Pre-design Experiment Guide Sheet[1]

The use of pre-design experiment guide sheets provides a way to systematize the process by which an experimentation team does this planning, to help people to (a) more clearly define the objectives and scope of an experiment and (b) gather information needed to design an experiment.

Steps of Experimentation

1. Recognition of and statement of the problem
2. Choice of factors and levels
3. Selection of the response variable(s)
4. Choice of experimental design
5. Conduction of the experiment
6. Data analysis
7. Conclusions and recommendations

Pre-design Master Guide Sheet

1. Name, Organization, Title
2. Objectives
3. Relevant Background
4. Response variables
5. Control variables
6. Factors to be "held constant"
7. Nuisance factors
8. Interactions
9. Restrictions
10. Design preferences
11. Analysis & presentation techniques
12. Responsibility for coordination
13. Trial run?

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[1] Adapted by Erik Barry Erhardt (2007/02/23) from Technometrics, February 1993, Vol. 35, No. 1, A Systematic Approach to Planning for a Designed Industrial Experiment, David E. Coleman, Douglas C. Montgomery

Pre-design Master Guide Sheet

1. Experimenter's Name and Organization:

Brief Title of Experiment:

2. Objectives of the experiment (should be unbiased, specific, measurable, and of practical consequence):

(To be **unbiased**, the experimentation team must encourage participation by knowledgeable and interested people with diverse perspectives. The data will be allowed to speak for themselves. To be **specific and measurable**, the objectives should be detailed and stated so that it is clear whether they have been met. To be of **practical consequence**, there should be something that will be done differently as a result of the outcome of the experiment.

Members of the experimentation team should ensure that all interested parties agree on the objectives, agree on what criteria will determine that the objectives have been reached, and arrange that, if the objectives change, all interested parties will be made aware of that fact and will agree on the new objectives and criteria.)

3. Relevant background on response and control variables: (a) theoretical relationships; (b) expert knowledge/experience; (C) previous experiments. Where does this experiment fit into the study of the process or system?

((a) to establish a context for the experiment to clearly understand what new knowledge can be gained; (b) to motivate discussion about the relevant domain knowledge, since such discussion may change the consensus of the group, hence the experiment; and (c) to uncover possible experimental regions of particular interest and others that should be avoided. With this background, we reduce the risks of naive empiricism and duplication of effort.)

4. List: (a) each **response variable**, (b) the normal response variable level at which the process runs, the distribution or range of normal operation, (C) the precision or range to which it can be measured (and how):

1. It is preferably a continuous variable.
2. Should capture, as much as possible, a quantity or quality of interest for the experimental unit
3. Should be in appropriate units
4. Should be associated with a target or desirable condition (which motivates the experiment).
5. Is preferably obtained by nondestructive and nondamaging methods so that repeated measures can be made and measurement error can be quantified.
6. Should not be near a natural boundary.
7. Preferably has constant variance over the range of experimentation.

Response variable (units)	Normal operating level and range (current use)	Measurement precision, accuracy—how known? (ability to measure)	Relationship of response variable to objective (knowledge sought through experimentation)

Different categories of factors that affect response variables, based on three key characteristics—magnitude of influence on response variables, degree of controllability, and measurability (e.g., precision and accuracy).

A description of the diagram is as follows:

1. Control variables are measurable, controllable, and thought to be (very) influential.
2. Held-constant factors tire controlled.
3. Nuisance factors are uncontrolled factors (either they cannot be controlled, or they are allowed to vary).

