EXPERIMENTAL DESIGN AND OFF-LINE QUALITY CONTROL

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1. Historical remarks

The success of Japanese products in the western world is proverbial. Part of this success is due to the superior quality of Japanese products. One source for this superior quality is the continuous effort over the last 20 years or so to implement proper statistical methods in the production process. These statistical methods not only cover acceptance sampling for incoming and outgoing products. Rather they climax on the off-line, i.e. preproduction, stage.

G. Taguchi, the leading protagonist of the Japanese view of off-line quality assurance says in the preface to the 1981 English translation of his book "Introductory Text for Design Engineers: Design and Design of Experiments":

> "Japanese engineers' attitude of using experimental designs is quite different from the USA's. Most English books on experimental designs are written from the viewpoints of science, emphasizing the importance of mathematical models and statistical theory.
>
> Japanese engineers want to find better product designs which are robust enough against all noise variables by choosing the level of parameters."

The rapid growth of the share of Japanese products in western markets has offset a great number of activities to equalize the Japanese quality standards. In particular the automobile, chemical, and electronic

industries have undertaken great efforts to improve their quality. Although the longstanding work of G.E.P Box and coauthors is aimed at precisely achieving this goal, much of the recent efforts have centered around the Japanese approach.

Major sources in the literature are the two English books of G. Taguchi, the proceedings volumes of the three Supplier Symposia on Taguchi Methods, and a special issue devoted to this topic both in the Journal of Quality Technology and Communications in Statistics - Theory and Methods. A number of case studies which are available in the literature are listed in the references.

There are some spectacular examples of the superior quality of Japanese products as compared to U.S. products. One such study on manufacturers of room air conditioners is reported in the article "Quality on the line" by D.A. Garvin. The conclusion is twofold. Management has to set up a climate in which product quality ranks first, rather than producing at low cost, meeting the production plan, or improving worker productivity. Second, the statistical methods have to be appropriate to evaluate the multi-factor aspects of production processes, rather than varying one variable at a time. It is in this second aspect where design of experiments comes in as a helpful tool.

2. Design objectives

Planned experiments in the off-line quality control center around the design stage of a product (off-line), in order to secure from the very beginning a high quality production stage (on-line).

Thus the objective is not one of evaluating the product design and the production process after production has started with, say, sampling plans. Instead planned experiments are run in the design phase in order to find the appropriate factor combinations in order to run the production phase at a high quality level right from the very beginning. An instance of such a quality engineering based on design of experiments is reported by M.S. Phadke (1982, p. 13): Based on a planned experiment a production process was reorganized to increase stability and robustness of the new process parameters. The gain in quality was such that the processing engineers could

eliminate a number of formerly applied in-process checks. As a result the overall time spent by the product in the production process was reduced by a factor of two.

It is evident that designing a product correctly in the first place is much cheaper than waiting for the production process to go astray. The present activities can be reduced to the issue to put more efforts into preproduction quality engineering. Taguchi preaches to objectives for the off-line quality control experiments, to identify whether a factor is "responsible" for production variation, or whether a factor is an appropriate tool to keep the production process on the target value. When a factor does not contribute to either case its level may be chosen according to cost considerations. Factors which affect the variability of a response are called control factors, while those which affect the mean level of a response are called signal factors. The prime objective of a planned off-line experiment is to find out whether a factor belongs to one group or the other.

If the analysis is successful this leads to a production process which is robust against all noises while at the same time being kept on target with a minimum number of parameters.

In order for the experiment to be able to discriminate between various courses of variation, "planned noise" forms an essential ingredient of the experiment. Thus variability is deliberately produced in order to mimic environmental noise. Thus the experiment anticipates in a laboratory setting process variability long before the process is actually started.

There is some discussion going on as to which response ought to be evaluated for planned experiments in off-line production problems. A response which helps communication with engineers is the signal-to-noise ratio. Even then it is not immediate which signal-to-noise ratio is appropriate, whether a transformation such as a logarithmic transformation ought to be carried out, etc. A response which has gained some popularity is

$$\frac{\text{mean}}{\text{standard deviation}}$$

or its logarithm. The discussion in issue No. 4 of the Journal of Quality Technology (1985) throws some light on this topic as do Jugle's (1984) comments.

The statistical models applied by Taguchi are quite simple, in that usually only main effects are considered. The role of interactions is very much de-emphasized. This makes Taguchi insist to run a confirmation experiment. New factor levels are implemented only after a confirmation experiment has "proved" them to be superior to the old settings.

A number of such experiments run one after the other may then result in a stepwise approach towards the optimum. One such instance of iterating on experiments is reported by M.G. White in the Third Supplier Symposium on Taguchi Methods (1985, p. 269).

In summary I should think that Taguchi is successful in compromising between two conflicting goals. The statistical methods advertised are sophisticated enough in order to pick up typical process behaviour. On the other hand they are simple enough in order to be easily taught to process engineers.

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Inhalt / Contents

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