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Report No. 171

# Quality Quandaries*
# Proposals: A Mechanism for Achieving Better Experiments

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*October 1998*

*Edited by George Box and Søren Bisgaard

*CQPI*
University of Wisconsin

Report No. 171

***Report Series***
*in Quality and Productivity*

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# Proposals: A Mechanism for Achieving Better Experiments

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*ABSTRACT*

In this paper we outline how a simple procedure of requesting a proposal before management signs off on an experiment can dramatically improve the effectiveness of experimenters. An eleven step process is provided.

KEYWORDS: Management of Experiments, Industrial Experimentation, Administrative Procedures.

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# Proposals: A Mechanism for Achieving Better Experiments

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In this paper we outline how a simple procedure of requesting a proposal before management signs off on an experiment can dramatically improve the effectiveness of experimenters. An eleven step process is provided.

A key to success in experimentation is good planning and careful preparation. Every year I get involved in a large number of experiments, some of which are not well executed. It has been my observation that the more time spent on planning and preparation, the more successful the experiments. A carefully prepared proposal for an experiment prior to its execution often seems to improve the final results.

When teaching experimental design, I have for years used the late Bill Hunter's (1977) idea requiring the students to run an experiment as a class project, providing them with practical experience that cannot be conveyed through lectures and textbooks. When I first started this I simply required the students to design and execute an experiment and provide me with a final report. Unfortunately many of these experiments were done in a last minute fashion and were poorly planned and executed. Without adequate preparation the students seemed to rush into the actual execution of the experiments with insufficient thought about its objective. A dramatic improvement was produced when I began to ask the students to prepare a written proposal as a preliminary homework.

Over the years I have refined my requirements and made them closer to what might be required in industry. The outline is shown in Table 1. I have also used the proposal idea in my industrial consulting. It seems to have had a similar effect providing the experimenters, as well as management with a checklist to assure that relevant issues have been considered prior to the execution.

1. A concise statement of the objective(s) of the experiment
2. A list of factors (treatments) and their levels
3. A short description of how to measure the response(s)
4. A table showing the design and possible confounding
5. A layout of the data collection sheets
6. A flowchart and a description of the experimental procedure
7. A plan with a timetable and calendar for the experiment
8. An outline sketch of how to analyze the data
9. A budget for time, money and other resources needed
10. Anticipated problems and how to deal with them

*Table 1: A summary list of the eleven points to be covered in a pre-experiment proposal. Extended versions of each point are discussed in the text.*

## A Template for A Proposal for an Experiment

The discussion that follows applies best to factorial experiments conducted in the sequential mode in which they are most often used. The level of detail necessary for a pre-experimental proposal will depend on the scale and scope of the project. For minor experiments a very elaborate proposal may not be necessary. But if the experiment is large and expensive and is to be run by a team rather than a single investigator, it is wise to allocate a reasonable amount of time to its planning and preparation. The eleven points with accompanying discussion follow:

1. A clear and concise statement of the reason for the experiment and its objective(s) and background.

*Discussion:* Most experiments are part of a larger investigation. The objective of an investigation may change as new knowledge is gained. A rigid definition of the objective applying to the whole investigation is therefore not necessary. Only a clear formulation of the objective of the next experiment is required. It is important that investigators at each stage are forced to think why this experiment is needed. This discipline is often half the battle. As

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Cochran and Cox (1957, p. 10) said:

> The statistician who expects that his contribution to the planning will involve some technical matter in statistical theory finds repeatedly that he makes a much more valuable contribution simply by getting the investigator to explain clearly why he is doing the experiment, to justify the experimental treatments whose effect he proposes to compare, and to defend his claim that the completed experiment will enable its objective to be realized.

In a nutshell the purpose of the proposal is to force the thought process implied in the above quote. Most experimenters are action-oriented people. They prefer to tinker rather than to plan. By making the proposal and the subsequent review and approval by management a standard administrative procedure, the proposal mechanism can temper the urge to act before thinking and planning.

2. A list of factors (treatments) and their levels.

*Discussion:* From their understanding of the process under investigation, the experimenters need to determine what they think are the appropriate factors to manipulate and over what range to change them. If it is a screening experiment then a cause-and-effect diagram is helpful in creating an initial list of factors. This list may contain too many factors. It will then need to be pruned to a manageable number by discussion among the parties involved.

When picking the factor levels it is important to consult with people knowledgeable about the process. For quantitative factors the selection of factor levels is often a balancing act between changing the factors enough to make a perceptible change yet not setting the levels so far apart that the process "explodes".

It has sometimes been suggested that the experimenters should also list all the potential interaction effects. This may sound like a good idea in theory, but in practice I have found it less than useful. It takes a lot of time, yields unreliable results, and often creates disagreement between team members arguing passionately on the basis of little or no facts. The reason an experiment is necessary is because we don't know the effects of the factors. Under those circumstances it would seem rather unusual if the experimenters should be able to predict with any confidence which factors will interact.

