Serbian Contribution for High Performance and High Aided Value Manufacturing – An Industrial Application

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1. INTRODUCTION

- The **implementation of the advanced quality improvement programs**, such as six sigma, could present a step in accomplishing top priorities of Manu*future* SRA, e.g. **zero-defect paradigm** and **knowledge-based manufacturing**, particularly in developing countries and also in Serbia –*Serbian Contribution for High Performance and High Aided Value Manufacturing - An Industrial Application.*
- **Six sigma**: disciplined approach to **improving product and process quality**, based on customer quality requirements.

  - **From 'intuition-based decisions'** (what we think is wrong), **to 'fact-based decisions'** (what we know is wrong)
  - For **the existing system**, six sigma is deployed according to **DMAIC** (Define-Measure-Analyse-Improve-Control) systematic procedure

➢ **A case study** performed in a Serbian cookware production system to **reduce the product (enamelled pot) defects** using six sigma – DMAIC approach:

- *Define*: presented in brief (IDEF0, Pareto, Ishikawa, …)

- *Measure*: presented in brief (MSA, …)

- *Analysis*: process performance analysis for non-normal data distribution

- *Improvement*: Taguchi's location and dispersion modelling approach for process parameters optimisation

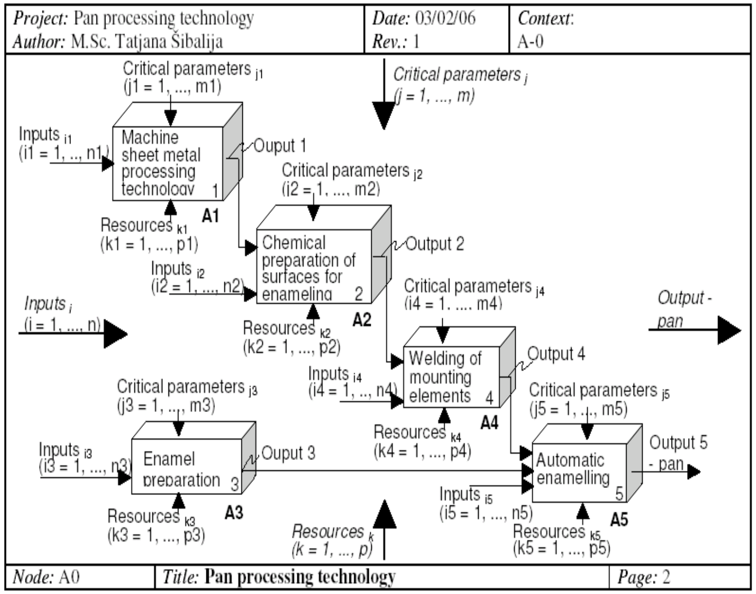
- *Control*: presented in brief

2. SIX SIGMA APPLICATION - *Define*

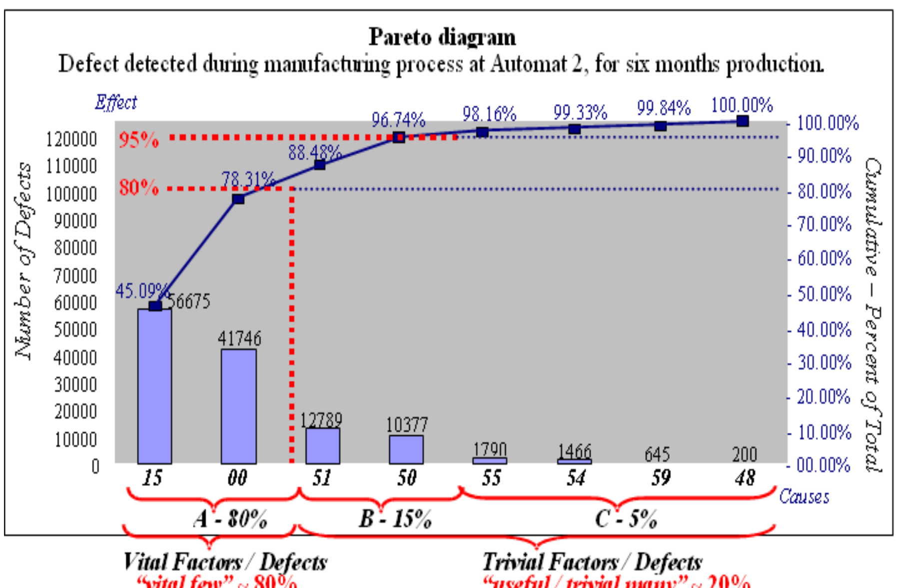
➢ **DMAIC approach** - reduce waste and cost of poor quality (COPQ) and improve sigma level of the **automatic enamelling process (cookware production system)**

