

**STATISTICAL METHODOLOGY:
PREREQUISITES FOR
EFFECTIVE IMPLEMENTATION
IN INDUSTRY**

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**STATISTICAL METHODOLOGY:
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EFFECTIVE IMPLEMENTATION IN INDUSTRY***

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ABSTRACT

Our consulting and teaching experiences in industry have led us to conclude that if statistical methodology is to be effectively implemented in industry, the following prerequisites must be satisfied:

- (i) statistical studies of processes must be perceived as carefully planned systematic investigations;
- (ii) statistical techniques presented to industry must address their unique problems in a manner that is understandable to them;
- (iii) training must be done by professional statisticians with extensive industrial experience.

This paper discusses our interpretations of these prerequisites and how we are assisting companies in meeting them through our work in the Institute for Improvement in Quality and Productivity at the University of Waterloo.

* This paper was read at the Industrial Quality and Productivity with Statistical Methods Meeting organized by the Royal Society of England, March 1988.

INTRODUCTION

Because of their potential for improving quality and thus productivity, there is greater interest in the use of statistical methods in industry than ever before. Unfortunately, professional statisticians are playing a relatively small role in the training and application of these methods. The non-professionals who are filling this gap often approach the subject in a very mechanical manner without paying adequate attention to the care required in data collection; as a result statistical methods are often naively or incorrectly applied. Unless professional statisticians pay greater attention to the special problems of industry, there will be few success stories and industry will quickly become disenchanted.

Industrial applications of designed experiments are complex and often very expensive. Randomization is not always possible; efficient screening of factors is much more important than statistical significance; usually assumptions must be made regarding the nature or presence of interactions. We must make informed compromises. Designed experiments are only as good as the factors and factor levels studied; the choice of factors and levels is difficult and requires teamwork between management and labour. It is even more difficult to convince management that statistical problem solving tools are efficient and effective. Management has seen a lot of fads come and go and they are justifiably skeptical of what to them, may be just another fad. Many expect a "quick fix" both with respect to courses (they expect to learn statistical process control or experimental design in three days or less) and experiments (often answers to complex problems are expected after a study taking a day or less).

To avoid disenchantment and to have statistical methodology effectively implemented in industry, the following prerequisites must be met:

- i) Studies of processes must be perceived as carefully planned, systematic, sequential scientific investigations that take random variation into account, and that recognize the need for factorial rather than one-at-a-time experimentation.
- ii) The statistical techniques used must address the unique problems of industry in a manner that is understandable.
- iii) Applied case studies relating the successful application of statistical methodology must be promptly communicated so that a body of statistical knowledge applicable to industry becomes available and so that it can be seen that these relatively low cost methods work.
- iv) Training must be done by professional statisticians with extensive industrial experience.

This paper discusses our interpretation of these prerequisites and how we as statisticians can assist industry in meeting them.

EDUCATION

The problems to which statistical methodology is being applied in industry are often complex. The perception that statistical techniques will provide a "quick fix" to these problems is one which will quickly discredit their usefulness. It is important that company personnel, especially upper and middle management, be convinced that statistical investigations require a strong commitment of time and resources. They should be open to this point of view since they have a lot of evidence that "quick fix" studies do not provide long term solutions. Education, through seminars and short courses appears to be one of the most important methods of convincing industry to adopt this point of view. For these seminars to be effective it is important that:

- i) The discussion of statistical techniques and the need for planning be done in the context of industrial problems using examples and case studies based on experience;
- ii) The seminar instructors have a thorough knowledge of statistics and industrial experience in its application;
- iii) When the purpose of the course is to develop some technical skills, the course enrolment should be limited to give ample time for course participants to work on case studies and to discuss problems with instructors;
- iv) The seminars stress that statistical investigations compliment, enhance and depend on engineering know how and ingenuity and are not a substitute for it.
- v) In the technical courses participants come with specific problems in mind and start to apply the methods to the solution of these problems during and immediately after the courses.

At the Institute for Improvement in Quality and Productivity we are using one to three day management overview seminars on statistical process control and experimental design to reach upper and middle management. These seminars not only discuss the scope of the techniques available but also heavily stress the dependence of successful implementation on:

- careful problem definition;
- an intimate knowledge of the process being studied;
- a knowledge of the crucial role of sample selection in any statistical analysis;
- careful factor and level selection in an experimental design;
- the team approach to problem solving;
- a commitment of time and resources;
- continuing management leadership and personal involvement as well as "commitment".

Even in the more technical courses that are directed towards those who will be implementing the statistical techniques, there must be a heavy emphasis on planning in addition to the more detailed explanation of the relevant statistical techniques. However, in these more technical seminars we must observe the dictum of Tukey (1954):

"While techniques are important ... knowing when to use them and why to use them is more important."

