R&R analysis as an effective tool for controlling logistics production

Introduction

The role and tasks of production logistics depend on many factors and appropriate defining logistics. Currently, in many companies it is becoming increasingly common to integrate planning production planning logistics because production and logistics are closely related. An addiction, it observes the need to analysis of measuring devices (systems) which is important in the area of production logistics.

The study refers to the analysis and decision support regarding performance of the measuring. At present, the key value from the customer point of view is the quality of manufactured products. Controlling logistic production not only focuses on techniques to optimize the manufacturing process, but also the MSA (Measurement Systems Analysis) may prove to be an effective tool for quality control on production. The key to success is the fast access to correct and reliable information. That capacity MSA is an important supplementing periodically control/calibrate the devices. It allows you to assess the suitability of a measurement system to perform measurement tasks defined by the measured characteristics (its value, diversity and tolerance), the skills of operators, the external conditions (noise) and measurement procedure. Results from MSA analysis can gives an important information used for reduce the risk of claims and costs deficiencies.

R&R analysis

The main function of the measuring system, as writes Pajzderski [6] is the realization of the measurement process which is a part of the manufacturing process. The devices and for measuring should be implemented and monitored in such a way that measuring capacity in accordance with the requirements for measurements as mentioned in ISO 9001: 2000 [5].

Gage repeatability and reproducibility (R&R) is a MSA method for finding out the variations within a measurement system. Basically, there are 3 sources for variation: variation of the part, variation of the measurement device, and variation of operator. Variation caused by operator and interaction between operator and part is called reproducibility and variation caused by measurement device is called repeatability. Measurement system error can be classified into three categories: accuracy, precision, stability and correctness. The following picture shows the decomposition of variations for a product measured by a device.

Fig. 1. Elements of accuracy
Source: Own work based on Pajzderski [6]
Accuracy

Accuracy is a term most general in relation to the characteristics of the measuring system. Accuracy describes the difference between the measurement and the actual value of the part that is measured. It is defined as the degree of conformity in relation to the whole set of measurements and is associated with random and systematic errors. The accuracy of measurements is influenced by two factors: trueness which is the closeness of the mean of a set of measurement results to the actual (true) value [3] and precision which describes the variation during measuring the same part repeatedly with the same device. It is associated with random errors. A measurement system can be accurate but not precise, precise but not accurate, neither, or both, what the following picture shows:

Fig. 2. Accurate vs precise
Source: Own work based on Kończak [4]

The figure 2 shows four possible situations. On the first one scenario we can see consistently hit the center of the target. Measurements are both accurate and precise. In the second one, measurements are consistently but they are missing the center of the target. That is consistently and systematically measuring the wrong value for all respondents. This measurements are precise, but no accurate (they are consistent but wrong). The third, shows hits that are randomly spread across the target. It is seldom hit the center of the target but, on average is good but not very well for individuals. Finally the forth scenario shows a case where hits are spread across the target and they are consistently missing the center. Measure in this case is neither accurate nor precise.

Types of errors

The obtained results at every stage of the process should be as close as possible to the expected value and that expected value should be as near as possible the certified (references) value. Very often happens that the measurements have errors of various kinds. Basically there are three types of errors on the basis. They may arise from the source. This category of errors includes all the human mistakes while reading, recording and the readings.

Gross errors are errors that are so serious (i.e. large in magnitude) that they cannot be attributed to either systematic or random errors associated with the sample, instrument, or procedure. Gross errors can tend to affect both accuracy and precision.

Random error is caused by any factors that randomly affect measurement of the variable across the sample. For instance, each person's mood can inflate or deflate their performance on any occasion. The important thing about random error is that it does not have any consistent effects across the entire sample. Instead, it pushes observed scores up or down randomly. This means that if we could see all of the random errors in a distribution they would have to sum to 0 -- there would be as many negative errors as positive ones. The important property of random error is that it adds variability to the data but does not affect average performance for the group. Because of this, random error is sometimes considered noise.

Systematic error is caused by any factors that systematically affect measurement of the variable across the sample. Unlike random error, systematic errors tend to be consistently either positive or negative -- because of this, systematic error is sometimes considered to be bias in measurement which is a measure of the difference between the true value and the observed value of a part (element). If the “true” value is
unknown, it can be calculated by averaging several measurements with the most accurate measuring equipment available.

