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Attribute Agreement Analysis With The Multi-Variant Reference Standard

Magdalena HRYB[1], Michał PAWLACZYK[2], Jiehan ZHOU[3], Joanna MAJCHRZAK[4]

[1] *Faculty of Mechanical Engineering, Poznan University of Technology, Poland*
[2] *Paper pigmentation specialist, Poland*
[3] *College of Computer Science and Engineering, Shandong University of Science and Technology, China*
[4] *Faculty of Engineering Management, Poznan University of Technology, Poland*

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Abstract
The purpose of this work is to present a concept of a methodology in the area of Attribute Agreement Analysis. The study was conducted using the process control of decorative paper (laminate) for furniture applications. The specificity of decorative paper quality control inspired the authors to propose a modification of the classical cross-tabulation method with the Cohen's Kappa coefficient, enabling the consideration of a multi-variant reference standard (mvREF). The results show that the proposed approach can solve the problem of the necessity of using the multi-variant reference standard (mvREF). To illustrate the proposed approach, a numerical example is used. The results demonstrate that the proposed approach is useful for Attribute Agreement Analysis.

Keywords
Knowledge Management, Decision Making, Visual Inspection, Quality Control, Level of Agreement, Attribute Agreement Analysis (AAA), Measurement System Analysis (MSA).

Introduction

Paper is one of the most important inventions in human history. The history of paper dates back to ancient times and is associated with various cultures around the world. One of the earliest known methods of papermaking was using plant fibers, such as sea grass or tree bark. The ancient Egyptians used similar techniques around 3000 BCE, but it was the Chinese who are credited with inventing paper as it is known today. Around the 2nd century CE, the Chinese inventor Cai Lun developed a process for making paper using plant fibers, which greatly improved the production process (Rückert et al., 2009). Since then, the appearance and properties of paper have changed significantly, but above all, this product has found new areas of application. The history and development of paper is also the development of its production technology and the quality of the final product. Currently, paper is mainly made from wood, or more precisely, from cellulose from coniferous and deciduous trees. Today, there are many types and applications of paper, including:

1. The paper and printing industry – production of printing and writing paper, labels, books, magazines, documents, and many other writing materials, etc.
2. The production of paper packaging and personal hygiene products – cardboard and paperboard, which are types of paper, are used to produce a wide range of packaging, such as for food products, electronics, toys, and paper towels.
3. Art and crafts – paper is popular material in art.
4. The furniture industry – one of the popular forms of paper is decorative paper used in furniture production; paper patterns are used on furniture fronts, countertops, doors, floor and wall panels, and other interior design elements.

Further considerations in this work concern decorative paper, in short laminate, produced for the needs of the furniture industry. In this application of paper, elegance is the main goal pursued by designers and furniture manufacturers. The final effect in the form of print quality is a critical customer requirement for paper manufacturers. The current advancement of decorative

Corresponding author: *Magdalena Hryb – Poznan University of Technology, phone: +48661403938, e-mail: magdalena.hryb@put.poznan.pl*

paper production technology means that furniture with their use does not lose anything in visual effects (compared to natural materials such as wood or stone). On the contrary, for the average user, decorative paper and veneer are often indistinguishable on furniture. Furniture production using laminates, rather than veneers or solid wood, significantly reduces the cost of the final product (furniture), which additionally constitutes the enormous competitiveness of paper on this market.

Along with the development of production technologies, production techniques and processing of decorative paper for the furniture industry, due to the volumes and variety of products offered, the areas of production support processes, including control processes, also require development.

The basis of management is to base information from data (from measurement or control results) and use it to make decisions about activities in the organization. In order for decisions about the course of the production process or product quality to be correct, control processes, i.e. methods of monitoring and controlling production processes, should be appropriate, i.e. they should be a reliable source of data (Meller et al., 2023; Denysenko, 2023; Rogalewicz et al., 2023). Unreliable data is not only useless, but can also lead – through incorrect decisions – to incorrect directions of development and unsuccessful investments of the company.

Various control processes take place in the production of decorative paper. The control of the critical customer requirement – color control – is carried out as a visual control based on a sample from the batch (Çiçekler et al., 2016; Istek et al., 2010). The result of such control is the classification of the product batch as good or bad. The method of visual evaluation of the laminate, presented in detail later in the work, requires the adaptation of the method proposed in the literature for attribute features.