Define:

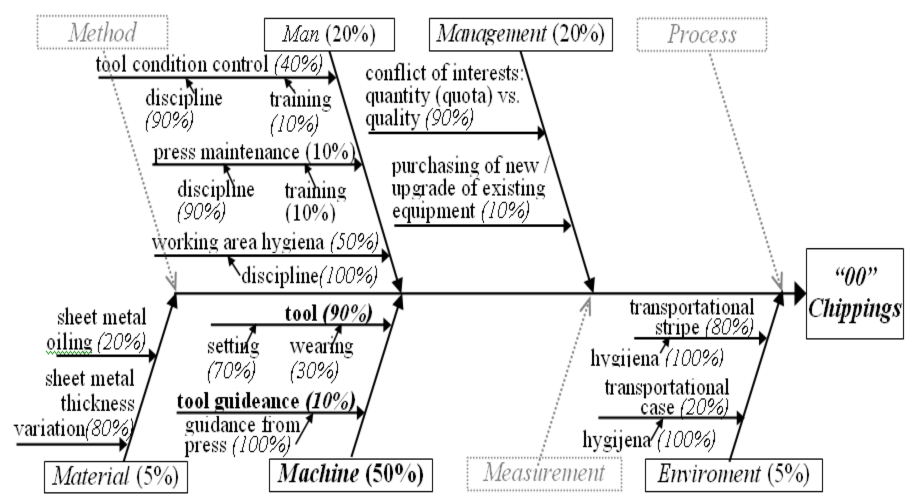
1. Process mapping (**IDEF0** method): main processes, sub-processes and activities
2. **Pareto** analysis: rank defect found in the automatic enamelling process ⟶ **vital defects** mainly related to the **pot enamel thickness**
3. **Ishikawa** diagrams: analyse vital defects and their main causes ⟶ the majority of the defects are related to **sub-process base enamelling**