**GAGE repeatability and reproducibility**

R&R analysis has its beginning in the assessment of the measurement system by one of the calibration method - validation. It was noted that reference value can be replaced temporarily their poorer counterparts, and can be estimated by the value of valid indications. This type of assessment contains several methods of R&R analysis. The usual method of assessing the suitability of measurement systems to perform specific measurement tasks is the analysis of repeatability and reproducibility of measurements (R&R). Analysis of R&R is a very useful procedure because it takes into account the impact of the measurement system components on the variability of the measurement results.

This tool helps to give an important answer, in which extent the variability of the measurement results distorts the observed variability of the manufacturing process. It also can be used to determine variation of the part, variation of the measurement device and variation of operator. It is extremely important information for the quality control process. Data obtained using the devices and measurement systems are not perfect and identical, because the measuring system is not only the instrument, but also the method, templates, operators, devices, software, hardware, environmental conditions and other relevant elements which could affect of the result of measurement. In practice it means that each measurement \( x_m \) which obtained using the measurement system only partially reflects the actual value of the unknown measured feature \( x_0 \).

According to [3] precision describes the variation you see when you measure the same part repeatedly with the same device. It includes the following two types of variation:

- **Repeatability**: the ability of an operator to consistently repeat the same measurement of the same part, using the same gage, under the same conditions. Variation due to the measuring device.

![Graphical representation of repeatability of measurements](source: Own work based on Chryster, Ford, General Motors (1998))

- **Reproducibility**: the ability of a gage, used by multiple operators, to consistently reproduce the same measurement of the same part, under the same conditions. Variation due to the operators and the interaction between operator and part.
Fig. 4. Graphical representation of reproducibility of measurements

Source: Own work based on Chryster, Ford, General Motors (1998)

Procedures for the determination of these parameters are very similar. After collecting a series of measurements should be calculated: arithmetic mean, standard deviation and relative standard deviation $RSD$ according to the formula (1). In spite of the identical calculations, repeatability and reproducibility of the results will be very different, mainly due to the conditions in which research is conducted. Pasek [7] uses the term intermediate precision which similar to repeatability and reproducibility is a measure of the variability of the measurement process.

$$RSD = \frac{s}{x} \times 100\%$$ (1)

Purpose of the assessment R&R is to define how much (which part) of the observed variability comes from the measurement process. The purpose is also the evaluation of the volatility of individual components of the measurement process. It assumed following linear model:

$$y = x + \varepsilon$$ (2)

where:
- $y$ - observed measurement result
- $x$ - the value of the correct value (reference)
- $\varepsilon$ - measured error

The variability of the measurement system caused by changes in measurements is related to the reproducibility of the system and can be characterized by the variance $\sigma_o^2$. Repeatability, represents a basic and inherent precision of measuring system with errors which can be defined as the value of derivatives of variance repeatability $\sigma_e^2$.

$$\sigma_m = \sqrt{\sigma_e^2 + \sigma_o^2}$$ (3)

where:
- $\sigma_e^2$ – variance of reproducibility
- $\sigma_o^2$ – variance of repeatability

$$\sigma_e = \frac{R_s}{d_2^*}$$ (4)

where:
- $\sigma_e$ – estimated standard deviation of repeatability
- $R_s$ – mean value for ranges in the measurements done by the operators for next
- $d_2^*$ – values recommended by MSA standards
\[
\sigma_o = \frac{R_o}{d^*_o}
\]  
where:
\(\sigma_o\) – estimated standard deviation of reproducibility
\(R_o\) – range for average values for individual operators
\(d^*_o\) – values recommended by MSA standards

\[
\sigma_p = \frac{R_p}{d^*_p}
\]  
where:
\(\sigma_p\) – estimated standard deviation of variation for the parts (of the process)
\(R_p\) – range for average values for individual parts
\(d^*_p\) – values recommended by MSA standards

\[
EV = 5.15 \times \sigma_e
\]  
\[
AV = 5.15 \times \sigma_o
\]  
\[
AV^* = \sqrt{AV^2 - \left(\frac{EV}{n \times r}\right)^2
\]  
\[
PV = 5.15 \times \sigma_p
\]  
where:
\(EV\) - repeatability
\(AV\) – reproducibility
\(AV^*\) – reproducibility after correction because of the error of estimator (correction AIAG)
\(PV\) – variability of parts
\(n\) – number of measured parts
\(r\) – number of trials

\[
R & R = 5.15 \times \sigma_m
\]  
\[
\sigma_t = \sqrt{\sigma_p^2 + \sigma_m^2}
\]  
\[
TV = 5.15 \times \sigma_t
\]  
where:
\(\sigma_m\) – standard deviation for the measurement system (R&R- formula no 3)
\(\sigma_t\) – the overall process variability
\(TV\) – total process variability