3. A short description of how the team plans to measure the response(s). Preferably the team should conduct a physical test to verify the way they plan to measure the response(s) is reliable. Documentation of evidence of the measurement process being in statistical control can be attached in an appendix to the proposal.

*Discussion:* If I were to provide a list of the most frequently encountered reasons why experiments fail, trouble with the measurements would come in as the clear "winner". In many experiments the response that relates best to the objective is not one for which we have reliable instruments. Considerable creativity and ingenuity may be needed to come up with ways of measuring what they want measured. In any case, the method must be calibrated. It must also show an acceptably low amount of variability. It is also necessary to check that repeated measurements remain in statistical control.

To achieve this goal the experimenters might often have to conduct a separate study prior to the experiment to document that, in fact, the measurement process is calibrated and in statistical control. If these precautions are not taken and documented it may be found that the measurements drifted during the experiment and the results, therefore, are of little value.

At the analysis stage, some of the telltale signs of measurement problems are: few or no significant factors, outliers, inconsistent results and excessive variability among trials that supposedly are replicates. A typical consequence of this is that the experimenters need to go back and conduct the measurement process study they decided they "did not have time to do" before the experiment. And, of course, then they need to repeat the experiment! Time used on first checking the measurement process is time well spent.

Related to the issue of measurements is how samples are to be labeled and stored. For example, in the food industry the response may be some quality characteristic of the product after a specified number of months of storage. Much confusion may then result if samples are not carefully labeled, dated and stored. The team may need to develop rather elaborate storage management systems to assure that samples can be traced to the appropriate factor combinations and that samples are stored in one for the objective appropriate manner.

4. A table showing the design and possible confounding.

*Discussion:* Having to set out the design table explicitly in the proposal forces the team to think through a number of important issues. How large should the experiment be? How many replicates and center points are needed? Should a full factorial design be used? Can the team live with the confounding that occurs in fractional factorials? A typical mistake is to design large comprehensive experiments that are supposed to provide answers to all questions in one shot. A better and safer approach is to proceed sequentially with a series of small experiments as explained in $BH^2$ Chapter 9.

5. A layout of the data collection sheets the team plans to use for the experiment.

*Discussion:* Poor bookkeeping is another major source of trouble in the practical execution of experiments. Experimental results that make little or no sense often occur because the standard order and the random order are mixed up, the wrong factor combinations are applied, or the results are recorded for the wrong trial number. Admittedly in "the heat of the battle" such things can happen. However, it is inexcusable if bookkeeping mistakes derail a large, expensive and time-consuming experiment.

Carefully worked out data collection sheets can go a long way to prevent this type of problem. For example, for two-level factorial designs I recommend that individual data collection sheets be prepared for each trial. These sheets should specify the settings for each factor for that trial written out in terms of the actual non-coded values, and have clearly marked areas for recording the response(s), general environmental conditions and other comments. Each of the sheets should then be numbered with the standard order, physically randomized and — very importantly — *stapled* together as a book. To execute the experiment in the chosen random order and to assure that the results are recorded for the appropriate factor combinations only requires the team member responsible for recording the results to turn over the pages of the book one-by-one as the trials are executed.

6. A flowchart and a description of the experimental procedure (i.e. a detailed description of how the team will execute a single trial).

*Discussion:* By experimental procedure I am referring to the operational steps involved in executing an individual trial. Frequently this may require several complicated steps. A flow chart of this process is useful. It helps to make sure the procedural steps are agreed upon, understood by the team members responsible for carrying them out, and sufficiently standardized so they do not change during the experiment even when performed by different team members.

7. A plan with a timetable and calendar for executing all the steps of the experiment. The timetable should include time for a pilot experiment to get the procedure right before the team gets started on the formal experiment, execution of the experiment, data analysis, a possible follow-up experiment, report writing, presentation preparation, presentation to management, etc.

*Discussion:* Experimentation takes time. Having to draw up a plan is useful even if the team does not necessarily follow it in all details. I recommend the plan be made up as a Gantt chart typically used for project scheduling. Gantt charts provide a simple graphical display showing the steps of the process as well as calendar times. When making the Gantt chart I recommend that an explicit provision is made for conducting a pilot experiment. What I have in mind is a small experiment before the actual experiment. Typically one or two of the trials from the actual experimental design possibly replicated a few times can be used. Such a small experiment will often reveal problems with the experimental procedure, the measurement process, the calibration, excessive replication error, etc. It also provides a dress rehearsal so the team does not have to learn the procedural steps during the first few trials of the actual experiment, something that invariably causes trouble. Moreover, the pilot experiment is a good time to fine-tune job responsibilities among the team members and discover overlooked details that otherwise may trip up the larger experiment, but at that stage with much more serious consequences.

8. An outline sketch of how the team plans to analyze the data.

*Discussion:* This requirement provides for reflection about the experiment. It is a check to see if what is wanted will be delivered. What is expected here is an outline of the steps of the analysis possibly augmented with an analysis based on simulated numbers. This last suggestion is a good idea but not something I absolutely will insist on.