The objective of the paper is to present the concept of the novel methodology and verify the proposed approach in the area of evaluation of the effectiveness of organoleptic control systems. The study was conducted on the example of the visual inspection process of decorative paper color, i.e. laminate produced for the furniture industry. The specificity of decorative paper production and inspection inspired the authors to propose a modification in the classical approach to the cross-tabulation method with the Cohen's Kappa coefficient. To conclude, the paper formulates the Measurement System Analysis (MSA) test methodology for organoleptic evaluation with the consideration of multi-variant reference standard – mvREF.

The article uses a bibliography to support its scientific argument and case study. Each cited work directly addresses the key issues raised in the article, allowing for a deeper understanding of the research context. The bibliography also includes references to important works that can provide a foundation for future research in the field.

The paper is organized as follows: The second section, based on a literature review, redefines the analysis of the effectiveness of organoleptic control and presents the general concept of the multi-variant reference standard method. In the *Materials & Methods* section, the study object and research methodology are presented. The *Results and Discussion* section applies the proposed approach to a special case study. Finally, the last section not only provides a summary but also indicates the limitations of the new approach and directions for further research.

Literature review

If you can't measure something, you can't manage it – every economist and every production engineer knows that. Measurements or judging compliance have long accompanied people in learning about the world and the reality surrounding them, and today they are widely used, among others, in industry, supporting decision-making about production processes (Kaščak et al., 2022; Shi et al., 2018). In today's industrial environment, we can encounter a huge amount of data describing processes and operational activities (Harugade et al., 2018; Maresova et al., 2022). This information is used for the purposes of improvements, modernization and actions increasing added value, therefore the reliability and credibility of the analyzed results of assessments or measurements is a significant factor influencing the efficiency and directions of development of manufacturing enterprises.

The quality of data from an assessment or measurement can be assessed using the methods and procedures of statistical analysis of measurement systems MSA (for continuous data) or estimation of the level of agreement of appraisers Attribute Agreement Analysis (AAA) (Marques et al., 2018) (for attribute data whose values are based on a nominal or ordinal measurement scale), collectively referred to as control and measurement systems. A control and measurement system is a set of control and measurement equipment, standards, methods, software, personnel, environment and other factors and tested objects that may influence the results of assessments or measurements (AIAG, 2010).

In summary, evaluation of control processes through MSA or AAA allows avoiding actions that are unfavorable for the production company.

There are numerous works in the literature on the evaluation and the analysis of the effectiveness of organoleptic control (Kujawińska & Hryb, 2024). For attribute data, the literature primarily proposes the cross-tabulation method using the Cohen's Kappa coefficient, KC in short (Cohen J., 1960; AIAG, 2010). This method is commonly used in the automotive industry, but also in other industries. In the cross-tabulation method, it is assumed that the appraiser can provide one of two ratings (nominal dichotomous scale) – a good object (1) or a bad object (0). For a set of parts, based on several series of appraisers' responses, the level of agreement is determined – the result is in the range from 0 to 1, where 1 means the highest compliance, and 0 means a complete lack of compliance. The literature also presents a method for assessing the level of agreements of appraisers with the AC Gwet's coefficient (Vach et al., 2023; Gwet, 2008), that allows the use of an ordinal scale. For parts that can not only be evaluated but also measured, a signal detection method is known (AIAG, 2010). For each of these methods, attention is paid to the specific conditions of their application, and each of them has certain limitations and even disadvantages (Viera et al., 2005). An interesting case is the one taking into account the lack of data, described in (De Raadt et al., 2019) or the proposal of the Delta index, which eliminates the problem of asymmetric marginal distributions for KC (Andrés et al., 2004). Among the new approaches, it is worth mentioning the method based on the novel fuzzy similarity coefficient SC, in which many features of the product may be rated in the same study, and the value of these features can be expressed in nominal or ordinal scale (Diering & Dyczkowski, 2016; Diering et al., 2019).

Due to the nominal nature of the features assessed during the laminate color assessment, the Cohen test is used as a method for analyzing the control system. As part of adapting the method to the specifics of laminate control, the MSA test methodology was formulated, the method of preparing objects for testing and the method of assessing each part were described. The concept proposed in the paper was called the multi-variant reference standard method. This concept is a supplement to the MSA method and procedures database for the so-called special cases.