IDEF0: system decomposed presentation



Pareto analysis



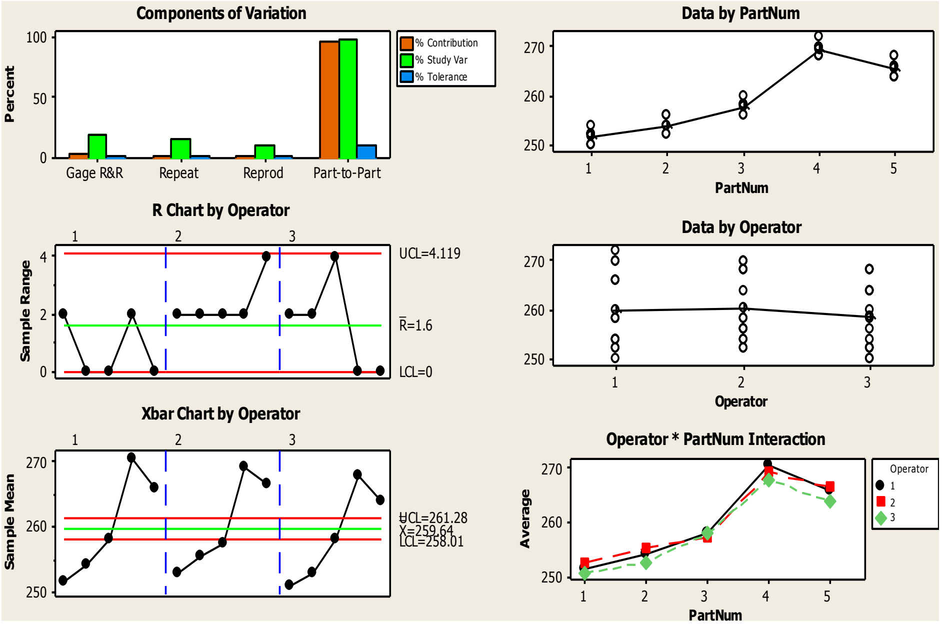
Ishikawa analysis

Measure:

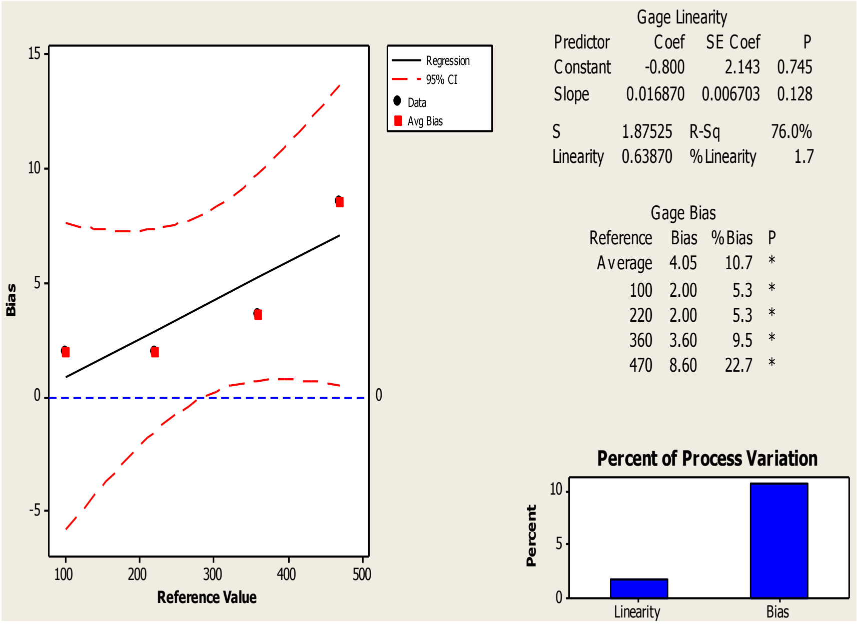
Measuring System Analysis (**MSA**) - to verify the measuring system used to measure the pot enamel thickness

- **Gage R&R** - to estimate the equipment variation (repeatability), operator variability (reproducibility) and variation of pot enamel thickness (part-to-part variation)
  → - operators and equipment caused < 20% of variation
  - number of distinct categories = 7 (> 5 - the minimal requirement) } - OK
- **Linearity and Bias Study** → the gage bias was statistically insignificant - OK

Conclusion: **the measuring system could be accepted for the measurement of pot enamel thickness and process analysis**



Gage R&R Study



Linearity and Bias Study

Analyse:

Process capability & performance analysis

- **Process capability indices** show what is achievable rather than what is currently being achieved :

  - **Cp** (ratio of the specification width to the natural tolerance spread of the process)

  - **Cpk** (specification width with respect to how well the process spread is located about the target) - incorporate the measure of process location

  The assumptions required for the interpretation of the process capability indices:
  - process stability;
  - representative samples;
  - normality (the underlying process distribution is normal);
  - independences (the observations are independent of each other).

- **Process performance indices do not assume that the process is in-control or is normally distributed and they use all of the data collected**:
  - **Pp**
  - **Ppk**

  The process performance indices use the **within sample standard deviation including both common and special cause of variation**, hence they **provide a more realistic assessment of what is being produced**.

