An Overview of Experimental Design and Process Optimisation

Prof. John D. Kechagias
Editor in Chief, *International Journal of Experimental Design and Process Optimisation*

Experimental design methodology aims to provide researchers with the statistical tools to analyse and understand engineering and cross-disciplinary problems, predominantly in quality or process optimisation issues. In brief, the primary concern of a researcher who wishes to optimise a process is decisions made on matters such as the studied experimental area by defining the variable parameters (inputs) and their values. This procedure is unique; not a routine, especially when the cost, time and environmental impact of the processes are significant aspects. Secondly, the performance indexes (outputs) should be determined and measured appropriately and accurately. Last but not least, selecting the mathematical model to fit the inputs with the outputs and multi-parameter multi-objective (MPMO) algorithms are of utmost importance for effective process optimisation. In recent years, computerised techniques are frequently applied in processes and systems and sophisticated optimisation algorithms that mimic nature are implemented for optimisation purposes.

A great number of researchers have utilised full-factorial or fractional factorial design in engineering problems. Full factorial design is used in the optimisation of friction stir welding (FSW) of aluminium plates[1]. One parameter with three levels (the type of pin profile tool) and two with four levels (the welding transverse and the rotational speed) were adopted as input, while the tool wear rate and the weld mechanical strength were used as as outputs. Analysis of means (ANOM) and analysis of variance (ANOVA) approaches decomposed the parameter effects on outputs while linear regression models with interaction products were used for multi-parameter multi-objective process optimisation. Additionally, a full factorial design with three parameters and four levels each ($L3^4$; 64 experiments) during hard turning of AISI 4340 steel was presented by Sahoo et al.[2]. The influence of cutting speed, feed rate and the depth of cut on flank wear and surface roughness were investigated and the grey-Taguchi methodology (g-TM) was adopted for multi-parameter multi-objective optimisation. Kechagias et al.[3] adopted the Taguchi experimental design approach with an orthogonal L9 array to investigate the turning process of a glass fibre polymer composite known as Ertalon 66 GF-30. They utilised descriptive statistical tools such as main effect plots, ANOM and ANOVA in order to study the process parameters' effects on average surface roughness. In Thanigaivelan et al.[4], multi-parameter multi-objective optimisation during the electrochemical micromachining (EMM) process was proposed. The Taguchi approach with an L18 ($2^1 x 3^3$) orthogonal array was selected as an experimental design for input parameters (the tool electrode tip shape, machining voltage, pulse on-time, electrolyte concentration) while fuzzy logic was applied to optimise the output (machining rate and overcut).

In Johnson & Montgomery[5], response surface methodology (RSM) was examined as a modern, robust parameter design. Quadratic mathematical models investigated fitting issues in central composite design (CCD) and Box-Behnken design (BBD). They proved that the combined CCD-BBD methodology results in good data-fitting, providing that the response follows the normal distribution. Alao & Konneh[6] also adopted the CCD technique to optimise the grinding process, considering three processing parameters as inputs (the depth of cut, the feed rate and the spindle speed) and then applying quadratic mathematical models.

The application of experimental design techniques for process optimisation is suitable for numerous industrial applications. In Hwang & Noack[7], the quality and cost of a pharmaceutical product included the active pharmaceutical ingredient (API) and inactive ingredients that enhance manufacturability and help the medicine, optimised by a systematic approach using experimental design. In Arin et al.[8], multiple design of experiment (DOE) methods were employed and their results were used to tune genetic algorithm (GA) parameters. Though most metaheuristics are characterised by several parameters that need to be tuned before attaining good results, DOE methods offer practical approaches to adjusting these parameters effectively. In Krenek et al.[9], the concept of minimising waste in manufacturing processes to promote sustainability and save companies' time, money and physical resources was approached by exploring the mathematical foundations of various truncated normal distributions and the convolutions of these distributions to offer insights into the noteworthy methods used. In Ghosh & Martinsen[10], an iterative multi-objective deep-learning assisted optimiser was developed and a non-dominated search technique was employed to obtain the Pareto optimal sets of the process parameters, which could improve yarn quality in textile industries.

