Improvement of the Measurement System Analysis Using Experimental Design

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***Abstract**: Continuous improvement is an important demand of quality management systems in the automotive industry. The main objectives of our project were the improvement of the measurement system analysis in case of the measuring instruments that are built into the production line to control production parameters. In practice, we developed a new method to determine and reduce measurement uncertainties. The new method comprises a few techniques of finding cause, a variant of risk analysis, and subsequently the methods of experimental design on the chosen influential factors. We used this model to reduce measurement uncertainties at a measuring point where the risk was higher. The verified improvement method can be adapted as a general methodology of the production process.*

***Keywords**: continuous improvement; measurement uncertainties; DOE*

1 The Information Value of the Measurement, Costs of the Measurement

Processes can be technically and economically improved though their optimization. For this, different management theories, such as Lean, Six Sigma, and several supply management regulations in car industry (ISO TS 16949) provide assessment possibilities. It is rarely examined, however, on what conditions can the different measurement and test methods (tools and systems), the expectations about measurements and the control of the measurement tool be effective [1]. This fact is especially problematic, knowing that – according to some analyses – the costs of measurement deficiencies can amount to 3 to 5 per cent of the total costs.

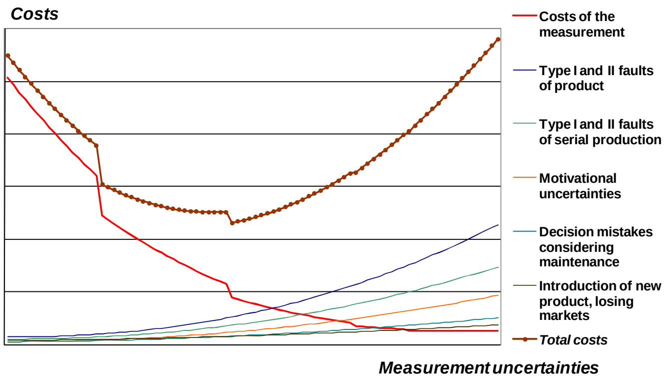

Figure 1
Costs coming form changing measurement uncertainties and the total costs

This problem leads us to achieving the management objective of controlling the measurement tool. The value to be achieved: the minimum sum of the costs of measurement uncertainties and the costs of measurements. The costs resulting from unsufficient information can usually be identified as risks.

These come from the following:

- decision mistakes concerning the product (type I and II faults),
- decisions about the process,
- losses coming from the client's approval at the introduction of a new product (faulty samples, unregulated processes causing market loss),
- false report for the maintenance process,
- losses resulting from wrong or uncertain identification of employees' decisions (motivational uncertainty), etc.

Measurement uncertainty is the parameter associated with the variations of measurement (e.g. multiple of the deviation). The easiest way is to estimate this value based on the variation of the recorded (actual) measurement results, but sometimes it is necessary to calculate the value (which is sometimes a theoretical one) in a special way.

Measurement uncertainties can be improved by reducing the measurement environment and the background noise [2]. The problem is relevant for scientific research, but have some important consequences in practice too. We prove this through a case study which shows the processes in the automotive industry.

2 A Practice-oriented Method to Constantly Reduce Measurement Uncertainties

2.1 The Process of Calculating Measurement Uncertainty

In practice (if we have actual tools, samples and environments), we collect those noise factors which might occurring during measurement. We give the variability of possible effects with variation intervals. These remain between the standard values in case of controlled noise factors (a standard can be, for example, that the maximal outer temperature variable is ±2°C).

