Workshop on Quality Improvement Methods
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Abstracts

Part 1: Taguchi-methods

The use of noise factors in robust design experiments.

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One of the novel ideas of Genichi Taguchi is the inclusion of noise factors in industrial experiments. Noise factors represent process conditions that are impossible or too expensive to control during product manufacture or use. They may include ambient conditions, variations in raw materials or production parameters or differences in the use environment. Noise factors are used to "force" variation into experimental results. This talk will address two fundamental questions.
(1) Should noise factors be included in an experiment? Perhaps it is wiser to simply use replicate observations to assess variation.
(2) If noise factors are included, how should the data be analyzed?
We will show that including noise factors can substantially increase the power to detect factors that affect variation, but only if the noise factors are explicitly modeled in the analysis. Measures that summarize data across noise factor settings, whether as standard deviations or signal-to-noise ratios, are inefficient and potentially misleading.

An experiment to compare the combined array approach and the product array approach

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It is widely advocated by statisticians to use the combined array approach instead of Taguchi's product array for experiments with noise-factors. Even when a product-array has been carried out, it is recommended to replace the analysis with signal-to-noise ratios by a combined array analysis.
The arguments are convincing. However, they are based on theoretical considerations, or the reanalysis of past experiments. We therefore did not find published examples where the predictions from both approaches could be checked by confirmation experiments. To get a practical example, we have done an experiment where we used both designs simultaneously: of the 64 runs that we did, 32 were a product array, 32 others were a combined array. The experiment was done as part of a project where we use DOE-methods for the optimisation of the metal spinning process.

As expected, we found that the results of the combined array were much easier to interpret (because there was a simpler confounding structure). However, for one of the response variables, it turned out that from the product array, we could identify a factor that has an influence on the variance. We did not see this effect in the combined array.
A confirmation experiment seems to support these findings.

Bias considerations for transformation parameter estimation in extended Box-Cox models

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Box-Cox transformation models are characterized by a mean-variance relationship that can be removed by carrying out a power transformation. In extended Box-Cox models, variances after transformation are independent of the mean, but may still be functionally related to the design variables.
For estimating the corresponding transformation parameter, the application of a Generalized Linear Model (GLM) in place of the Box-Cox transformation model (TM) yields approximately identical results but allows theoretical considerations regarding the properties of maximum likelihood (or related) estimates.
These estimates are consistent if the true underlying dispersion structure is assumed. However, if dispersion effects are neglected, they may be badly biased. For the pseudo likelihood approach, the resulting bias is examined for a wide variety of models in a computer experiment.

Analysis of non-orthogonal saturated designs

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Even if a fractional factorial design with many factors is planned to be orthogonal, it often happens that the design becomes non-orthogonal and saturated. This is because one or more observations might be missing.
In the present paper we review several methods for the analysis of non-orthogonal saturated designs which were proposed by Draper and Stoneman (1964), Box and Meyer (1993), and Kunert (1997), respectively. Their performance is compared with the help of a simulation study.

Part 2: Experimental design

Optimal design for non-linear calibration models

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Calibration models are intended to link a quantity of interest X (e.g. the concentration of a chemical compound) to a value Y obtained from a measurement device. In this context, a major concern is to build calibration models that are able to provide precise (inverse) predictions for X from measured responses Y.
This talk aims at answering the following question : which experiments should be run to set up a (linear or non linear) calibration curve that maximises the inverse prediction precision? The class of optimal designs is presented as a possible solution.
The calibration model set up is first reviewed in the linear case and extended to the heteroscedastic non linear one. In this general case, asymptotic variance and confidence interval formulae are derived for inverse predictions.
Two optimality criteria are then introduced to quantify *a priori* the quality of inverse predictions for a given experimental design. The V_I criterion is based on the integral of the inverse prediction variance over the calibration domain and the G_I criterion on its maximum value. Algorithmic aspects of the optimal design generation are discussed.
Finally, the methodology is applied to 4 possible calibration models (linear, quadratic, exponential and four parameters logistic) and V_I and G_I optimal designs are compared to classical D, V and G optimal designs. There predictive quality is also compared to the one of simple traditional equidistant designs and it is shown that, even if these last designs have very different shapes, their predictive quality are not far from the optimal design ones. Finally, some simulations evaluate small sample properties of inverse prediction confidence intervals.