This is particularly true when we consider that some of the techniques discussed, such as experimental design, are very sophisticated and require not only a high level of statistical expertise, but also very careful management throughout.

However it must always be remembered that the solution to a serious problem may well be a simple data based analysis, such as plotting a histogram for each of the separate streams of a process. We must avoid the temptation to train people who will go around looking for a place to apply specific techniques; rather we must train (and act as) broad general problem solvers.

In the technical courses offered through the Institute (a 15-day statistical process control course, a 10-day design course and 3-day overview courses) about half of the time is spent on tutorial sessions. These tutorials give hands on experience with the techniques discussed and provide an understanding of how and why they work. In addition, the tutorials are important in providing an opportunity for interaction between student and instructor. In these tutorial sessions, participants are encouraged to discuss with the instructor the use of the course material in the context of the problems they have in their own plants and, if appropriate, to give presentations to the group.

Another key to successful training is to provide it "just in time", i.e. for immediate application. That is, the company sending participants to courses should be prepared to commit the time and resources to allow the participants to implement the material studied during and immediately following their return to the plant. There is no point training people unless they plan to use the material immediately. To this end we encourage participants to bring problems to the courses for discussion. For in-house 10-day design courses, we insist that every participant be involved in a project to which statistical design techniques can be applied. These projects are screened beforehand, and on-site follow up consulting sessions are held with the participants to help and encourage their work on the project. These follow up sessions tend to be very beneficial in that they:

- sustain the momentum of the project;
- give an opportunity to reinforce points made in class in a production setting;
- improve the statistician's image within industry.

The educational approaches discussed above will have an impact in the short term. However, for the long term, universities need to provide undergraduate engineers, some scientists and statisticians with in-depth training in the statistical techniques that are useful to industry. They should **all** be made aware that a statistical study takes time and careful planning. If we do not provide this undergraduate training, statistical process control and design of experiments will, due to improper use through poor training, become a passing fad in the industrial community.

WHICH CONCEPTS AND TECHNIQUES?

If statistical methodology is to be effectively implemented in industry, then we as statisticians must present statistical concepts and techniques that directly address the real problems. Below we discuss a few of the concepts and techniques that we have found to be important in this regard and which do not seem to be well understood in industry.

The sources of variation that affect the quality characteristics under consideration dictate the method of data collection, the amount of data to be collected, the method(s) of analysis, and the interpretation that can be made. This principle is not well understood, even though it is basic to the implementation of statistical methods. Control charts, for instance, are a relatively simple tool to use, but often the concepts of natural variability, statistical stability and the role of sample (rational subgroup) selection are not understood. Nor is it understood that they provide a tool for process improvement not just process monitoring. They are thus often used indiscriminately and as a result, are often ineffective and thus doomed to be viewed as an additional piece of bureaucracy.

In experimental design, the use of blocking to control variation in unstable processes and the use of randomization to reduce the influence of possible systematic variation is not well understood and in fact discouraged in many applications. Blocking and randomization are not always feasible in an industrial context; the costs are sometimes high. We must, however, make clear that without blocking and randomization many investigations may be misleading and/or uninformative; the result will be a mistrust of statistical methodology. The presentation of case studies which reflect failure due to lack of blocking or randomization will help to make the point.

Statistically designed factorial and fractional factorial experiments provide the most efficient methodology for studying complex relationships in modern manufacturing processes. The unique problem of trying to optimize process output and minimize process variability, in the presence of a very large number of potentially important factors, should cause us to rethink our approach to experimental design. Should we not, in such instances, be recommending a sequence of experiments? The first experiment should usually be a highly saturated design to prioritize (screen) the factors that influence the process output. One factor at a time experimentation is known to be very unreliable, are the findings of an experiment on only three or four factors when there are twelve contenders much more reliable? Is it not better to try and prioritize as many factors as are of interest by including them all in a highly saturated design? Follow up experiments can be done if necessary to sort out interactions. In many studies in which we have assisted, we found that if an interaction exists between two factors, it is most frequently "synergistic" in that it does not alter conclusions regarding optimum conditions from those that would have been based on a main effects design (Figure 1).

