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ANALYSIS PROCEDURE OF INSPECTION ERRORS BASED ON MSA ATTRIBUTE STUDY DATA SET FOR THE IMPROVEMENT PURPOSES: PART 1 – METHODOLODGY

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Abstract: The article presents an authorship version of the analysis procedure of data set from MSA Attribute Study for the purposes related to the reduction of conformity assessment errors and improvement of production process effectiveness. The MSA manual does not include any clear guidelines on how to eliminate errors or guidelines on how to analyse data sets from attribute study to eliminate errors. The article attempts to fill the gap identified in this field. In this article (Part 1), the author outlines the key features of own methodology of analysis data from MSA attribute study. In this article, which is one of the two parts, a research problem has been identified. It was emphasised that the influence on the reduction of the effectiveness of the production process have errors committed by the controllers in the alternative assessment of the product's conformity with the requirements, i.e. errors of I and II type, in particular, II type errors, which should be first eliminated. A traditional approach to research analysis and evaluation of alternative inspection system practised in the MSA manual was presented. Four key assumptions that were adopted for the research goal were presented. Author's procedure for analysis of errors from the attribute study data set is to point to the direction of activities in the field of error analysis, emphasise intolerance to any error, assume to use the root causes analysis and the coaching sessions to reach the root causes of conformity errors. In the second, final article in the series (Part 2), the author illustrates how, step by step, the procedure could be used in practice. It also presents the advantages and limitations of its own procedure.

Keywords: Attribute MSA Study, errors in inspection, procedure, key assumptions

1. INTRODUCTION

Quality inspection is a very often critical stage of the production process. However, it does not create added value (Bożek et al., 2017). Nowadays, in many industrial manufacturing and assembly systems the attribute (also called alternative) inspection, based on decisions OK/NOK or GO/NO-GO for parts produced during an on-line operation mode, plays a significant role for quality control (Lughofer, 2011). In today's turbulent environment, many companies want to increase productivity and reduce costs (Nowicka-Skowron and Ulewicz, 2015; Tran et al., 2020). Hence, there is a need to

improve all processes efficiency, including the quality control processes, namely, to enhance their effectiveness, efficiency (Hamrol, 2000; Hamrol, 2015) and reduce their duration (Gangala et al., 2017). Effectiveness of processes is considered as a maturity indicator of the quality management system (Grabowska and Takala, 2018). The production process effectiveness is influenced by errors in the quality inspection; this mainly refers to a situation when the quality inspection is the last stage in the whole process before the product is delivered to the customer (Bożek and Rogalewicz, 2013). The burden of responsibility for erroneous decisions in alternative inspection, in particular in visual inspection, rests with the human, as this is a human being what is a control tool here. Inspection errors made by a man are inevitable because "to err is human" (Seneca). Human visual inspection is estimated to be only 80% effective when implemented via a rigidly structured checklist because many inspection tasks are both time-consuming and tedious (Smith, 1993). Companies are capable of eliminating the errors in the inspection by investing in solutions for automatic, visual detection of irregularities. At the same time, it is not always technically possible or economically viable (Durivage, 2015). Errors in inspection made by human tend to result from numerous factors that affect the evaluation process itself, which can jointly be included in the P.I.S.M.O.E.A category (Stoklosa, 2019), where one of the important factors is the inspection station ergonomics (Akutsu, 1995) and organization of the visual inspection process (Kujawinska et al., 2018). Being aware of imperfections of a human being as a tool of inspection, and the inevitability of errors made by inspectors cause that managers seek for possibilities to limit those errors, where results of the inspection often pose a starting point for such actions, audits of inspection areas, periodic evaluation of the effectiveness of alternative inspection systems. To this end, specific procedures developed for the needs of the automotive industry are used, in particular those contained in the MSA manual (MSA, 2010) and VDA 5 (VW) (VDA 5, 2011). The most common way to evaluate visual inspection system in the automotive industry is the Kappa method combined with an analysis of system effectiveness (indicators: effectiveness, miss rate, false alarm rate) (MSA, 2010). This approach focuses on attribute study data set and calculating indicators and comparing them to the appropriate values that are the basis for assessing the control system. However, there is a lack of guidelines on how to analyze data to improve the alternative control system, so how to approach errors in inspection to eliminate or reduce them. The article aims to present a new approach to analyzing the results from the Kappa study based on conformity assessment errors for improvement purposes – increase the effectiveness of the attribute control system.

