Topic 7: Optimizing Processes

Introduction to the Topic

Once the structure of a design has been defined (i.e. functions identified, product structure and manufacturing methods optimised and potential risks mitigated), but before the design has been finalised and released, the relationship between parts and processes can be optimized to generate the most stable and cost effective manufacturing outcomes.

Using prototype parts or computer simulations (wherever appropriate), experimental evaluations can be applied to determine the optimum settings for variable processes to help determine the conditions that generate the best outcomes.

Learning Outcomes

At the completion of this Topic you will be able to:

- discuss the application of experimental design (DOE)
- apply Taguchi’s ‘Quality Loss Function’
- discuss the relevance of Robust design practices
- discuss the application of Signal to Noise ratio
- explain Taguchi’s approach to Parameter design
- discuss the concept of Technology Development.

Session 7.1: Introduction to Optimizing Processes

While the application of statistical data and process monitoring techniques (e.g. SPC) along with structured problem solving procedures (e.g. Ford 8-D) have been very successful at stabilizing processes and improving capability, their effect is mainly relevant at eliminating variation brought about by primary causes; e.g. typically Special Causes. More sophisticated techniques are available to evaluate problems with multiple causes. Further, there may be a need to evaluate the effects of interactions between multiple inputs. Various forms of experimental design have been devised to isolate and evaluate the impact of multiple causes of problems and identify the best conditions for optimum productivity through the application of Design of Experiments (DOE).
In this approach, parts and products are tested according to a statistically derived sequence defined by an array. The test results can be used to identify the optimum settings and/or the best combination of conditions that favour the most productive or economical outcomes.

Many forms of experimental design have been devised over recent times.

A conventional approach is to test for one factor (cause) at a time. That is where one factor is changed while all other contributing factors are fixed. The test is conducted and the results are analysed for effect on the results. However this does not provide information on the outcomes for all combinations and permutations of variable factors.

In the 1950s Ronald Fischer\(^\text{10}\) developed experimental design (including the Full Factorial technique) in which all factors and permutations are sequentially evaluated through a statistically generated test plan.

Soon other mathematicians/statisticians developed specific experimental designs that could be used to identify the effect of interactions, as well as each individual primary factor. In each case the design of the experiment is statistically generated and representative parts/products are tested according to the conditions specified by the array. The results are then used to identify the conditions that produce best results. This approach is often referred as Classical Design of Experiments (DOE).

Towards the 1970s Genichi Taguchi\(^\text{11}\) introduced his ‘Quality Engineering’ approach in his quest to develop ‘robust’ engineering practices through the application of a modified form of DOE.

**Session 7.2: Taguchi’s Approach to ‘Quality Engineering’**

Taguchi’s definition of Quality Engineering is based upon the simple tenet:

‘The quality of a product is the (minimum) loss imparted by the product to society from the time the product is shipped.’

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Taguchi approaches this situation on two basic fronts:

- The Quality Loss Function identifies the economic loss incurred as a quality characteristic deviates from its target value. It is based on the premise that reduced variability reduces cost.

- Parameter Design applies planned experimentation (DOE) to make products more robust; i.e. resistant to ‘noises’ (or factors that cannot be controlled).

The aim is to identify nominal values for factors that can be controlled (Control Factors) and applies planned experimentation (DOE) to identify:

- maximum performance and productivity
- minimum cost
- minimum variation (maximum robustness).

In this approach Taguchi applies a modified form of DOE using his ‘Orthogonal Arrays’ to conduct tests using control factors set at nominal values and a ‘Signal-to-Noise’ (S/N) ratio to evaluate results. Throughout his tests, Taguchi deliberately introduces noise factors to induce variability so that the noise factors that are least sensitive to noise can be identified and to make the process more robust.

**Session 7.3: Quality Loss Function**

Obviously loss occurs when a product falls outside the allowable specification limits for a given quality characteristic (e.g. in the form of increased scrap, rework, warranty, downtime, decreased capacity etc.). For this reason it is important to ensure that the nature of the quality characteristic and size of the specification are both appropriate.

Selecting the right characteristic that defines customer satisfaction can sometimes be as difficult as selecting the allowable variation (specification).