R&R ratio shows % R&R relative to the total variance from analyzed measurements \(\sigma_e^2\):

\[
% R & R = \frac{R & R \times \times 100}{TV}
\]  

**Case studies**

The aim of R&R analysis is to repeat measurements what is called a gage R&R crossed experiments which means that each part is measured multiple times by each operator. The same sample of selected products representing the variation in the manufacturing process. Experimental system R&R ensures that absolute errors, although they are not known, will be reflected in the end result, which is to determine the cumulative effect of all the random and systematic errors. To specify the values in range of R&R should be Measurement Capability Index calculated. It indicates whether the measurement system should be used in practice, when it provides reliable data. An important result of R&R analysis is specify the measuring indicator of the ability - MCI, according to the following formula:
The subject of the analysis is to determine the impact what the operators and used measuring devices have on variability of process of measuring thickness of aluminum film. Two following experiments were performed.

**Experiment R&R 1**

Measurements relate to the device, which is used to measure the film thickness in one of the manufacturing companies. The original study was based on a testing references plate with a thickness of 0.5 mm with a tolerance of 0.05 mm according to the specifications issued by the Director of the Regional Office of Weights and Measures in Katowice. In the 160 measurements measured by 4 operators in a completely random way selected 4 measurement parts for 2 days gets by 2 different operators.

![R&R graph](image)

**Fig. 5.** R&R graph (deviations from the mean value for 2 operators).

*Source: Own work*

The most important result of the R&R analysis is a graphical plot of the variability of results (Fig. 5) that shows measurements of each individual operator. Measurements are presented in the form of deviations from the each average values for the next parts tested. Deviations are grouped separately for each operator, but taking into account each measured element (in this case a piece of film). The central line in each frame shows the average deviation from the average measurements of the same parts for all operators. From the graph is possible to see big variability in the process. The results of the overall R&R analysis confirmed the diagram (Fig. 6) box-plot, which also requested the difference between the operator 1 and 2. Both operators were given different average values. In addition, the operator 2 does not obtain measurement in the range of values above the upper quantile.

![Box-plots](image)

**Fig. 6.** Box-plots.

*Source: Own work*
Experiment R&R 2

That experiment was designed to check if the unknown value of the absolute error are taken into account in the R&R procedure and what is the impact of these errors on the indicators which determining the suitability of the measurement system.

160 measurements (an original collection) represents 160 measuring values of aluminum film. From that collection randomly chosen 4 sets by computer simulation. Selection was as follows: the 1st and 2nd group contains of 10 measurements and they were selected completely randomly. Group 3 was selected of 10 measurements in the way to show the maximum difference between the reference value and the measurement values. In contrast, the group 4 includes the measures closest to the references value. All sets are devoid of shortcomings. From the graph (Fig. 7) can be concluded that the spread of the measurement results for both the operator 1 and 2 is similar, but the operator 3 overestimates the results, what may suggest that operator 3 gets the measurements of the film not carefully. In contrast of that, the operator 4 is measuring with the smallest scatter of results.

![Fig. 7. R&R graph (deviations from the average value for 4 operators)](source: Own work)

The results of the overall R&R analysis confirmed the figure 8 which showed the most significant difference between the operator 3 and 4 and the similarity of operators 1 and 2.