2. RESEARCH PROBLEM

Errors in alternative quality inspection should be eliminated total because they affect the effectiveness of the production process. Virtually every error can be controlled at a fraction of the cost of traditional quality control methods (Hinckley, 2003). Errors in alternative quality control are typically grouped into two types labelled Type I and Type II. A Type I error (called a false positive) occurs when a product is identified as defective when in fact it is not. A Type II error (called a false negative) occurs when a product passes the inspection, but it is defective (Rosandich, 1997). The concepts of those errors are presented in Figure 1.

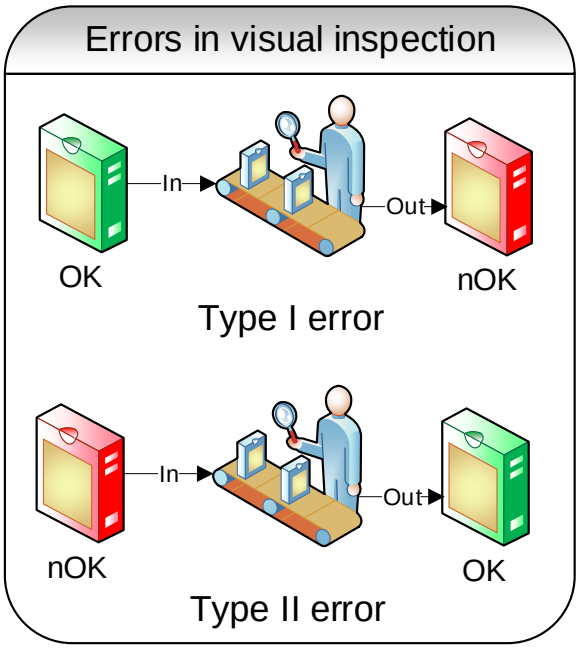

Fig. 1. Errors in alternative quality inspection, e.g. in visual inspection

Because the consequence and frequency of each type of error vary, prioritizing the error-proofing order is an essential part of a quality control strategy. Type I errors are referred to as the manufacturer's risk, as this is the manufacturer who risks having a good product rejected. In contrast, Type II errors refer to the supplier's risk because this is the client who is at risk of receiving a defective product (Knop et al., 2018). A non-conforming product erroneously accepted by an inspector may move to the next station or eventually reach the client. In contrast, a good product that is erroneously rejected by will be scrapped (in the worst-case scenario). Possible errors paths resulting from an alternative quality inspection are presented in Figure 2.

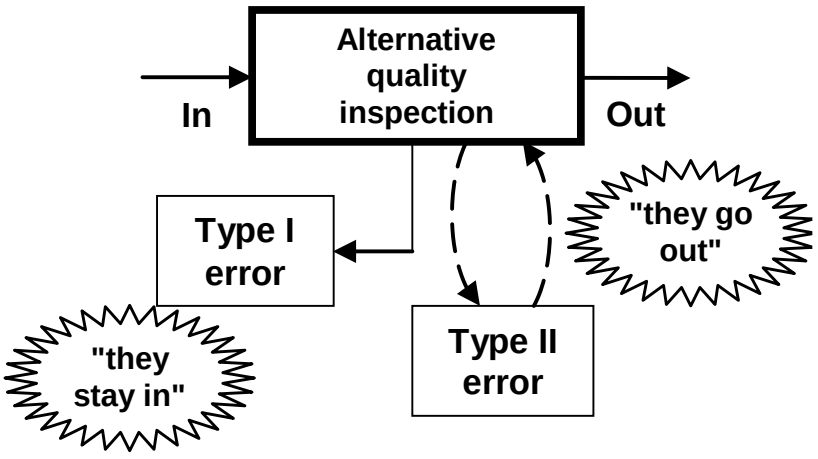

Fig. 2. „Road" of the type I error and type II error

The II Type errors are be considered to have more serious consequences, as they are usually related to greater risk and costs for the manufacturer when a non-conforming product wrong assessed reaches the customer (Webber and Wallace, 2007). They should be at first eliminated because of their more significant negative consequences.