Process performance for a non-normal distribution

- Clementh's method based on Pearson family of distribution estimates capability indices based on evaluation of the skewness and kurtosis - by replacing the unknown 6σ distance by *Up* - *Lp* based on the available sample data, a **natural tolerance** is:

$$Tolerance_{natural} = \mathrm{Up} - \mathrm{Lp} = \mathrm{X}_{0.99865} - \mathrm{X}_{0.00135} \qquad (1)$$

- **Process performance calculation does not require the assumption that the underlying process distribution is normal** - **the process performance indices for non-normal distribution** could be expresses as:

,

$$Pp = \frac{USL - LSL}{\mathrm{X}_{0.99865} - \mathrm{X}_{0.00135}} \qquad Ppk = \min\left\{\frac{USL - \mathrm{X}_{0.50}}{\mathrm{X}_{0.99865} - \mathrm{X}_{0.50}} ; \frac{\mathrm{X}_{0.50} - LSL}{\mathrm{X}_{0.50} - \mathrm{X}_{0.00135}}\right\} \qquad (2)$$

where:

- *Up* and *Lp* estimate the 99.865 and the 0.135 percentile, and the distance between 99.865th and 0.135th percentiles is equivalent to the 6σ spread in the normal case
- the process median is presented by the 50th percentile value for the non-normal distribution, which is equivalent to the average value in case of normal distribution

2.1. Process Performance Analysis: Non-Normal Distribution (2)

➢ **Automatic base enamelling**:

- specification limits for base enamel thickness LSL÷USL = 80÷120 µm
- the specified target value = 95 µm

• **process does not follow the normal distribution - the *Weibull* distribution** is the best one to fit the actual process data (confirmed by Anderson-Darling goodness-of-fit and *p*-value tests)

- **Pp = 1.26** ⟶ the process is capable of producing min. 99.74 % of conforming parts
- **Ppk = 1.10** ⟶ **lower than the value required for 'six sigma process'**
- the process median is off the target ⟶ **the location problem**