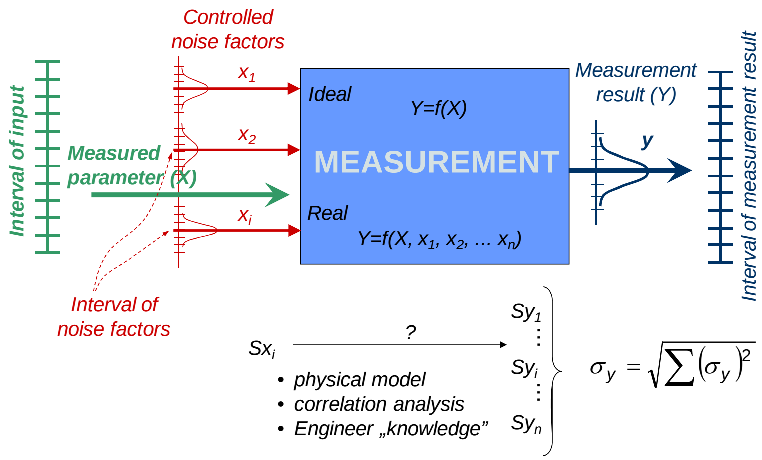

Figure 2

The connection between measurement uncertainties and input noise factors

We have to examine the noise factors, identified by the cause-and-result analyses, on the basis of their strength, and also their effect. For this we estimate the correlation between changing the noise parameter and the measurement result. We developed a method with proved to be effective in our work. The method collects the errors, identifies the causes and improves the process. The improvement of the measurement potential is the task of a responsible person or organization (e.g. metrology council or workgroup). We indicate the steps on the following flowchart, where the colour orange means innovation elements that can be implemented beyond the car industry as well.

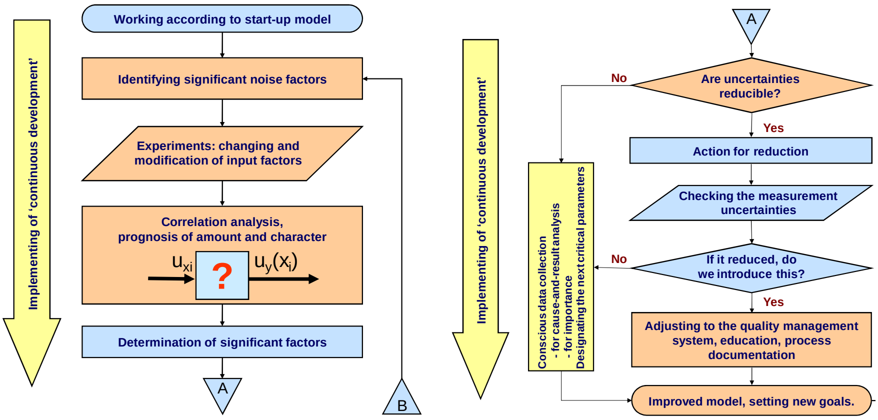

Figure 3
Flowchart showing the continuous development of measurement uncertainties [3]

3 Defining the Area of Reducing Measurement Uncertainties

3.1 Defining the Developmental Examinations

We record the process phases on the basis of production logic and with help of the control plan. We identify the phases in practice as well, and collect data about the possible risks from the viewpoint of measurement uncertainties. We highlight the methodological aspects of measurements in the control plan, and occasionally melt together some processing with common effects. We put the elements of the process into a table format to analyse the risk caused by the measurement technology.

Measurement activities critical for the success of the process are identified in work groups. The output of the analysis is the risk analyses of the measurement points. We suggested that the analysis should be realized in a table, based on the process control plan. The main aspects of the risk analysis are:

- R1: The frequency of the failure which is to be detected [1-5]
- R2: The reliability of the detection (measurement method, sampling) [1-5]
- R3: Detecting the failure at a later measurement [1-3]
- R4: The efficiency of changing measurement parameters and circumstances [1-3]
- R5: The importance of the failure [1-5]

Table 1
A sample of the risk analysis of the measurements

Process stage	**Evaluation/ Measurement Technique**	**Sample**	**Control Method**	**R1**	**R2**	**R3**	**R4**	**R5**	**Risk**
Post reflow inspection	Automated AOI inspection	100%	Computer controlled	5	2	2	2	4	160
	Set-up verification using master units	Once every model set-up	Control sheet	1	1	3	1	4	12
	Visual inspection by the operators	100% of detects	Computer controlled	3	3	2	3	4	216

The risk of a measurement point is the multiplication of the several factors and values. At the end of the process, we put the values into order showing their risk. According to our engineering experience, the validated result allows us to implement development only for the most important measurements (in the next round the then most risky measurements will be developed.

The results determined further improvement activities focusing only on a few measurement points. The engineering chose these points considering the risk value and the experiment possibilities. The chosen measurement points have a discrete value, so the output has attributive character.

The points that were chosen for thorough analysis were the visual inspection by the operators after the AOI.

3.2 Opportunity for Examination of Measurement Uncertainties

We used the Ishikawa diagram for the analysis of the critical measurement points and for recording the possible influencing factors (Figure 4) [4]. We designed the 2^p-en experiment plan for the signaled noise factors. We merged the outer movement and noise factors.

Table 2 summarizes the settings for the experiment plan based on different factors. The different levels are defined by the opinion of the realizers and the evaluator of the experiments. We estimated the size of the variation intervals on the basis of the typical factor variations, so that they could represent the effect of the noises in a realistic way.