Measures for designs in experiments with correlated errors

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In this talk we consider optimal design of experiments in the case of correlated observations. This situation may arise when observing a random process or random field with a given covariance structure. We utilize and further develop the concept of design measures for approximate information matrices introduced by Pázman and Müller, 1998 for the construction of a simple, quick and elegant design algorithm. We motivate the usefulness of this algorithm for a general correlation structure by an interpretation in terms of norms. Some examples demonstrate that our results prove to be helpful for the construction of exact designs by sampling from the obtained design measures.

Reference:
Pázman, A. and Müller, W. G. (1998): A New Interpretation of Design Measures, *in: MODA5 - Advances in Model-Oriented Data Analysis and Experimental Design*, Atkinson, Pronzato and Wynn (eds.), Physica-Verlag (Heidelberg), 239-246.

Factorial designs with dependent observations

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Several definitions of efficiency of run orders for factorial designs are possible. Their consequences will be discussed, before concentrating on efficiency under positive dependence (because of small time lags in industrial experiments, or a linear spatial arrangement in agricultural experiments). The importance of level changes will be considered, and some secondary criteria will be introduced, initially for 2-level factors and subsequently for higher levels. Some recent results on spatial layout when there is dependence in both directions will be outlined.

Sorting of raw materials with focus on end product quality.

Ingunn Berget and Tormod Næs
MATFORSK, As

Raw material variation is one of the most important factors causing unstable end-product quality. A methodology for sorting raw materials into homogeneous groups with constant and optimized processing within each group will be presented. The sorting criterion is based on the squared distance between the predicted response and its target value. The raw materials are split into homogeneous categories by a partitioning algorithm related to the fuzzy c-means algorithm. The method will be illustrated on data from a baking experiment.

Part 3: Dynamics

Testing effects in semi-parametric dynamic mixed models

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The quality improvement of personal care products at the industry is supported by intensive laboratory research activities on skin behaviour. The skin of subjects is treated in several ways, and measurements are taken over time to compare the effects of the treatments. Dynamic mixed models, also called repeated measurement models, are useful to model the data but they are complex; besides the fixed effects the subjects contribute random main effects to the models, and random interactions with the factors of interest. Many model-fitting approaches from literature are too complex to be carried out by the skin researchers. We shall present results on an Anova approach that satisfies the most important needs for the industrial researchers: the estimation and testing of factorial effects.
Optimum design of experiments questions mostly concern the choice of time points to allow the fitting of several types of models.

Experimental Design Considerations for Models on Periodogram Ordinates

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In the Project "Analysis and Modelling of the Deephole-Drilling- Process with Methods of Statistics and Neuronal Networks" it turned out that the online measurements of the boring moment are dominated by few well-separated frequencies. These frequencies differ in amplitude for different settings of machine parameters and over time. The latter finding turned out to be important for the prediction of a disturbance called chatter: when the amplitude of one of these frequencies becomes larger than a critical bound it grows faster than exponentially and dominates the process completely.
From these findings the idea developed to construct regression models on periodogram ordinates of relevant frequencies, in the case of BTA-Deep-Hole Drilling torsion eigenfrequencies or bending eigenfrequencies. Gallant et al. (1974) describe an ANOVA based on transformed periodograms using a normal approximation. This approximation is justified by assuming a stationary Gaussian process in the data. In our problem the situation is slightly different, because we have approximately a harmonic process with an assumed additive white noise error. This leads to non-central χ^2-distributed periodogram ordinates at the relevant frequencies. In this case several approximations to the normal distribution are known (Johnson et al., 1994). As a first step in developing an appropriate model and corresponding experimental design the goodness of one of these approximations in the case of time-independent influences on the ordinates was tested in a simulation study. The results of this simulation study will be presented and first consequences for an experimental design will be proposed. Furthermore, considerations for the next step towards time-varying models will be presented for discussion.

References
A. R. Gallant, Thomas M. Gerig, and J. W. Evans (1974): Time series realizations obtained according to an experimental design. *JASA*, 69:639-645.
N.L. Johnson, S. Kotz, and N. Balakrishnan (1994): *Continuous univariate distributions*, Volume 1,2. Wiley, 1994.

Analysis of time series data in reconstructed state spaces

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Starting from the paradigm of deterministic chaos, methods for the analysis, classification, identification, and manipulation of time series data have been developed, which make use of a representation of the data in vector spaces. Recent work has generalized these appraoches towards stochastic Markov processes. The talk reviews the basic ideas, in particular the state space reconstruction by embedding, and then focusses on the treatment of non-stationary nonlinear stochastic processes. The methods and their usefulnes will be illustrated by application to experimental data.