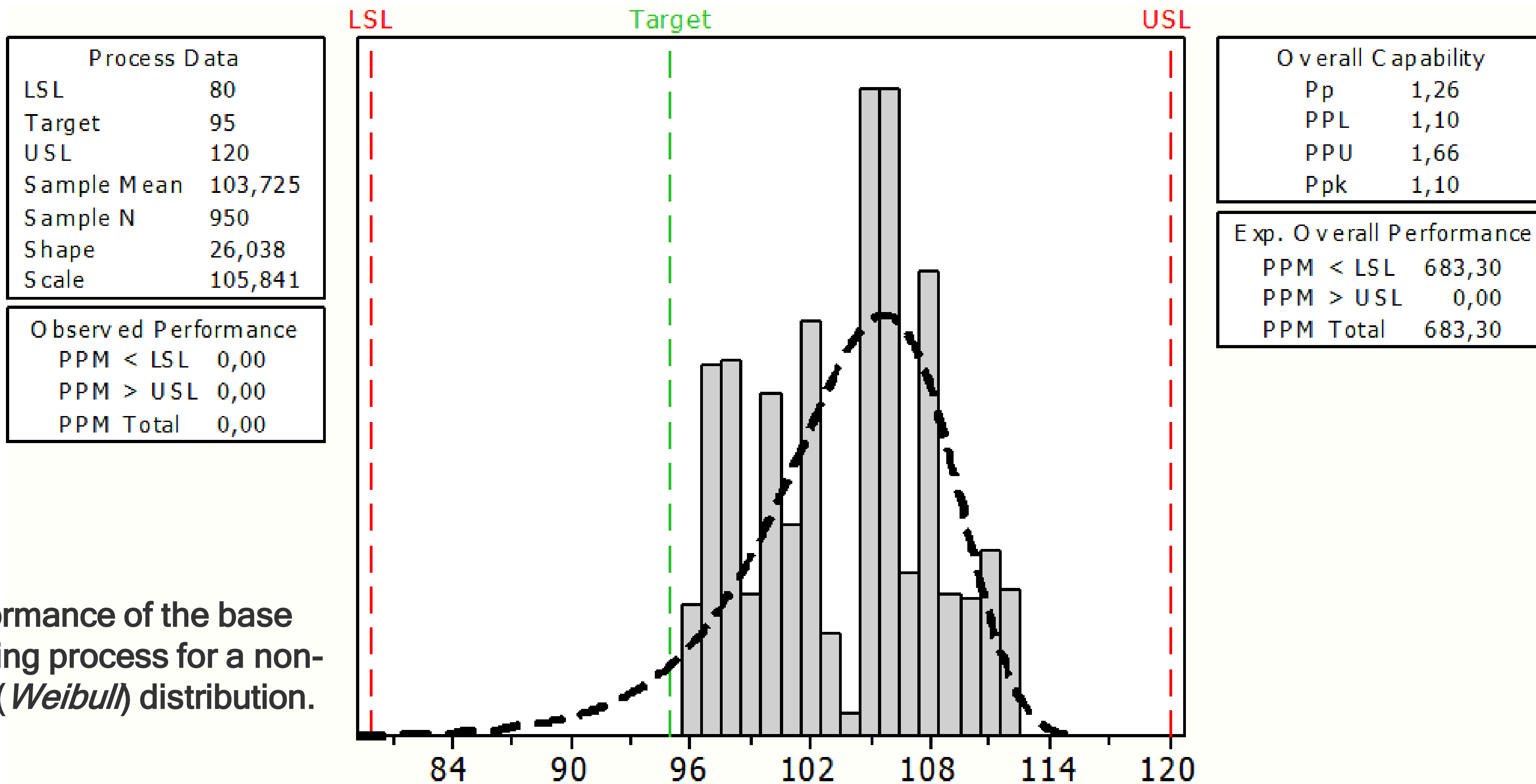


Fig. 1. Performance of the base enamelling process for a non-normal (*Weibull*) distribution.

2.2. Process Parameters Optimisation

Improve:

Location and Dispersion Modelling

- Improve process capability using **Taguchi's location and dispersion modelling**:
  - **identification of the control parameter & interaction effects on location (mean) and dispersion (variation)** of the observed quality characteristic (response)

  At each control factors setting, the sample **mean** y_i and sample **variance** σ_i are used to present the location and dispersion:

$$\gamma_i = \frac{1}{n_i}\sum_j y_{ij} \qquad \sigma_i^2 = \frac{1}{n_i - 1}\sum_j (y_{ij} - \overline{y_i})^2 \qquad (3)$$

  where *ni* is number of replicates at for the *i*th control factors setting.

- The **half-normal probability plot** is a graphical tool that uses ordered estimated effects to help assess which factors are important - least squares estimation – a list of the main effects and interactions ordered by the effect magnitude:
  - **unimportant factors** are those that have near-zero effects - centred near zero
  - **important effects** tend to have a distribution centred at their respective true large (but unknown) effect values

2.2. Process Parameters Optimisation: experiment

- Process performance analysis: the automatic base enamelling process needs optimisation to **solve the location problem** (achieve the target base enamelling thickness) and **improve process performance** (Pp and Ppk values)

- **Experiment** – to identify the optimal settings of critical-to-quality (CTQ) control parameters and interactions for the process - process parameters (control factors):

- **enamel parameters**:
  - specific weight (**SW**) [gram cm^{-3}]: lower ('-1') / upper ('+1') level = 8.0 / 11.0 [gram cm^{-3}]
  - deposit weight (**DW**) [gram cm^{-3}]: lower ('-1') / upper ('+1') level = 1.68 / 1.70 [gram cm^{-3}]
  - **SW** · **DW** interaction
- **process parameters**:
  - pouring speed (**PS**) [turns min^{-1}]: lower ('-1') / upper ('+1') level = 0.0 / 3.0 [turns min^{-1}]
  - automat speed (**AS**) [parts min^{-1}]: lower ('-1') / upper ("+1') level = 5.0 / 9.0 [turns min^{-1}]
  - **PS** · **AS** interaction

✓ Design of the experiment - Taguchi orthogonal array **L16** (16 experim. trials)

✓ **Half-normal plots:** to model the relationship between the response (base enamelling thickness) location/dispersion and control factors - to **show the significance of parameters and interactions effects on the response**

2.2. Process Parameters Optimisation: location modelling

- Location half-normal plot (Fig. 2.a.): significant effects on location (MEAN) are effects of **SW, DW, PS** and **AS·SW·DW** – **location regression equitation**:

$$MEAN = 87.8 + 6.51 \cdot SW + 5.74 \cdot DW + 3.02 \cdot SW \cdot DW \cdot AS + 2.79 \cdot PS \qquad (4)$$

according to the results of regression analysis presented in table 1.a.