Each detected errors should be analysed by applying appropriate methods and tools in this aim, facilitating such analysis. Each error in quality inspection, adequately analysed, is a source of knowledge and makes it easier to eliminate, according to Kaizen philosophy and Toyota approach (Liker and Meier, 2006). Errors are analysed numerically by calculating appropriate indicators. Recommended by the part of the automotive industry (AIAG) indicators are the Kappa index (Cohen, 1960) and auxiliary indicators (effectiveness, miss rate, false alarm rate) (AIAG, 2010). There is no perfect indicator, an example of this is the Kappa index, which as a measure of conformity, has its weaknesses and limitations cited numerous times in (Klaput and Vykydal, 2018; Diering et al., 2015; Knop and Borkowski, 2011; Starzyńska et al., 2018) where an alternative with greater possibilities is the Gwet's AC1 index (Gwet, 2014). The MSA manual provides for the method of calculating Kappa and other indexes. It presents their scopes, which are to be the basis for evaluating the inspection system and thus to initiate the improvement actions (Table 1, Fig. 3).

Table 1.
Criteria of the attribute measurement system acceptance based on 3 indexes (AIAG, 2010)

Decision Measurement system	**Effectiveness**	**Miss Rate**	**False Alarm Rate**
Acceptable for the appraiser	≥ 90%	≤ 2%	≤ 5%
Marginally acceptable for the appraiser – may need improvement	≥ 80%	≤ 5%	≤ 10%
Unacceptable for the appraiser – needs improvement	< 80%	> 5%	> 10%

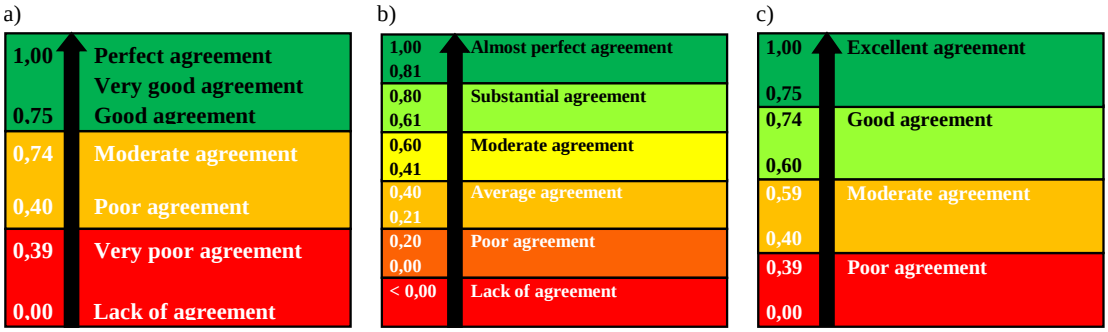

Fig. 3. Range of Kappa index values acc.: a) Cicchetti, b) Lendis and Koch, c) Fleiss

In the case of the Kappa index, there are no single interpretative guidelines for its value (Fig. 3). The MSA manual accepted the recommendations proposed by Cicchetti, where another alternative is the guidance given by Landis and Koch or Fleiss (Munoz and Bangdiwala, 1997; Tang et al., 2015; Sim and Wright, 2005). It may create problems in determining the moment of improvement actions based on the value of this index. The manager may have a dilemma after evaluating the alternative inspection system with the above-mentioned indexes: should the improvement actions already be taken up regarding the level of the above-mentioned indexes, or can these actions still be neglected? The MSA manual itself does not provide for any clear guidelines here, because it makes some questions to be considered: "*Do the acceptance guidelines*

need to be changed for this process? Are these risks acceptable?" (MSA, 2010). More detailed guidelines or procedures are needed on this issue.
Based on the calculated value of MSA indexes, a decision is made whether improvement actions will or will not be launched. However, in the MSA reference manual, there are no guidelines on how to approach the attribute study to reduce inspection errors. The author, based on own experiences as well as comments and suggestions reported by practitioners dealing with such an analysis, notices the need to develop a procedure determining the way of analysis of the attribute study data set to reduce inspection errors and improve the inspection and production process. This need has been reflected in the article (Part I and II). This article is an attempt to fill the observed gap, i.e. lack of guidelines on how to analyse inspection errors to improvement purposes. The first and second part of the article presents an author's approach to the analysis procedure for inspection errors for the purposes related to improvement. The article is also intended to stress the need to the depth analyse the occurring inspection errors as a valuable source of information about the inspection process itself. Executed attribute study and obtained data set (the results of the assessment of samples of products) should initiate such an analysis process and improvement action every time.

3. METHODOLOGY

The basis for analyzing errors in quality inspection in aim to improve visual control system according to the new approach is the Kappa study along with effectiveness analysis of the inspection system (AIAG, 2010). The Measurement System Analysis manual (MSA, 2010), where the methodology of these studies was presented, is reference material. There are specific recommendations in this manual on how such the attribute study should be carried out: a quasi-random sample of products (preferably 50 parts), classified by three appraisers into category "1" or "0" (OK, NOK), in 3 trials. Example results from Kappa study were presented in Table 2 (MSA, 2010). It was assumed that for the research purposes, the results of the evaluation of product samples from the attribute study are saved in a spreadsheet in Excel, which will facilitate their subsequent analysis.