To sum up, the review of research results and the literature on the subject indicate a research gap in the area of analysis of the effectiveness of laminate colour assessment in the form of the lack of a method for assessing the level of agreement of appraisers taking into account the multi-variant reference standard. The authors' concept fills this gap.

Materials & Methods

Research Methodology

The research work used an original methodology consisting of the following stages:

1. Identification of the research environment
   In the first step, the team familiarized themselves with the research object, its requirements, as well as the decorative paper manufacturing process and the quality control process of the laminate. This served as the foundation for selecting a method from the AAA area.
2. Adaptation of the cross-tabulation method to the case study
   At this stage, the AAA method was formulated for the special case. The subsequent part of the chapter describes a new approach, namely the multi-variant reference standard (mvREF).
3. Preparation of the sample for testing – production of control moldings
   For the purposes of the study, several dozen samples and reference laminates were produced.
4. MSA/AAA test – data acquisition
   In this stage, data acquisition was carried out. In real conditions (in the quality control office), a sensory evaluation (visual inspection) was conducted involving three assessors and an expert (color specialist).
5. Calculations
   In the next step, calculations were performed according to AIAG requirements (cross-tabulation method with KC coefficient) (AIAG, 2010), and results were interpreted.
6. Research conclusions
   The final stage of the research methodology was to prepare a research report along with recommendations for improvement and suggestions for further research directions.

Study Object

The object on which the research was carried out was decorative paper (laminate). Decorative paper is a product used to produce laminates and finish foils, which are then ironed onto wood-based boards used in the furniture industry.

The production of decorative paper begins with the preparation of paper pulp, the ingredients of which include: short-fibre or long-fibre cellulose; pH stabilizers; fillers; water-fixing agents; antifoaming agents; organic and inorganic pigments. The next processes leading to the creation of paper are: dosing and mixing of the ingredients in a hydropulper; grinding; mixing with additives (resin and titanium white solution); removing impurities; pouring onto a sieve table; dewatering and forming; web pressing; drying; smoothing and moistening; winding the paper onto rolls; cutting and packaging. The final purpose of decorative paper is to press it onto a chipboard or other wood-based board in order to obtain a decorative furniture board of a specific aesthetic value. Each piece is checked in the visual inspection process, because during lamination, the following defects may occur: pronounced porosity, matte spots, surface defects, whitening, cracks and spots.

Multi-variant reference standard (mvREF)

A critical characteristic in product evaluation is the color of the laminate, i.e. the quality of the overprint, understood as the color match on the paper with a known reference standard. The color is assessed visually (visual inspection) in terms of color in daylight and spectrophotometrically. The criteria for visual inspection are the opacity provided by the paper and the degree of color intensity in relation to the standard. Measurements using a spectrophotometer are performed in the CIELab system.

In the case of visual inspection of the color (overprint) of raw decorative paper, it is necessary to prepare a sample from the batch in the form of a special molding, so that the quality of the color (overprint) in the entire batch can be assessed on its basis. The visual assessment of each sample in the form of a molding is carried out based on its comparison to the reference standard prepared for the purpose of comparison. The reference is placed next to the laminate sample on one common control molding each time (Fig. 1 and Fig. 2).

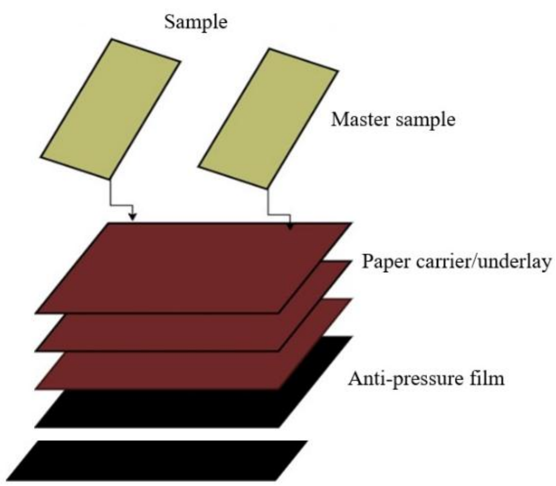

Fig. 1. Schematic diagram of the preparation of the control molding. Own study

Fig. 2. Object prepared for visual evaluation; left side of the sample is the Master Sample, right side – the laminate sample for evaluation. Own study

In the classic Cohen's Kappa method, a separate standard for each of the parts assessed in the study is not used. Therefore, such a method of visual assessment requires the adjustment of the applied method of analysis of the control and measurement system. The concept proposed in the work has been named the method with a multi-variant reference standard, in short mvREF.

