to run the original study and implement inaccurate recommendations. Consider too, the damage done to the credibility of data-based decision-making when the expected experimental results do not appear. Industrial practitioners who continue to use the t-test and other enumerative statistics must be aware of their limitations. Recognition of both the limitations and the strengths of these methods will increase successful use in the description and prediction of many industrial processes. Δ

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