All the above-mentioned comprehensive studies are characterised by a common denominator: they used experimental design for process optimisation. The *International Journal of Experimental Design and Process Optimisation* (*IJEDPO*) serves as a valuable resource for presenting new and innovative studies, and offers a prestigious international forum for the rigorous peer-reviewed publication of work describing the latest research and innovative applications across a broad coverage of applied experimental statistics and experimental design for understanding and enhancing processes and systems in the engineering sciences and in cross-disciplinary problems. While the journal encourages a broad spectrum of contributions in those fields, its core interest lies in issues concerning classical or modern experimental design and optimisation algorithms, applied statistics and data analysis combined with modelling.

References

(1) Hassan, A. M.; Almomani, M.; Qasim, T.; Ghaithan, A. Statistical Analysis of Some Mechanical Properties of Friction Stir Welded Aluminium Matrix Composite. *International Journal of Experimental Design and Process Optimisation* **2012**, *3* (1), 91. https://doi.org/10.1504/IJEDPO.2012.045616.

(2) Sahoo, A. K.; Sahoo, B. Mathematical Modelling and Multi-Response Optimisation Using Response Surface Methodology and Grey Based Taguchi Method: An Experimental Investigation. *International Journal of Experimental Design and Process Optimisation* **2011**, *2* (3), 221. https://doi.org/10.1504/IJEDPO.2011.042745.
(3) Kechagias, J.; Petropoulos, G.; Iakovakis, V.; Maropoulos, S. An Investigation of Surface Texture Parameters during Turning of a Reinforced Polymer Composite Using Design of Experiments and Analysis. *International Journal of Experimental Design and Process Optimisation* **2009**, *1* (2/3), 164. https://doi.org/10.1504/IJEDPO.2009.030317.
(4) Thanigaivelan, R.; Arunachalam, R. M.; Jerald, J.; Niranjan, T. Applications of Taguchi Technique with Fuzzy Logic to Optimise an Electrochemical Micromachining Process. *International Journal of Experimental Design and Process Optimisation* **2011**, *2* (4), 283. https://doi.org/10.1504/IJEDPO.2011.043565.
(5) Johnson, R. T.; Montgomery, D. C. Choice of Second-Order Response Surface Designs for Logistic and Poisson Regression Models. *International Journal of Experimental Design and Process Optimisation* **2009**, *1* (1), 2. https://doi.org/10.1504/IJEDPO.2009.028954.
(6) Alao, A. R.; Konneh, M. A Response Surface Methodology Based Approach to Machining Processes: Modelling and Quality of the Models. *International Journal of Experimental Design and Process Optimisation* **2009**, *1* (2/3), 240. https://doi.org/10.1504/IJEDPO.2009.030320.
(7) Hwang, R.; Noack, R. M. Application of Design of Experiments to Pharmaceutical Formulation Development. *International Journal of Experimental Design and Process Optimisation* **2011**, *2* (1), 58. https://doi.org/10.1504/IJEDPO.2011.038051.
(8) Arin, A.; Rabadi, G.; Unal, R. Comparative Studies on Design of Experiments for Tuning Parameters in a Genetic Algorithm for a Scheduling Problem. *International Journal of Experimental Design and Process Optimisation* **2011**, *2* (2), 102. https://doi.org/10.1504/IJEDPO.2011.040262.
(9) Krenek, R.; Cha, J.; Cho, B. R. Zipping and Re-Zipping Methods to Improve the Precision and Accuracy of Manufacturing Processes. *International Journal of Experimental Design and Process Optimisation* **2015**, *4* (3/4), 256. https://doi.org/10.1504/IJEDPO.2015.072828.
(10) Ghosh, T.; Martinsen, K. Deep-Learning Assisted Iterative Multi-Objective Optimisation of Yarn Production Process. *International Journal of Experimental Design and Process Optimisation* **2020**, *6* (3), 234. https://doi.org/10.1504/IJEDPO.2020.113558.