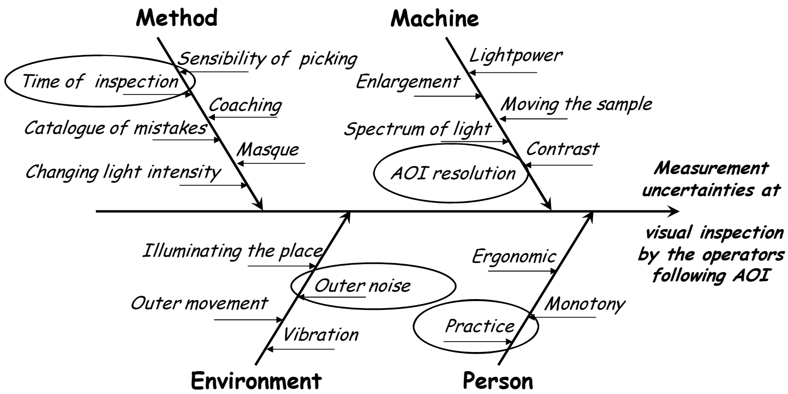

Figure 4
Ishikawa diagram for the analysis of the critical measurement points

Table 2
Physical variations of the experiment plan

i	Input factor	Implementation	x_i factor	
			x_i=-1	x_i=1
1	Experience	Two operator with different experience	less experienced	more experienced
2	AOI resolution	One picture versus three pictures	one picture	3 picutres
3	Outer noise Outer movement	Operator working in factory noise vs. working separately with harmonic music	separately with harmonic music	factory noise
4	Inspection time	Different inspection time	fast inspection	thorough inspection

For the measurement analysis we prepared a set of test samples. The test samples contained obvious defects, border defects and perfect units. We changed the measurement process so that we can repeat measurements on the test samples. We eliminated correction and we recorded the defects on paper instead of the computer at the visual inspection after the AOI.

The regression equation estimated on the basis of significant parameters:

$$y=15,8 \cdot x_0+1,4 \cdot x_2-0,6 \cdot x_3-1,1 \cdot x_1 \cdot x_3-1,0 \cdot x_1 \cdot x_2 \cdot x_3 \quad (1)$$

It can be seen form the equation that the effect of one of the linear components is significant. This is well illustrated by the sharp sloping of the effect of the linear components.

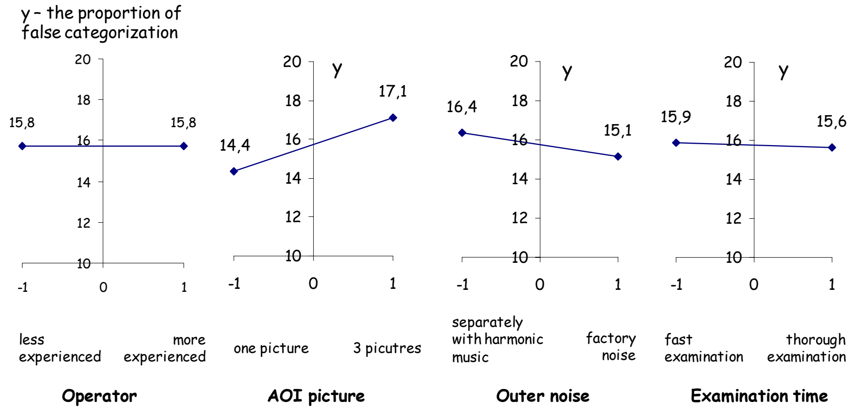

Figure 5

Graphical interpretation of the major effects of the experiment plan

As for the other significant components, another important observation was made: replacing factory noise with harmonic music had a cross-effect which was very much dependent on the person. The operator with bigger experience was very much disturbed, while the other operator was supported by the harmonic music coming from headphones.

The final format of the regression equation can be described by five components. This way the newly developed model proved 95 per cent adequate.

Conclusions

In practice we suggested that two factors should be modified as part of the innovation. In case of the first factor, we suggest that as the pins are wearing out, they should be check by "Gold" units more often. In case of the second factor, it is necessary to keep a homogenous temperature of the units before the test.

The next check/inspection (which can occur annually or in other intervals, depending on the clients' demands), will again start with identifying the hierarchy of the most critical examinations. If there will be no changes in the process, or the change will only mean that earlier developments prove efficient, presumably the development of the next inspections in the priority list will be implemented.

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