Table 1.a. Statistical parameters of regression equitation for location modelling

Location modelling			
Predictor	Coef.	T	P
Constant	87.80	95.79	0.000
SW	6.51	7.10	0.000
DW	5.74	6.26	0.000
SW·DW·AS	3.02	3.30	0.007
PS	2.79	3.04	0.011

< 0.05

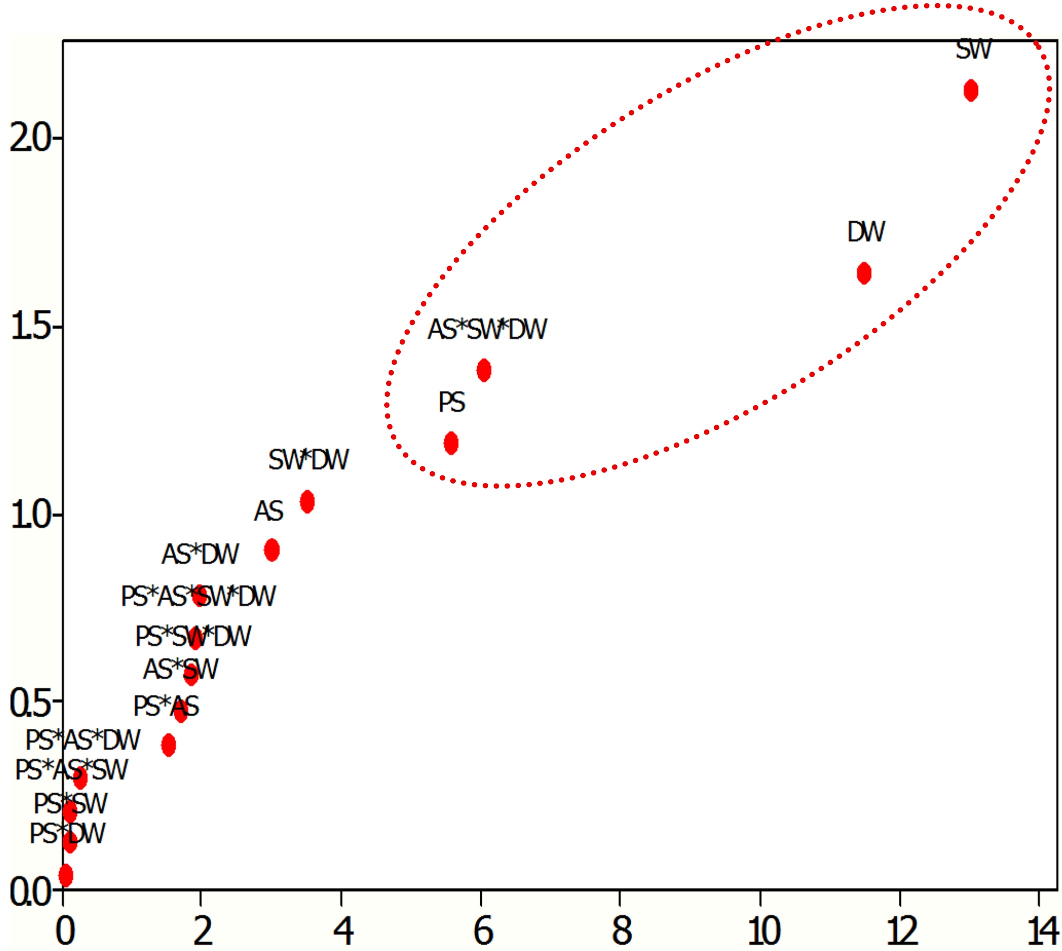


Fig. 2.a.
Half-normal plot of location (response mean value) effects

2.2. Process Parameters Optimisation: dispersion modelling

- Dispersion half-normal plot (Fig. 2.b.): significant effects on location (Ln Sigma^2) are effects of **PS, PS·AS, DW** and **PS·DW** – **dispersion regression equitation**:

$$LnSigma^2 = 3.22 + 0.25 \cdot PS + 0.2 \cdot PS \cdot AS + 0.19 \cdot DW + 1.6 \cdot DW \cdot PS \tag{5}$$

according to the results of regression analysis presented in the table 1.b.

Table 1.b. Statistical parameters of regression equitation for dispersion modelling

Dispersion modelling			
Predictor	Coef.	T	P
Constant	3.22	55.33	0.000
PS	0.25	4.33	0.001
PS·AS	0.20	3.51	0.005
DW	0.19	3.20	0.008
DW·PS	0.16	2.76	0.018

< 0.05

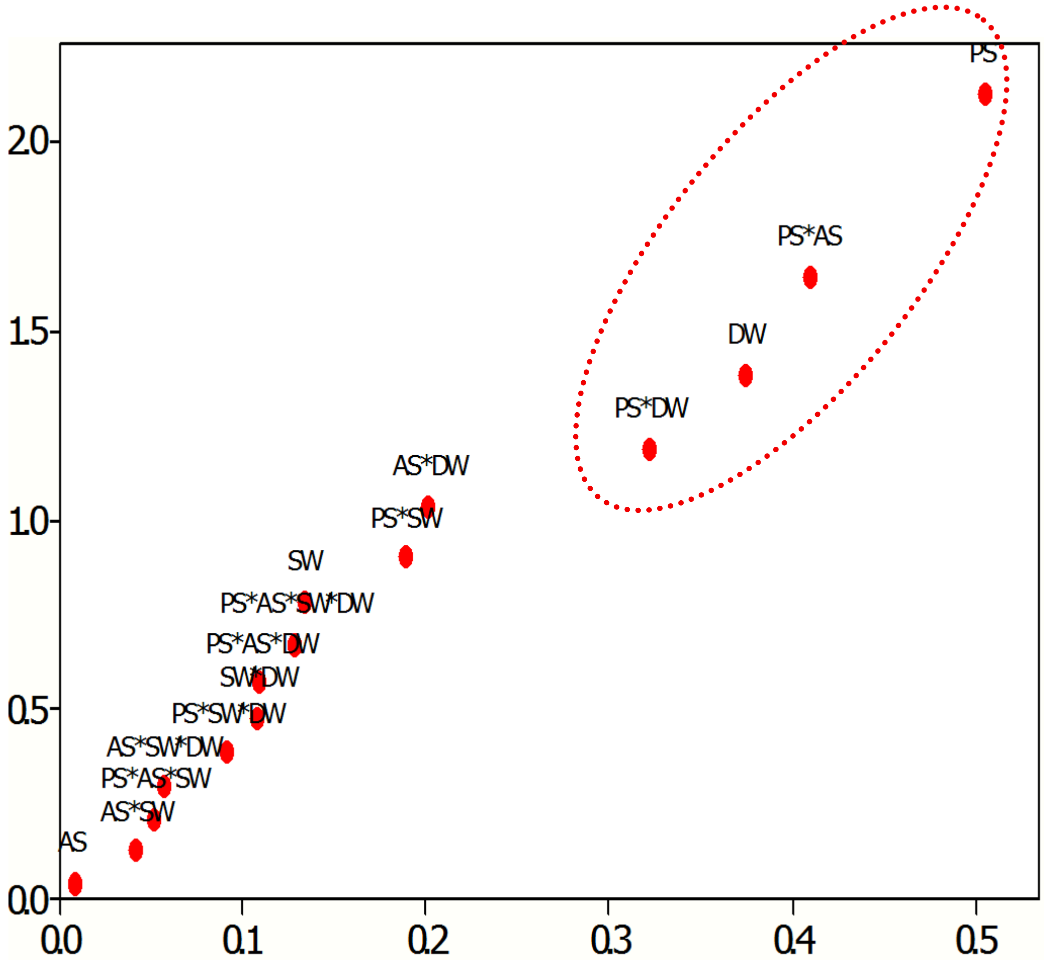


Fig. 2.b. Half-normal plot of dispersion (Ln Sigma ^{2}) effects

2.2. Process Parameters Optimisation: optimal solution

✓ **The objective**: achieve the nominal (**target**) response mean value of **95 μm**

- According to the **two-step procedure for Nominal-The-Best (NTB) problem**:

1. Select the levels of dispersion factors to minimise dispersion:

From the regression equation for dispersion effects:

$$LnSigma^2 = 3.22 + 0.25 \cdot PS + 0.2 \cdot PS \cdot AS + 0.19 \cdot DW + 1.6 \cdot DW \cdot PS \qquad (5)$$

- recommended levels of dispersion factors: **PS at “-1” (0.0), AS at “+1”(9.0)**
- factor SW could be used to bring the mean on the target depends of the DW level

2. Select the levels of location factors to bring mean to the target:

From regression equation for location effects:

$$MEAN = 87.8 + 6.51 \cdot SW + 5.74 \cdot DW + 3.02 \cdot SW \cdot DW \cdot AS + 2.79 \cdot PS \qquad (4)$$

and by solving the following equitation (6):

$$95 = 87.8 + 6.51 \cdot SW + 5.74 \cdot DW + 3.02 \cdot SW \cdot DW \cdot (+1) + 2{,}79 \cdot (-1) \qquad (6)$$

there are two possible solutions:

(a.) **DW at “-1” (1.68)** then calculated **SW = 16.2** – not practically possible

(b.) **DW at “+1” (1.70)** then calculated **SW = 10.5** ≈ **11.0** - OK

➢ **Optimal parameters setting: DW=1.70; SW=11.0; PS=0.0; AS=9.0**

2.3. Discussion

- *Previously* - automatic enamelling process capability study performed under the **assumption of normal distribution** - **results misleading** (e.g. Pp > Cp and Cp > Cpk, which is practically impossible).