Table 2.
Attribute MSA Study data set as a source for error analysis (MSA, 2010)

Part	Appraiser A			Appraiser B			Appraiser C			Ref. value
	A - 1	A - 2	A - 3	B - 1	B - 2	B - 3	C - 1	C - 2	C - 3	
1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	1	1	0	1	1	0	1	0	0	1
7	1	1	1	1	1	1	1	0	1	1
8	1	1	1	1	1	1	1	1	1	1
9	0	0	0	0	0	0	0	0	0	0
10	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1
12	0	0	0	0	0	0	0	1	0	0
13	1	1	1	1	1	1	1	1	1	1
14	1	1	0	1	1	1	1	0	0	1
15	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1
19	1	1	1	1	1	1	1	1	1	1
20	1	1	1	1	1	1	1	1	1	1
21	1	1	0	1	0	1	0	1	0	1
22	0	0	1	0	1	0	1	1	0	0
23	1	1	1	1	1	1	1	1	1	1
24	1	1	1	1	1	1	1	1	1	1
25	0	0	0	0	0	0	0	0	0	0
26	0	1	0	0	0	0	0	0	1	0
27	1	1	1	1	1	1	1	1	1	1
28	1	1	1	1	1	1	1	1	1	1
29	1	1	1	1	1	1	1	1	1	1
30	0	0	0	0	0	1	0	0	0	0
31	1	1	1	1	1	1	1	1	1	1
32	1	1	1	1	1	1	1	1	1	1
33	1	1	1	1	1	1	1	1	1	1
34	0	0	1	0	0	1	0	1	1	0
35	1	1	1	1	1	1	1	1	1	1
36	1	1	0	1	1	1	1	0	1	1
37	0	0	0	0	0	0	0	0	0	0
38	1	1	1	1	1	1	1	1	1	1
39	0	0	0	0	0	0	0	0	0	0
40	1	1	1	1	1	1	1	1	1	1
41	1	1	1	1	1	1	1	1	1	1
42	0	0	0	0	0	0	0	0	0	0
43	1	0	1	1	1	1	1	1	0	1
44	1	1	1	1	1	1	1	1	1	1
45	0	0	0	0	0	0	0	0	0	0
46	1	1	1	1	1	1	1	1	1	1
47	1	1	1	1	1	1	1	1	1	1
48	0	0	0	0	0	0	0	0	0	0
49	1	1	1	1	1	1	1	1	1	1
50	0	0	0	0	0	0	0	0	0	0

Specific assumptions (#4) have been made to achieve the research aim.
Assumption #1: *Data set from attribute study as a valuable source for error analysis for their elimination, better than the indicator itself*.

Data are closer to the process (Wheeler, 1999) than their aggregated form, i.e. indicators. Noteworthy is also the quality of the exploited data which must be born in mind (Diering and Dyczkowski, 2016). In-depth analysis of data (results) from any process is an invaluable source of knowledge about such a process (Martin, 2013); it brings plenty of valuable information which should be used in the improvement actions. One of the data presentation principles formulated by Walter Shewhart states that "the way data is presented in must never obscure the information and signals which the data contained, and which may affect the conclusions" (Wheeler, 1999). Indicators, as a condensed measure based on data, can distort the results of the process and ultimately affect the failure to make a decision or make the wrong decision. The indicator as a measure of the effectiveness of actions taken is not an ideal "product". You can measure everything (Hubbard, 2014) and find the right indicator for it. Striving for a satisfactory value of indicators tends to be a reason for numerous abuses (so-called "straining", falsifying the results) which causes that the real problems in the process are hidden. The use of indicators not rarely becomes more an end in itself than a means to achieve the goal, which should be the process improvement (Reinfuss, 2012). The data, in turn, allow you to capture much interesting information about the behaviour of the process; they are closer to the process than indicators. The detailed analysis of the attribute MSA data set served as a valuable source of information which was used to improve the inspection process.

Assumption #2: *Every single error in the assessment of the alternative compliance of the product with the requirements should be analyzed, because each error affects the costs, has its cause and disregarded it may in the future become a severe problem*.