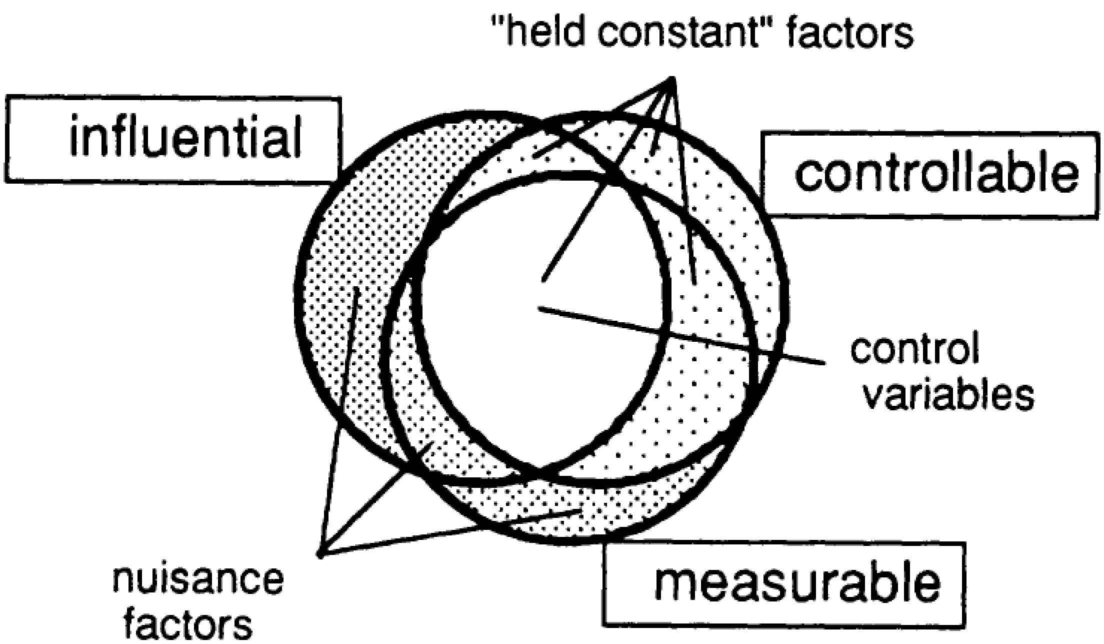


Figure 1 Different Categories of Factors Affecting Response Variables.

5. List: (a) each **control variable**, (b) the normal control variable level at which the process is run, and the distribution or range of normal operation, (the precision (s) or range to which it can be set (for the experiment, not ordinary operations) and the precision to which it can be measured, (d) the proposed control variable settings, and (e) the predicted effect (at least qualitative) that the settings will have on each response variable:

other issues and constraints taken into account when settings are selected—safety, discreteness of settings, process constraints, ease of changing a setting, and so forth.

attempting to predict the outcome of the experiment before it is run can foster good interaction within the experimentation team and often leads to revised choices of settings. An additional advantage is that the predictions will always be wrong, so it is easier to see what knowledge has been gained through experimentation.

- Current Use (col. 2)
    - historical process data can be used to gain relevant knowledge may be revealed.
    - select a range large enough to produce an observable effect and to span a good proportion of the operating range, yet not choose so great a range that no empirical model can be postulated for the region.
- Ability to Measure and Set (col. 3)
    - know how measurements will be obtained and the precision of measurement
    - how the control variable settings will be obtained and "setting error."

Control variable (units)	Normal level and range (current use)	Measurement precision and setting error—how known? (ability to measure and set)	Proposed settings, based on predicted effects (knowledge sought through experimentation)	Predicted effects (for various responses) (knowledge sought through experimentation)

6. List: (a) each factor to be **"held constant"** in the experiment, (b) its desired level and allowable s or range of variation, (c) the precision or range to which it can measured (and how), (d) how it can be controlled, and (e) its expected impact, if any, on each of the responses:

Held-constant factors are controllable factors whose effects are not of interest in this experiment.

to help ensure that there are no extraneous factors distorting the results.

can force helpful discussion about which factors are adequately controlled and which factors are not. In so doing, it is often necessary to consult experts to help prioritize factors, recommend preexperiment studies to assess control, or develop control strategy.

Factor (units)	Desired experimental level and allowable range	Measurement precision—how known?	How to control (in experiment)	Anticipated effects

7. List: (a) each **nuisance factor** (perhaps time-varying), (b) measurement precision, (c) strategy (e.g. blocking, randomization, or selection), and (d) anticipated effect:

Processes and experimental conditions vary over time.

Some of these can be measured and monitored to at least ensure that they are within limits; others must be assessed subjectively by experts; still others are unmeasured. If the level can be selected for any experimental unit, however, blocking or randomization might be appropriate. If levels cannot be selected (i.e., the levels of the factor are unpredictable, perhaps continuous), then the nuisance factor becomes a covariate in the analysis. If a nuisance factor is not measurable and thought to be very influential, it may also be called an *experimental risk factor*. Such factors can inflate experimental error, making it more difficult to assess the significance of control variables. They can also bias the results.

strategies (randomization, blocking, analysis of covariance, stratified analysis) to reduce the impact of nuisance factors.

Blocking will introduce a bias in the estimates confounded with the blocking van- able(s). whereas randomization will inflate the experimental error.

Nuisance factor (units)	Measurement precision — how known?	Strategy (e.g., randomization, blocking, etc.)	Anticipated effects

8. List and label known or suspected **interactions**:

For interactions tutorial, see Figure 2 on next page.

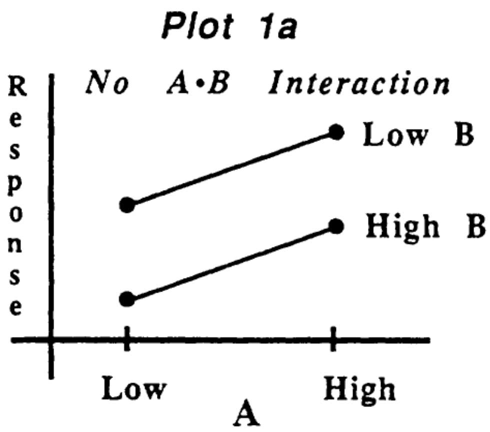
The interactions table explicitly recognizes only pairwise interactions of linear terms.

This input is helpful when the experiment is later designed—to choose resolution, or more generally to choose which effects should or should not be confounded.