A detailed description of the research procedure (this information is important to allow for the study's replication by other researchers, if interested) – as part of the adaptation, not only the new methodology was formulated, but the authors also indicated the method of preparing the objects for the test and the method of assessing each of the parts – sample characteristics used (Fig. 3): the study used a sample consisting of 30 suitably prepared moulds (items of the study object); each of the assessed objects contains a master sample and a sample of the assessed paper, the boundary between them is intentionally blurred (a visible boundary would make it difficult for the human eye to detect any differences between the left and right sides of the sample); samples marked in a way invisible to the assessor. The set of samples for the study was prepared in such a way that:

1. 50% of the samples were good (1) and 50% were non-conforming (0)
2. about 30% of the samples were significantly outside the specification limits
3. about 30% of the samples were within the specification limits
4. about 30% of the samples were close to or slightly outside the specification limits

The laminate samples for the study were prepared by an Expert (E; a person from a company producing decorative paper). The Expert's decisions were a reference value for the assessment decisions. However, it

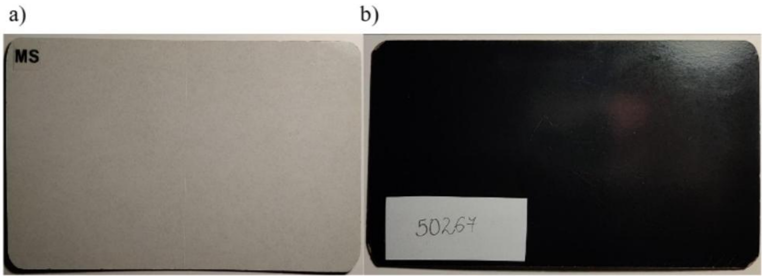

Fig. 3. Object prepared for visual assessment: a) "front" of the sample (for the Appraiser) – the left side of the sample is the Master sample, the right side is the laminate sample to be assessed (the boundary between them is intentionally blurred), b) "back" of the sample with its visible marking (for the person supervising the test). Own study

should be remembered that any changes in the intensity of light or diseases of the Appraisers' visual system may result in a different perception of the surrounding colors, which is why color vision is defined as a subjective feeling. Awareness of the abilities and limitations of the human eye in recognizing colors is crucial in building reliable and effective control systems based on organoleptic control, especially visual control. Therefore, the color control process should also be controlled, and the level of agreement of its elements – evaluative – with reference values should be analyzed.

To minimize the risk of a type I or type II errors by the Expert, a colorimetric measurement was performed when formulating the reference decision for each sample – the reference decisions were established, for each of the samples in the study, based on the ΔE parameter between the reference and the tested sample.

The study used the CR 100 Datacolor colorimeter, a compact device that allows for measuring the color of uniform surfaces in the CIELab system (Sharma et al., 2012). CR 100, together with the dedicated Color-Reader application (Figure 4), has a built-in quality control system for measured samples in relation to a set standard based on the ΔE coefficient. ΔE defines the difference between colors as a single numerical value (Sharma et al., 2012). The small size of the device and ease of use are features that make it a control and measurement device justified for use in produc-