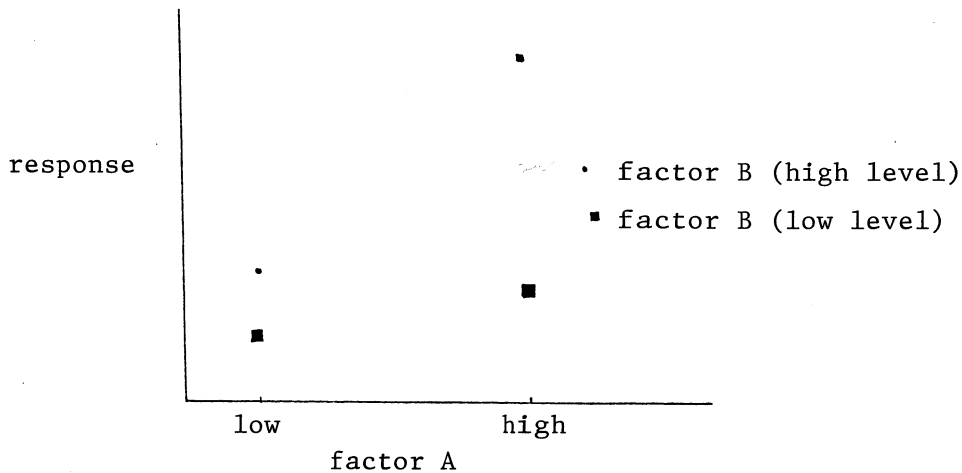


Figure 1: "Synergistic" interaction plot of factors A and B

Interactions which lead to different optimal factor levels than the main effects are much less frequent. This may be why highly saturated designs have been so successful in prioritizing the influence of the factors in a process.

In most industrial experimentations the main interest is centered on screening out the major factors and interactions, and any reference made to t-tests, F-tests, and confidence intervals will only cloud the issue. The importance of normality, equality of variance and other model assumptions fade when compared to factor and level selection and data collection methods. A number of us involved with teaching and consulting at the Institute have found that Joiner's (1988) comment:

"We must learn to scrap a huge portion of what we worked so hard at to get those degrees in statistics."

is much closer to the truth than we ever anticipated. It is, however, imperative that when we give overview seminars and more technical courses on experimental design we do our utmost to explain interactions, confounding, blocking, randomization and the efficiency of balanced fractional designs. If users understand these concepts and their importance, then they can judge the seriousness of ignoring or assuming them away in their particular applications.

In particular, we should point out the advantages of blocking. It is not well understood by industry that blocking can be used to protect an experiment against instability. In fact, it is often the view that processes need to be stable before an experiment can be carried out. Further, it is often not realized that the use of blocks that are representative of a wide range of production conditions will lead to more reliable conclusions. Blocking also provides a safety factor in that disaster during an experiment will usually only require restarting the current block of runs rather than the whole experiment. Finally, any study of a manufacturing process should be done under production conditions; blocking in runs of four often allows enough

flexibility to do this without too much disruption.

Every effort should be made to keep the statistical procedures and analysis as simple as the problem will allow. Again this requires initial planning. Often considerable savings result from the use of Pareto diagrams or histograms plotted separately by process streams. We must encourage the investigator to think about what simple "low tech" investigations would be fruitful before embarking on a complex "high tech" statistical investigation such as an experimental design. In one instance, a fractional design on 11 factors seemed to indicate that none were significant. This led the investigator to compare the three streams in the process using histograms; the streams were found to be dramatically different. A simple change resulted in direct cost savings of \$250,000 per year. Had this simple investigation been done first, the problem would have been solved much more quickly using only a fraction of the resources.

DOCUMENTATION

Nothing inspires a company more than a well documented, successful case study, especially when there is a significant pay back and the area of application is very similar to the company's own processes. Such documented case studies are needed to keep up the momentum of statistical activity in industry. However, in order to create a pool of knowledge for the company to draw on, detailed documentation of each study must be done, whether or not the study is viewed as being successful in improving the process or saving resources; we often learn more from mistakes than successes.

A good deal of the documentation should be done before and during the study. Indeed to implement a systematic statistical study effectively several crucial steps must be organized and followed before the study is done. These crucial steps and documentation for organizing the implementation of a factorial experiment are outlined below.

Project Implementation Steps

- Define problem/Set objective.
- Establish project team.
- Choose response quality characteristics.

Deliverable: Written Statement of Objectives

- Brainstorm potential factors.

Deliverable: Cause and Effect Diagram

- Ensure good measurement systems are in place.
- Choose factor levels.
- Develop experimental design.
- Develop plan and schedule of experiment.

Deliverable: Detailed Written Experimental Plan

- Perform representative trial runs.

Careful attention to these details will maximize the probability of success; ignoring one or more steps will do the reverse.

Information about the application of statistical methods to industrial problems should be published. Symposia such as those conducted by the American Supplier Institute or General Motors of Canada Limited, are excellent for the presentation and discussion of case studies. However, it is usually the successful studies that are presented at such symposia. The valuable information that could be provided from some selected, less successful studies rarely appears.