  This highlights **the importance of a proper calculation of process performance** indices, providing accurate data for the customer and for the process improvement.

- *Previously* - the analysis of the enamelling process experiment was performed using **ANOVA**. Although both methods resulted in the same optimal parameters setting, **the location and dispersion modelling outperformed ANOVA – it found new significant interactions** - effects on mean (AS·SW·DW) and variation (PS·DW) that ANOVA did not detect.

Control:

➤ Verification run confirmed the results of experimental analysis:

enamel thickness ***mean = 96 μm****, enamel thickness* ***st. deviation = 4.5*** *μm*

presenting **significant improvement** in comparison to the previous performance.

- Taguchi's quality loss function:
  - loss caused by previous performance ***Lp(Y)=K·70.06*** units (mean was 103.37 μm)
  - loss after optimisation is ***Lo(Y)=K·2.99*** units
  … expected that after optimisation the **loss will be reduced ≈ 23 times** - defects will be significantly reduced and process performance improved!

3. CONCLUDING REMARKS

- **Process performance analysis**: the significance of the **accurate estimation of process performance indices for non-normal** distribution.

- **Location and dispersion modelling**: clarified **a total contribution of control factors and interactions to the variation in the process** – successful method to optimise the observed single-response system.

✓ **Six Sigma** project implementation:

- the first step in introducing **advanced quality improvement programs in Serbia as a Serbian Manu*future* Program**
- the success of project **depends on a management devotion** and it **requires cultural changes** (i.e. 'facts-based' decision making instead of 'experience or intuition-based').
- importance of a theoretical underpinning and a proper training of company's personnel - to **bridge the gap between the theory and practice of six sigma**

Thank you for your attention!

Questions / Comments?!

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