However loss is also incurred as the quality characteristic varies within the allocated specifications (i.e. departs from target value).

Taguchi represents the total losses incurred due to variation with a simple quadratic function. The shape of the curve is determined by both the type of quality characteristic and the impact of failure. Sometimes known as the ‘shape of quality’, the Quality Loss Function is a measure of customer dissatisfaction. A robust product/process typically displays a flatter curve than one that is less robust.
It can be used to quantify the loss incurred as the characteristic deviates from target value and to identify cost cut-off points for rework.

For cases where maximum is better for the quality characteristic (e.g. insulation), or where smaller is better (e.g. shrinkage), the loss function is better represented as one half of a parabola.

![Quality Loss Function](image)

**Figure 7.1** Quality Loss Function for nominal-is-best condition - which curve represents the most stable (robust) process? copyright RMIT University, 2007, (Jacinta Eccles)

### Session 7.4: Signal to Noise Ratio (S/N)

Noises are unwanted conditions that produce functional variation in the performance of the product. By definition noise factors are either impossible to control or too expensive to control. The aim is to identify the conditions that are least sensitive to noises (i.e. robust).

There are three categories of noises, namely:

- **outer noise** is generated from outside the product/process and affects the manufacture or application (e.g. changes in temperature, humidity, current, material, operators etc.)
- **inner noise** is generated from within the product/process and causes variation that is impossible to control (e.g. worn tooling, deterioration of equipment, oxidation)
- **piece-to-piece noise** is due to production variation of parameters outside the nominal specified values (e.g. part-to-part variation, process-to-process variation)

Control Factors also impact on the performance and/or functional outcome but:
• control factors are controllable and can be set at realistic levels
• control factors may interact with noise factors
• the interaction between control factors and noise is used to generate stable, low cost and reliable products/processes.

Parameter Diagrams (P Diagrams) are used to identify the inputs and outputs of a selected product/process. Control factors, noise factors, input/output signals and error states (noise) are identified at the onset for further analysis with orthogonal arrays.

In the Taguchi approach of “planned experimentation”, the results are analysed using a signal-to-noise ratio (S/N) which is calculated using formulation developed by Taguchi.

Different quality characteristics require different methods for calculating the S/N ratio depending whether nominal is best, bigger is best or smaller is best (see attached). In all cases the higher the S/N value the greater the stability.

The advantages of using the S/N ratio are that it:
• accounts for both the mean (adjustment) and variation (stability)
• provides a measure of performance in the presence of noise
• can relate to cost
• can examine interactions between control and noise factors.
For **bigger is best**

\[ S/N (dB) = -10 \log (MSD) \]

\[ MSD = \frac{1}{n} \sum_{i=1}^{n} y_i \]

For **nominal is best**

\[ Ve = \text{sample variance} = \frac{\sum_{i=1}^{n} (y_i - \bar{y})^2}{n-1} \]

\[ S/N (dB) = 10 \log \left( \frac{1}{n} \left( \frac{Sm - Ve}{Ve} \right) \right) \]

\[ = 10 \log \left[ \frac{\bar{y}^2 - \frac{1}{n}}{Ve} \right] \]

For **smaller is best**

\[ S/N (dB) = -10 \log (MSD) \]

\[ MSD = \frac{1}{n} \sum_{i=1}^{n} y_i^2 \]

\[ = \bar{y}^2 + \sigma^2 \]

These equations are quoted from the American Supplier Institute and originate with Genichi Taguchi.

**Session 7.5: Parameter Design**

The aim of Parameter Design is to determine the values of product/process parameters to:

- maximize product performance
- minimize effect of noise
- maximize S/N ratio
- reduce costs.

Parameter Design examines the interaction of Control Factors (whose levels can be set and maintained) and Noise Factors (whose level cannot be maintained or are too expensive to maintain). Planned experimentation is applied and the S/N ratio is used to measure the effect of noise on the performance of the product.