Each error in alternative inspection is associated with costs, so no error should be underestimated. Detection of even a single error is also a chance to improve the effectiveness of the alternative inspection process. Each time after the attribute study, if there is any error in the evaluation of conformity by the inspectors, action should be taken to identify the cause or causes of this error and eliminate it effectively. This approach consisting of error analysis after it occurs in order to identify the error's underlying causes was adapted from root cause analysis RCA (Grissinger, 2003) for research purposes. The fact of the occurrence of any error in conformity assessment initiates taking action in the area of its analysis and elimination.

Assumption #3: *Reaching the root cause or root causes of an error in inspection is a permanent way to eliminate it.*

Errors in control do occur, but for them not to recur, it is necessary to analyze the root cause(s) of these errors and propose effective countermeasures. For this purpose, it can be used the technique straight from the Toyota production system, i.e. 5WHY/WHY-WHY or other tools based on discovering the source of the problem, e.g. Ishikawa diagram/4M analysis. Only finding the right root cause(s) of error in inspection will avoid it in the future. It is also crucial to archive data on problems and solutions, as well as analyses carried out, to build a knowledge base for the future.

Assumption #4: *Type and frequency of errors committed by inspectors as a determinant of improvement actions.*

The decision about the direction of improvement actions should be first of all affected by the type, and afterwards, frequency (number) of errors made by the inspectors. Errors in alternative inspection cause inevitable consequences. Possible consequences of Type I and II errors (Webber and Wallace, 2007) are summarized in Table 3.

Table 3.
Consequences of errors in alternative inspection (Webber and Wallace, 2007)

Type I error	< (risk)	Type II error
– loss of material, – re-selection of products (resources, time) – searching for a non-existing defect (resources, time), – lower costs.		– complaint, – repair or replacement of the product with a new one, – loss of reputation in the eyes of clients, – qualifying to a lower category of supplier or terminating the contract, – loss of health or life of customers, – higher costs.

Due to the more significant consequences for customers related to Type II errors (customer risk; the risk of obtaining a non-conforming product and higher potential costs for the producer), it is necessary first to analyze the cases of incorrect decisions of the controllers related to these errors. The second step is to look at the number of wrong decisions made concerning the single product submitted for conformity assessment (single controller assesses a given product three times acc. MSA requirements). The products which most conformity assessment errors were made for, should be analyzed at first. Summing, first, the type of error made, then the total number of errors made by controllers concerning a single product determine the order of analyzing the results, from attribute study, for improvement purposes. So the combination of both criteria, i.e. the type and frequency (number) of errors, according to the proposed procedure, points to a direction of improvement actions. On Fig. 4 priority of undertaking improvement action is directly related to the risk of errors. It is higher for type II errors due to the higher risk of these errors for the customer. That is according to a new approach, first, the cases of type II errors with the highest number of incorrect decisions are analyzed. Then the analysis of cases of type I errors with the highest number of incorrect decisions is made.

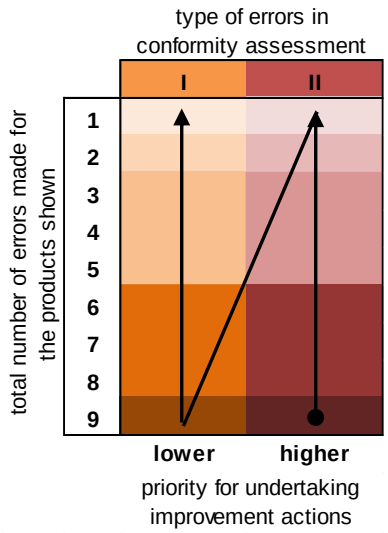

Fig. 4. Direction of undertaking improvement actions assuming that the starting point is the type and number of errors made by the controllers

Type I errors for two sample products, as a result of testing the effectiveness of the control system, are shown in Figure 5.

Part	Appraiser A			Appraiser B			Appraiser C			Ref Value
6	1	1	0	1	1	0	1	0	0	1
7	1	1	1	1	1	1	1	0	1	1

Fig. 5. Type I errors for 2 sample products

Type II errors for two sample products, as a result of testing the effectiveness of the control system, are shown in Figure 6.

Part	Appraiser A			Appraiser B			Appraiser C			Ref Value
12	0	0	0	0	0	0	0	1	0	0
22	0	0	1	0	1	0	1	1	0	0

Fig. 6. Type II errors for 2 sample products

The number of wrong decisions of the inspector, about a given assessed product, can be from 1 to 9 (each product is evaluated in 3 replications). In the case of type I errors, when the number of errors made is 9, there are so-called persistent tendency to reject the non-conforming product, while in the case of Type II errors - persistent tendency to accept. It was assumed that the cases of products for which the most errors of conformity assessment were made should first be analyzed for the improvement purposes.