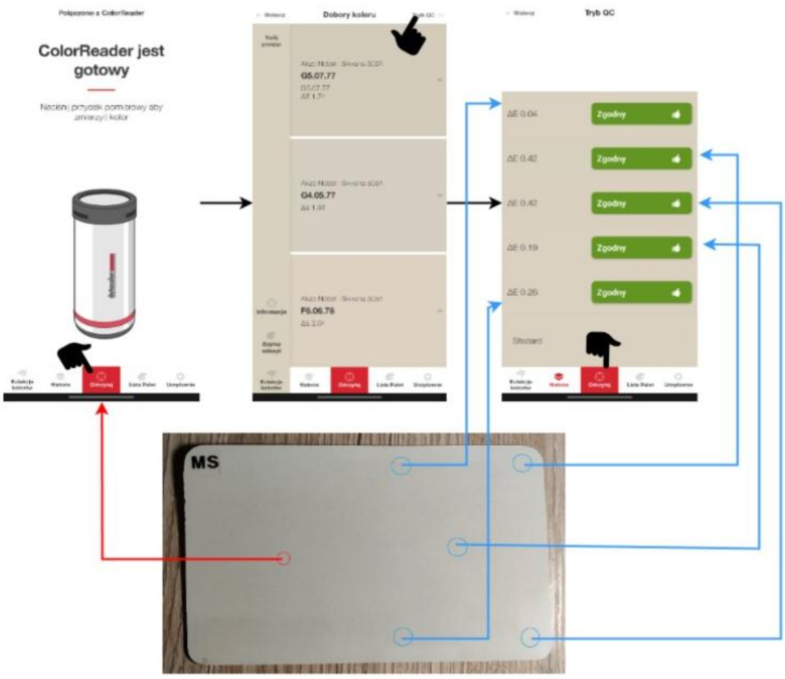

Fig. 4. Datacolor CR 100 colorimeter and flowchart for performing reference sample measurements using the ColorReader application. Own study

tion conditions (compared to professional laboratory spectrophotometers). This device is able to perform measurements of samples prepared for analysis in the CIELab system with high accuracy and repeatability of the obtained results.

Results and discussion

The expert performed 5 measurements for each sample – if the arithmetic mean ΔE for 5 measurements of the sample against the standard is ≤ 1, it was considered compliant, otherwise the Expert classified the sample as non-compliant (the sample acceptance criterion was adopted for the results $\Delta E \leq 1$) (Fig. 4).

The study involved 3 appraisers (Appraiser A / AppA, Appraiser B / AppB and Appraiser C / AppC) who rated a set of samples in 3 trials. Randomization of the ratings was ensured – the appraisers did not know the order or numbering of the samples (sample numbers were coded) and did not know the answers of the other appraisers. The results collected from the study are presented in Tab. 1.

The classical approach to MSA for attribute data, widely described in the literature, was used to analyze the results, i.e. the level of inter-rater agreement was

Table 1
Appraisers' ratings and Expert's decisions – results. Own study

Code	Item	Appraiser A			Appraiser B			Appraiser C			Expert
		Trial 1	*Trial 2*	*Trial 3*	*Trial 1*	*Trial 2*	*Trial 3*	*Trial 1*	*Trial 2*	*Trial 3*	
4955	1	Bad	Bad	Bad	Good	Good	Good	Bad	Bad	Good	Good
18462	2	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
23250	3	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
23493	4	Bad	Bad	Bad	Good	Good	Good	Bad	Bad	Bad	Good
26393	5	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad
31351	6	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
42784	7	Bad	Bad	Good	Bad	Bad	Bad	Bad	Bad	Bad	Bad
44450	8	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad
44556	9	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad
45942	10	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
50267	11	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
50552	12	Good	Good	Good	Bad	Bad	Bad	Bad	Good	Bad	Good
51072	13	Good	Good	Good	Good	Good	Good	Good	Good	Good	Bad
51853	14	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
53298	15	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad
54023	16	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
55670	17	Good	Good	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad
59446	18	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad
60740	19	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad
66081	20	Good	Good	Good	Good	Good	Good	Good	Good	Good	Bad
71609	21	Good	Good	Good	Bad	Bad	Bad	Good	Good	Good	Bad
75401	22	Bad	Bad	Bad	Bad	Bad	Bad	Good	Bad	Bad	Bad
78592	23	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
80150	24	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
80174	25	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad
80553	26	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
87083	27	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad
90991	28	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
91762	29	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad
93158	30	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good

estimated based on the Cohen's Kappa coefficient and using the cross-tabulation method (AIAG, 2010). Then, cross-tabulations/ contingency tables were created for appraiser-appraiser pairs (AppA-AppB, AppB-AppC and AppA-AppC) – for each appraiser pair, and for appraiser-Expert pairs – for each appraiser (AppA-E, AppB-E, and AppC-E) (Tab. 2).