9. A budget outlining the time, money and other resources that will be needed to execute this experiment.

*Discussion:* Experimentation is often very expensive. By having to make a budget the team is forced to think about the cost of running the proposed experiment. In many cases this kind of reflection may cause the team to modify their ambitions or find more cost-effective ways to proceed. The budget also provides management with an estimate of the resources that will be committed before approving an experimental proposal.

10. Anticipated problems and how the team plans to deal with them.

*Discussion:* No activity as complex as an experiment, which by its very nature is not routine, will occur without problems. The team must think about problems that may surface in the execution of the experiment. What is important is the thought process and reflections it provokes, and the preventive measures the team comes up with.

11. A list of the names of the team members and his/her responsibilities.

*Discussion:* Some experiments are small and can be executed by a single investigator, who is often the same person who prepared the proposal. In other cases an experiment may involve a large number of people. In that case it is important that each person knows what he or she is supposed to do and that his/her role has been clearly defined. Having to outline the job responsibilities will force the team to consider these issues.

Jobs and responsibilities can typically be classified into three phases: planning, execution and analysis. During the planning phase the proposal has to be worked out, materials and resources provided for, time reserved during which the experimental equipment may be used, job responsibilities worked out and team members selected. Most of these planning tasks will fall on the team leader in collaboration with someone knowledgeable in experimental design theory. During the execution phase the responsibilities are: general team leadership on the floor, calling out factor combinations, physical execution of trials, handling, labeling and storage of samples, measurements, data recording, note taking and checking of all the previously mentioned tasks. After the experiment is completed follows the analysis phase. Typically this task will be done by a single person knowledgeable in statistics. However, it is important, if not critical, that subject matter experts are involved too. This is to assure the analysis is guided by what is important from a scientific or engineering perspective, that all relevant issues regarding how the experiment was executed are taken into account, that important clues are not overlooked and scientific feedback facilitated.

The most critical part of the plan is the execution phase. Because this phase typically involves the largest number of people, many of whom may not have any previous experience in conducting experiments, considerable effort should be devoted to training. A good time to firm up the plan and fine-tune responsibilities for the execution phase is during the pilot experiment.

Finally, a few words about the team leader's responsibilities. This person is much like the captain of a ship—ultimately responsible for all activities and the person to step in and take charge when the unexpected happens. A key function of the team leader prior to the execution phase is to educate and teach all team members in his/her respective tasks. My own experience is that it is helpful to go beyond just telling people what to do. Giving them an idea of the big picture, the objective and what is involved in experimental design often pays off handsomely. If they understand, they can take pride in what they do, think for themselves rather than just taking orders, and make more informed decisions.

A frequently observed mistake is for the team leader to hand over all the details of the execution to lab technicians that have little prior experience in experimental design and who have been provided with little explanation of the background for the specific experiment. It is not reasonable to expect people to be able to conduct experiments without prior training and education. For example, in one instance a lab technician decided to "improve" the plan and run the trials in a way that "was more cost efficient." By doing so he essentially dispensed with the randomization. Moreover, again to be "more efficient" he modified the procedure midway through the experiment. The end result was disastrous, but I don't think he was to blame – the team leader was. Thus you must be sure that those you delegate to are sufficiently trained and instructed. Even so you should continue to keep an eye on what is going on. Experiments most often go wrong in the details. If you cannot trust the results because of subsequent doubt about how the experiment was executed, you could just as well not have conducted the experiment.

A proposal need not be long. Five to six pages including an executive summary is often sufficient. If necessary appendices can be attached providing details on the measurement process, data collection sheets, sample management, etc. If the proposal writing task as outlined above seems daunting, remember that the time spent on the proposal is not wasted. Most of the writing can be reused in the final report, another document that ought to be part of good management of experiment practice.

## Conclusion

Experimentation is a key to systematic organizational learning. It is a means for advancing the frontiers of knowledge. Organizations that consciously and deliberately nurture the skills of experimentation will be able to develop new and better products and services much faster, reduce the chance of field problems and costly product recalls, beat the competition, and succeed in their area of business. Many organizations squander large sums of time and money because of poor management of the experimental efforts in their organization. Organizations that invest in education in experimental design, nurture the skills of executing experimentation, and develop good management procedures for experimentation, are positioning themselves strategically for a leadership position in a rapidly changing market place.

The establishment of educational programs in the theory of experimental design is clearly a good starting point. However, it is also important to develop the practical skills of executing successful and informative experiments. Learning under a mentor is an effective approach. Management must set up apprentice systems that guarantee that the pool of employees with knowledge about how to run experiments will satisfy their future needs. An apprentice system ensures that experienced experimenters transfer their knowledge and skill to new generations of engineers and scientists. Lastly, management can improve the quality of the experimental effort in their organizations by instituting administrative procedures that facilitate high standards and good experimental practice. I believe that the proposal mechanism described in this column provides a good starting point.

## Acknowledgment

The work on this manuscript was supported by the National Science Foundation (NSF) Grant No. DMI 9500140 and Grant No. EEC 8721545. The author would like to thank George Box and Spencer Graves for helpful comments on a previous draft of this manuscript.

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