After identifying the various control factors and noise factors that affect the performance of the product, a suitable Orthogonal Array is selected. The control factors are allocated to the inner array and the noise factors to the outer array. Each combination of control factor is tested against varying conditions of noise and the conditions most resistant to the effect of noise can be identified.
L8 - orthogonal array
8 experimental runs
7 factors and 2 levels

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Figure 7.3 Taguchi Orthogonal Array for 7 factors and one noise factor, adapted from ASI

The Orthogonal Array is a ‘balanced’ experimental design that makes it possible to mathematically separate the effects of the experimental (control) factors on the performance of the product. Taguchi has developed a number of ‘standard’ orthogonal arrays that can be applied for different numbers of factors, at two or three levels and using a variety of experimental runs. In each case the basic procedure is:

- **team:** to define the problem and the quality characteristic
- **brainstorm:** to identify control/noise factors, measurement systems, levels of experimentation
- **select experimental design:** to suit the number of factors, runs etc.
- **conduct experiment:** to collect necessary results for analysis
- **analyse results:** to select S/N ratio and optimize parameter settings
- **confirmation run:** to check that the expected results are achieved
- **implement:** to release optimum condition.

In all cases it is important to conduct a confirmation run at the ‘ideal’ settings to check that the results can be met.
Session 7.6: Technology Development

The introduction of Taguchi’s Quality Engineering approach in the manufacturing sector throughout the 1980s principally saw the application of the Quality Loss Function and Parameter Design techniques. Here the quality characteristics (outputs) were assumed to remain ‘fixed’ after the parameters were set at their optimum levels. These are typically defined as non-dynamic characteristics where there are no adjustments needed after the optimum settings are made.

However in many cases the outputs may vary requiring variation to the inputs; e.g. variable pressure must be exerted on a brake pedal to stop an accelerating vehicle or a pulley belt will need to be tightened as the mechanism wears. Characteristics that need adjustment to achieve optimum results are defined as dynamic characteristics.

As an example, in the sport of golf the intention is to hit a ball to a target distance. In this analogy the selection of club is the parameter used to meet the intended target (i.e. the signal). The system is the player and the control factors may include force, grip, swing, stance etc. The noises may be wind, terrain, crowd distraction etc. How to adjust for the most effective outcome effectively and efficiently becomes the main consideration.

Using dynamic characteristics with parameter design and S/N ratios for analysis, another dimension can be provided by the Quality Engineering approach. The ability to develop products that are self adjusting for varying conditions and different designs enables a range of products to be designed using common technologies.
Technology Development is a term used by Taguchi to describe the development of technologies for the design of a family of products over a short period of time.

Technology Development requires a high degree of planned experimentation in the early design and prototype stages to develop a greater understanding of the full capability of the internal processes around a given technology and to generate a ‘knowledge base’ that can be used for a range of similar products.

As product development times become more condensed, and as the product range increases to satisfy the particular requirements of a greater range of niche markets, Technology Development provides a method of shortening the development cycle without sacrificing risk.

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**Activity 7 A**

**Optimizing Processes**

**Reading:**
- Please refer to the bibliography at the start of the programme and read the articles referring to DOE and Taguchi Methods. Many texts on the topic of six sigma will make reference to DOE.

**Websites:**
Visit and review these websites for information on DOE and Taguchi methods:
- Design of Experiments (DRM Associates)
- Design of Experiments (Wikipedia)

**Activity:**
For the 4-ring binder exercise from the previous Topics:
- define one important quality characteristic that is relevant to the successful operation of the binder
- identify what factors could determine the successful outcome of this quality characteristic
- how would you test for the best combination of factors to optimize the quality characteristic?
- would you use the classical DOE approach or the Taguchi approach? Be prepared to discuss why.
Discussion:

- Participate in groupwork during lectures and online discussions.

Summary and Outcome Checklist

This Topic introduced you to design optimisation.

Tick the box for each statement with which you agree:

- I can discuss the application of experimental design (DOE).
- I can apply Taguchi’s “Quality Loss Function”.
- I can discuss the relevance of Robust design practices.
- I can discuss the application of Signal to Noise ratio.
- I can explain Taguchi’s approach to Parameter design.
- I can discuss the concept of Technology Development.

Assessment

Assessment for this Topic will be included in Assignment 1.