Table 2
Contingency tables for appraiser pairs and appraiser-Expert pairs. Own study

			Appraiser B					**Expert**	
			Bad	**Good**				**Bad**	**Good**
Appraiser A	**Bad**	Obs	33	6	**Appraiser A**	**Bad**	Obs	33	6
		Calc	18.2	20.8			Calc	19.5	19.5
	Good	Obs	9	42		**Good**	Obs	12	39
		Calc	23.8	27.2			Calc	25.5	25.5

			Appraiser C					**Expert**	
			Bad	**Good**				**Bad**	**Good**
Appraiser B	**Bad**	Obs	37	5	**Appraiser B**	**Bad**	Obs	39	3
		Calc	19.6	22.4			Calc	21.00	21.00
	Good	Obs	5	43		**Good**	Obs	6	42
		Calc	22.4	25.6			Calc	24.00	24.00

			Appraiser C					**Expert**	
			Bad	**Good**				**Bad**	**Good**
Appraiser A	**Bad**	Obs	37	2	**Appraiser C**	**Bad**	Obs	35	7
		Calc	18.2	20.8			Calc	21.00	21.00
	Good	Obs	5	46		**Good**	Obs	10	38
		Calc	23.8	27.2			Calc	24.00	24.00

Based on the obtained results and in relation to the acceptance criteria, the results were interpreted. According to the acceptance criteria, agreement at the level of 0.4 to 0.75 is good agreement, and 0.75 and more is very good agreement (1.00 – maximum agreement). When interpreting the results from the study, each of the appraisers shows at least good agreement in decisions, in comparison with the other appraisers and with the Expert (Tab. 3).

Appraiser A has an agreement with Appraiser B of 0.66 (good agreement) and with Appraiser C of 0.84 (very good agreement); Appraiser B has a very good agreement with Appraiser C of 0.78. In relation to the reference values, the highest agreement was shown by Rater B – 0.80, and Appraisers A and B have an agreement with the Expert of 0.60 and 0.62, respectively.

Table 3
Analysis results – KC coefficient values and assessment of the level of agreement between appraisers. Own study

KC	**AppA**	**AppB**	**AppC**	**Expert**
AppA	x	0.66	0.84	0.60
AppB	x	x	0.78	0.80
AppC	x	x	x	0.62

The general conclusion from the research results – the applied visual inspection system with the use of changing reference standards (each of the assessed objects contains a master sample and a sample of the assessed paper) – multi-variant reference standard – is a useful tool in the process of controlling the color of the laminate / quality of decorative paper.

Based on the obtained results and in relation to the acceptance criteria, the results were interpreted. According to the acceptance criteria, agreement at the level of 0.4 to 0.75 is good agreement, and 0.75 and more is very good agreement (1.00 – maximum agreement). When interpreting the results from the study, each of the appraisers shows at least good agreement in decisions, in comparison with the other appraisers and with the Expert (Tab. 3).

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The main advantages of the proposed modification of the classical approach to the cross-tabulation method with the Cohen's Kappa coefficient are:

1. the ability to perform AAA for a special case, such as a multi-variant reference standard,
2. despite the special case situation, the possibility of evaluating the quality control process in accordance with the AIAG guidelines (AIAG, 2010).

In conclusion, the method with a multi-variant reference standard (mvREF), can be used in MSA/AAA study. The development of the presented approach will allow for extrapolation and application in similar studies for other cases of this type.

Conclusions

The considerations in this paper concern decorative paper, in short laminate, produced for the needs of the furniture industry. The paper discusses the paper production process and the method of its assessment. An example of a method of controlling the color quality of decorative paper became an inspiration for the authors to formulate a concept of methodology and verification of the proposed solution in the area of assessing the effectiveness of organoleptic control systems. A modification of the classic approach to the cross-tabulation method with the Cohen's Kappa coefficient was proposed. The author's concept includes the preparation of a part for conducting the test and conducting the assessment of the conformity of the appraisers for control processes in which, despite the constant acceptance criteria, the standard (so-called master sample) changes every batch. To conclude, the paper formulates the MSA test methodology for organoleptic assessment taking into account the variable standard (multi-variant reference standard – mvREF).

The paper takes into account the subjectivity of organoleptic evaluation, in particular the subjectivity of color perception by the human eye, but does not take into account the problem of imprecision of data. Data obtained from appraisers may be uncertain (the appraiser may "shoot" the answer), imprecise or even incomplete (no answer from the appraiser). Further considerations in this area should take into account the "grayness" of data in the analysis of control systems using human senses. The inspiration for continuing research in this area may be the results of research from the Grey System Theory (Xie et al., 2010; Xie et al., 2014; Zavadskas et al., 2009). The direction of further work of the authors in the area of analysis of control and measurement systems for organoleptic control data includes research aimed at developing MSA/AAA methods and procedures using models from the Grey System Theory.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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