A comparison of a traditional approach to the analysis of the results from attribute study (included in the MSA manual) and the new approach is presented in Fig. 7.

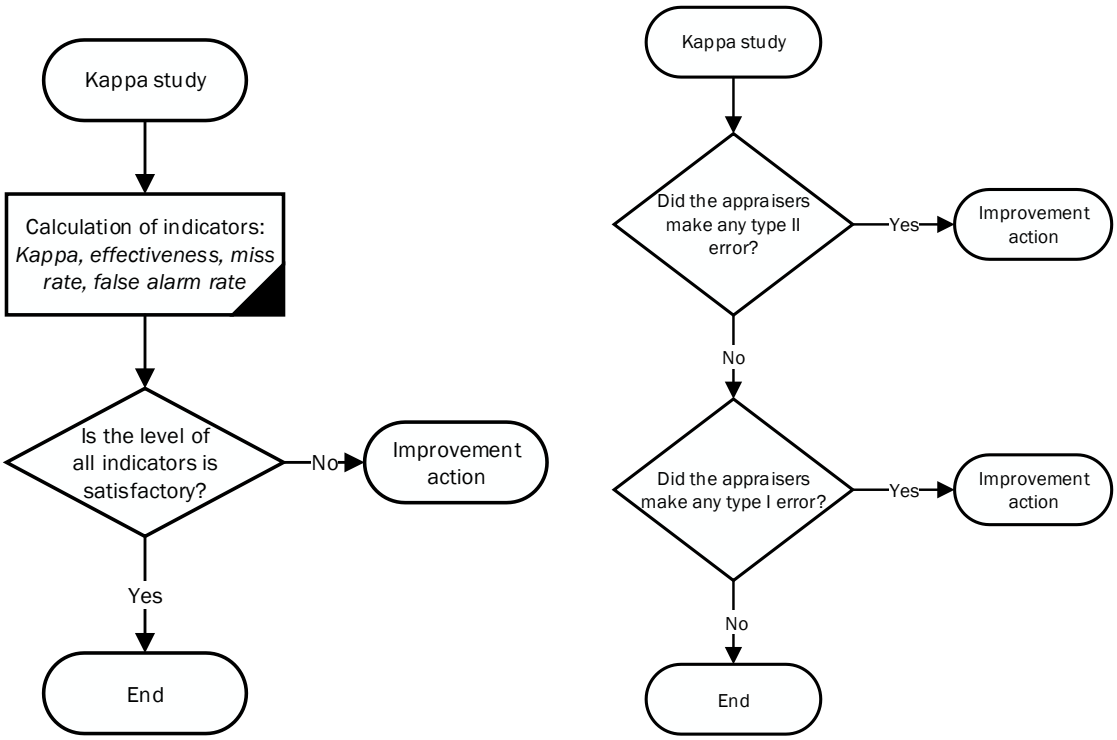

Fig. 7. Standard approach (MSA manual) to the analysis of results from traditional (left side) vs new approach (right side)

4. CONCLUSION

The first part of the article presents the research problem and adopted assumptions related to the research topic being implemented. The research aims to propose a new procedure for analyzing the results of Kappa study to improve the visual control system and the production process at the same time in the sense of its effectiveness. A gap was noted in the approach to assessing the visual control system proposed by the automotive industry in the MSA manual. This gap is the lack of precise guidelines on how to analyze the results of Kappa research to improve the visual control system. The MSA manual only provides guidelines for Kappa testing and recommends calculating appropriate indicators based on which corrective actions are to be taken or not taken. There is no hint on how to direct corrective actions, how to analyze the results of the control so that errors in the control do not happen again. The research goal was to propose a procedure for analyzing results to improve the visual control system. The author assumed in his procedure that corrective actions should be directed to Type II errors due to their more significant consequences. According to the new procedure, first, the cases of products (samples) with the largest number of wrong decisions, such as receiving the wrong one, should be analyzed. It will allow the team to focus their efforts on the most severe cases. Secondly, cases of type I errors, such as rejection of wrong, should be analyzed. How to make such an analysis based on the results of the Kappa study, step by step presents the second part of the article. It presents the author's procedure for analyzing the results of Kappa study, indicates the benefits but also limitations associated with the developed procedure.

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