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APPLICATION OF ARTIFICIAL INTELLIGENCE (AI) IN PRODUCTION OF THE PRINTED PACKAGING

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The fifteenth edition of the "Safe Packaging" Conference, held on 5-7 November 2025 in Sopot, confirmed the growing importance of packaging safety in the context of rapidly evolving regulatory, technological, and market conditions. The event gathered nearly 230 participants and featured four thematic blocks and eleven high-level lectures addressing, among others, sustainable development, carbon footprint assessment, process standardization, brand protection, digitalization, and compliance of packaging materials with FCM and NIAS requirements. Particular attention was given to new European and national regulations, including PPWR, PFAS restrictions, amendments to food-contact legislation, and increasing expectations regarding environmental data transparency. The conference program was complemented by hands-on workshops, case studies, and a study visit to the J.S. Hamilton Laboratory, underlining the strongly practical orientation of the event. The article invites readers to explore a detailed account of the event prepared by the long-standing moderator of the conference, Professor Stefan Jakucewicz, offering an author's perspective on the key topics and conclusions emerging from the fifteenth edition of "Safe Packaging".

Anna Naruszko, M.Sc. Graduate of the Institute of Printing at Warsaw University of Technology (currently the Department of Printing Technologies, Faculty of Mechanical and Industrial Engineering, Warsaw University of Technology). Editor-in-chief of the monthly trade magazines "Poligrafika" and "Opakowanie", CEO of Alfa-Print Sp. z o.o, publisher of these magazines and of the scientific quarterly "Packaging Review".

Piętnasta edycja Konferencji „Bezpieczne Opakowanie", która odbyła się w dniach 5–7 listopada 2025 roku w Sopocie, potwierdziła rosnące znaczenie zagadnień bezpieczeństwa opakowań w kontekście dynamicznych zmian regulacyjnych, technologicznych i rynkowych. Wydarzenie zgromadziło blisko 230 uczestników i objęło cztery bloki tematyczne oraz jedenaście wykładów poświęconych m.in. zrównoważonemu rozwojowi, śladowi węglowemu, standaryzacji procesów, ochronie marki, cyfryzacji oraz zgodności materiałów opakowaniowych z wymaganiami FCM i NIAS. Szczególną uwagę poświęcono nowym regulacjom unijnym i krajowym, w tym PPWR, PFAS, zmianom w rozporządzeniach dotyczących materiałów do kontaktu z żywnością oraz rosnącym wymaganiom w zakresie transparentności danych środowiskowych. Program konferencji został uzupełniony o warsztaty praktyczne, studia przypadków oraz wizytę studyjną w laboratorium J.S. Hamilton, podkreślając praktyczny charakter wydarzenia. Zapraszamy do lektury artykułu autorstwa prof. Stefana Jakucewicza, który stanowi przekrojową relację z konferencji, ukazując „bezpieczne opakowanie" jako pojęcie wielowymiarowe, łączące aspekty technologiczne, prawne, środowiskowe i ekonomiczne, a także wskazuje kierunki dalszego rozwoju sektora opakowań w Europie.

Mgr inż. Anna Naruszko. Absolwentka Instytutu Poligrafii Politechniki Warszawskiej (obecnie Zakład Technologii Poligraficznych, Wydział Mechaniczny Technologiczny PW). Redaktor naczelna miesięczników branżowych „Poligrafika" i „Opakowanie", prezes zarządu Alfa-Print Sp. z o. o, wydawcy tych miesięczników oraz kwartalnika „Packaging Review".

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APPLICATION OF ARTIFICIAL INTELLIGENCE (AI) IN PRODUCTION OF THE PRINTED PACKAGING

WYKORZYSTANIE SZTUCZNEJ INTELIGENCJI W PRODUKCJI OPAKOWAŃ DRUKOWANYCH

ABSTRACT: Artificial Intelligence (AI) is a transformative force in production of printed packaging as it increases the operating performance, innovativeness and the sustainable development. The present paper discusses the key application of AI, including the automated designing, predictive maintenance, quality control, personalization of printing and optimization of the supply chain. It also indicates the challenges such as high investment costs, competence gap, concerns about the data privacy and the resistance to the changes. In spite of the mentioned barriers, AI integration is indispensable for the future increase and competitiveness of the sector.
Key words: artificial intelligence (AI); production of printed packaging; printing industry; digital transformation; production automation; sustainable development