![Fig. 8. Box-plots](source: Own work)

In table 4 showed the descriptive statistics for the results done by 4 independent operators. For example the operator 4 of the collected measurements deviate average from the mean value about 0.189466 (Table 2).
Table 2. Statistics for operators

<table>
<thead>
<tr>
<th>Operator</th>
<th>Mean</th>
<th>Deviation</th>
<th>Min</th>
<th>Max</th>
<th>Stand. deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500,5375</td>
<td>-0,131250</td>
<td>499</td>
<td>502</td>
<td>0,850245</td>
</tr>
<tr>
<td>2</td>
<td>500,0000</td>
<td>-0,668750</td>
<td>499</td>
<td>502</td>
<td>0,884337</td>
</tr>
<tr>
<td>3</td>
<td>502,0875</td>
<td>1,418750</td>
<td>500,5</td>
<td>503,5</td>
<td>0,775320</td>
</tr>
<tr>
<td>4</td>
<td>500,0500</td>
<td>-0,618750</td>
<td>499,5</td>
<td>500,5</td>
<td><strong>0,189466</strong></td>
</tr>
</tbody>
</table>

Source: Own work

Table 3. % R&R analysis with tolerance

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Measure</th>
<th>% Variation</th>
<th>% Total share</th>
<th>% Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repeatability</td>
<td>2,003642</td>
<td>57,7145</td>
<td>33,3096</td>
<td>66,7881</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>2,779172</td>
<td>80,0534</td>
<td>64,0855</td>
<td>92,6391</td>
</tr>
<tr>
<td>Variation of parts</td>
<td>0,560309</td>
<td>16,1396</td>
<td>2,6049</td>
<td>18,6770</td>
</tr>
<tr>
<td>Total R&amp;R</td>
<td>3,426132</td>
<td><strong>98,6890</strong></td>
<td>97,3951</td>
<td>114,2044</td>
</tr>
<tr>
<td>Total variation of process</td>
<td>3,471646</td>
<td>100,0000</td>
<td>100,0000</td>
<td>115,7215</td>
</tr>
<tr>
<td>Tolerance</td>
<td>3,000000</td>
<td></td>
<td>100,0000</td>
<td></td>
</tr>
</tbody>
</table>

Source: Own work

The last figure 9 shows the mean for each elements and each operator. The graph shows that the operator number 1,2 and 4 gets relatively similar results going from part to part, but the operator 4 is completely different.
Conclusions

By identifying measurement systems which can be the sources of erroneous decisions (acceptance process or not) is possible to find the following benefits:

• significant reduction of risk of sending the product to the customer due to wrong decisions,
• reduce the risk of erroneous decisions on the status of the process (quality control),
• the possibility of verifying the correctness of the selection of control methods especially for characteristics associated with a high risk cost of incompatibility.

These are a sufficiently reason to use R&R analysis to get information about the realization of the measurement process which is a part of the manufacturing process also in logistic production. All of this methods (MSA) is used to identification problems when the process is unstable or to obtain information that the process is stable.

As an results from papers is the finding that in the case when the operator performs the work (duties) carelessly R&R analysis can be a useful and effective tool. Especially it can be seen by using R&R graph of variation when people gathering measures to collect the data. All described errors cannot be completely eliminated, but there are ways to minimize their impact on the size of the total error. Results flawed random errors can be disclosed by means of analysis on outliers. The solution to eliminate or minimize this type of error is a multiple repeat measurements.

The quality of the instruments, quality of reference materials, contamination, improper collection of measurements and errors in reading and calculating data is one of the most important and most common causes of systematic errors in the measuring in production and in logistic also. The results of the R&R analysis can indicate them (show that errors could be in that process) what is currently up to date in an economic area.

Abstract

The paper presents one of the tasks of logistics which refers to analysis and decision support making for performance measurement devices. Provide quality of the product comes down to continuous control of the degree of defective production stands and for this reason MSA measurement systems analysis may prove to be an effective tool. The need to analysis of measuring devices (systems) is visible also in the area of logistics.

Article performs two experiments R&R(real and simulated data). Sample was measured multiple times by 4 operators. The most important result of R&R analysis is a graphical plot of the variability of results. The percentage of tolerance defines the evaluation of the functioning measurement system, taking into account variation of the part, variation of the measurement device and variation of operator.

The paper discusses the process of measuring the thickness of the material used for packaging food products (films) and its characteristics. It describes the purpose and objective R&R analysis and also outlined the types of errors that can significantly affect the reliability of results which can be the persuasive information in the decision process. The study showed that consequently determining the capability of the measurement system is important aspect of quality and it may contribute to a significant reduction in the risk of claims and costs deficiencies.

Keywords: Packaging, quality of products, defectiveness, claims, R&R analysis, capacity measurement, measurement errors
References