Technical journals also provide an opportunity to present informative case studies. An excellent statistical process control case study discussing the moulding of a bumper is given in a paper by Werner and Berenter (1986). More publications of such studies would certainly aid in effective implementation of statistical process control through the information they provide directly to industrial personnel and through their use as teaching aids.

SUMMARY

In this paper, we have discussed what we believe to be the main prerequisites for the effective implementation of statistical methodology. The most important prerequisite is painstaking up-front planning and the allowance of sufficient time and resources for careful implementation; in many instances, it appears that industry is too busy putting out fires to take this longer term view. If we can convince industry to take the time to plan their studies on a sound statistical basis, we will have made a large step towards the effective implementation of statistical methodology in industry and thus to a dramatic improvement in quality and thus productivity.

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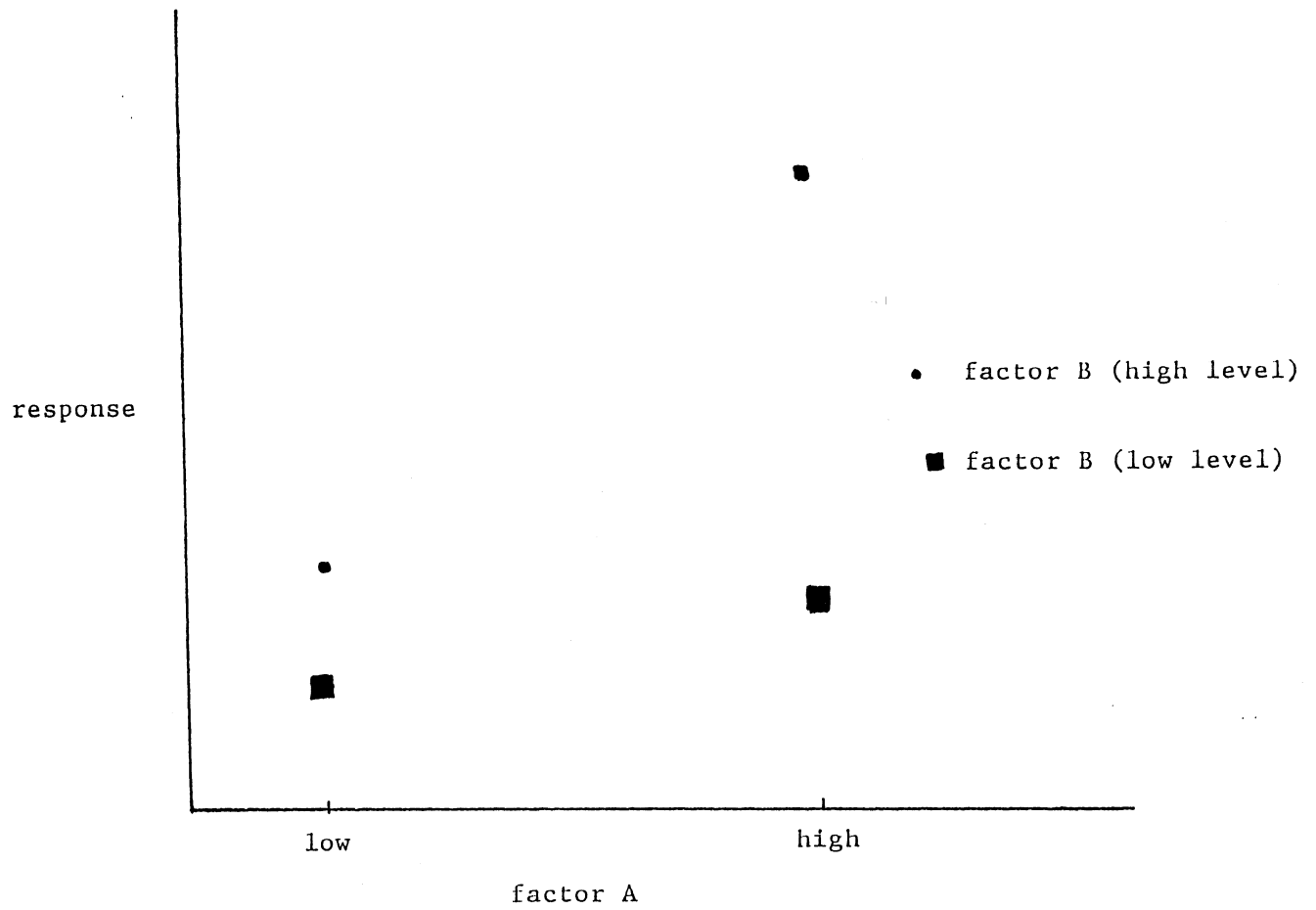


FIGURE 1: "Synergistic" interaction plot of factors A and B

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