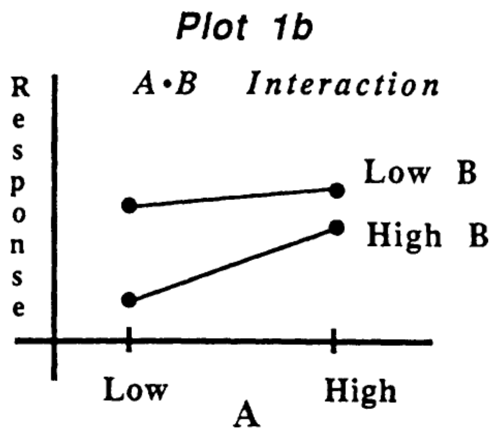
Use the process of elimination or inclusion. If interactions are generally important: "Are there any interactions that are arguably not present?" If main effects dominate interactions: "Are there any interactions that must be estimated clear of main effects?"

Control variable	A	B	C	D	E	F	G	H	I	J
A	—									
B		—								
C			—							
D				—						
E					—					
F						—				
G							—			
H								—		
I									—	
J										—

Use: Along either the upper or lower triangular region, place a dash "—" to indicate no predicted interaction. Place a letter, such as X, to indicate a predicted interaction between two control variables on response X. If multiple response variables, can use X, Y, Z, etc.



Simple, linear, additive model is sufficient.



Factors A and B interact, but no quadratic term is present (assumed).

Table 1a - No A•B Interaction

	Low A	High A
Low B	5	6
High B	3	4

response

Table 1b - A•B Interaction

	Low A	High A
Low B	5	5.2
High B	3	4

Figure 2 Interactions tutorial

9. List **restrictions** on the experiment, e.g., ease of changing control variables, methods of data acquisition, materials, duration, number of runs, type of experimental unit (need for a split-plot design), "illegal" or irrelevant experimental regions, limits to randomization, run order, cost of changing a control variable setting, etc.:

Theoretical optimal experimental design and practical experimental design are often worlds apart, and restrictions often make the difference.

Put these limitations and pitfalls in the open.

10. Give current **design preferences**, if any, and reasons for preference, including blocking and randomization:

When experimenters are statistically sophisticated and have a good idea of appropriate designs or analysis techniques.

When the experiment has been preceded by experiments in which a particular design or technique proved to be useful.

Discuss problem-specific issues that will affect the experimental design, such as multilevel factors, different sizes of experimental units, and logistics.

(a) choose candidate designs, (b) review them with the experimenters in the context of the collected information to determine if any of the designs should be dropped from further consideration, and (c) write an experimental design proposal that contains (at least) one or more proposed designs; a comparative analysis of the designs with respect to number of runs, resolution (or aliased effects), number of distinct control variable combinations, prediction error standard deviation, and so forth; a design recommendation with justification; and copies of the completed guide sheets.

11. If possible, propose **analysis and presentation techniques**, e.g., plots, ANOVA, regression, plots, t-tests, etc.:

12. Who will be responsible for the **coordination** of the experiment?

The statistician (or surrogate) can play a strong support role and be primarily responsible for that in which he or she is professionally trained—the design and analysis of the experiment and not the execution.

13. Should **trial runs** be conducted? Why/why not?

Logistical planning and planning for measurement capability studies , process capability studies , preexperiments to quantify the effects of various factors (held-constant and nuisance) on response variables, and trial runs.

Learn and refine experimental procedures without risking the loss of time and ex pensive experimental samples (when doing things never done before, some practice helps).

Estimate experimental error before expending major resources: widening the ranges of settings, increasing the number of replicates, or refining the experimental procedure.

Ensure that data-acquisition systems are functioning.

Trial runs may yield results so unexpected that need to change experimental plans.

Work diligently to bridge the gap in knowledge and experience between the statistician and experimenter. The consequences of not bridging this gap can be serious. Help ensure the experiment goes as planned by overcoming the challenges below.

The statistician's lack of domain knowledge can lead to:

1. Unwarranted assumptions of process stability during experimentation
2. Undesirable combinations of control-variable levels in the design
3. Violation or lack of exploitation of known physical laws
4. Unreasonably large or small designs
5. Inappropriate confounding
6. Inadequate measurement precision of responses or factors
7. Unacceptable prediction error
8. Undesirable run order

The experimenter's lack of statistical knowledge can lead to:

1. Inappropriate control-variable settings (e.g.. range too small to observe an effect or range so large that irrelevant mechanisms drive the response van able)
2. Misunderstanding of the nature of interaction effects. resulting in unwisely confounded designs
3. Experimental design or results corrupted by measurement error or setting error
4. Inadequate identification of factors to be "held constant" or treated as nuisance factors. causing distorted results
5. Misinterpretation of past experiment results. affecting selection of response variables or control variables and their ranges
6. Lack of appreciation of different levels of experimental error leading to incorrect tests of significance

Hahn advised, "The statistician's major functions are to help structure the problem, to identify important issues and practical constraints, and to indicate the effect of various compromises on the inferences that can be validly drawn for the experimental data".