STRESZCZENIE: Sztuczna inteligencja (SI) stanowi siłę transformacyjną w produkcji opakowań drukowanych, zwiększając wydajność operacyjną, innowacyjność i zrównoważony rozwój. Artykuł omawia kluczowe zastosowania SI, w tym zautomatyzowane projektowanie, konserwację predykcyjną, kontrolę jakości, personalizację druku oraz optymalizację łańcucha dostaw. Wskazuje również na wyzwania, takie jak wysokie koszty inwestycyjne, luka kompetencyjna, obawy o prywatność danych oraz opór przed zmianami. Pomimo tych barier, integracja SI jest niezbędna dla przyszłegowzrostu i konkurencyjności branży.
Słowa kluczowe: sztuczna inteligencja (SI); produkcji opakowań drukowanych; przemysł poligraficzny; transformacja cyfrowa; automatyzacja produkcji; zrównoważony rozwój

INTRODUCTION

Appearance of the artificial intelligence (AI) has become a transformational force in different sectors including printing-packaging industry which is more and more important in the post-industrial economy. Together with the development of service sector, the integration of the advanced technologies such as AI becomes a crucial element in the light of aiming at the increase of productivity and innovations in the printing processes. The role of the service sector as the component of economy which supports the system, stresses the necessity of adapting the practices of strategic management to the mentioned technological progress. However, the implementation of AI is not deprived of challenges as it requires conquering the considerable algorithmic limitations; it suggests that the continued research & development are indispensable for utilization of its full potential in real applications (Britchenko et al., 2018). Moreover, the frames of the cooperation, enabling different research groups to share their achievements in AI and their evaluation, have the crucial meaning for the support of innovations; it may lead to more advanced applications in the printing industry (Fathollahi et al., 2017). In general, understanding the role of AI in the mentioned sector will have a key meaning for the future increase and performance.

In the field of printing-packaging sector, understanding of the definition of the artificial intelligence (AI) has the key meaning because it constitutes the background of the transformational possibilities of the technology. AI includes many computational techniques, being designed with the aim to simulate human intelligence. It facilitates the machine performance of the tasks which usually require the cognitive functions such as learning, reasoning and solution of the problems. The discussed technology facilitates automation of different processes, increasing the performance and precision of printing tasks such as design, planning and scheduling of production. Moreover, the tools based upon AI may analyze the enormous data collections with the aim to improve the management of the supply chains, presenting the practical solutions which optimize the labour flows and lower the costs.

Printing-packaging sector has passed a significant revolution, passing from the traditional methods to the advanced technologies which increase the productivity and enable e.g. file versioning or personalization. We observe the appearance of the innovations, such as digital printing which enables quicker production and, in comparison to the conventional techniques, reduces the quantity of the produced waste. This dynamic sector meets various needs, becoming involved in the printed media, packaging and in the industrial printing and each segment reflects the unique requirements. Additionally, the integration of 3D printing has introduced a revolutionary paradigm in the discussed industry, enabling creation of complex structures and prototypes in various sectors, especially in such fields as health care and building industry. Implementation of the artificial intelligence is more and more important because it optimizes the processes and ensures better quality control and predictive maintenance, shaping thus the future printing 'landscape'. Moreover, the technological progress as it was discussed in (Mamo HB et al., 2023) and (Rane N., 2023), will strengthen additionally the necessity of adaptation and innovations in dynamically developing environment of the printing sector.

The early innovations such as printing press, have revolutionized the popularization of information, preparing the background for the future, later changes. Together with the appearance of digital technology, the printing landscape began to evolute again what brought about the introduction of the instruments based on digital technologies and, later on, on the artificial intelligence; the mentioned phenomena optimize the technological processes such as designing, data management and productivity. What is worthy attention, the passage towards generative applications of the artificial intelligence, being similar as those ones described in different sectors, suggests a considerable potential not only in respect of productivity increase but also in transformation of operating practices in the field of printing. The passage towards the artificial intelligence is a critical phase in historical evolution of printing technologies, bringing the challenges and opening the new possibilities.

INTRODUCTION OF ARTIFICIAL INTELLIGENCE TO PRODUCTION

The introduction of AI to production, especially in printing-packaging industry is a meaningful evolution towards optimization of manufacturing processes and increase of the effectiveness. Gradually with the adoption of the principles of Industry 4.0 by the particular sectors, AI technologies have become the integral part of automation, data analysis and predictive maintenance which, in total, minimize the operating costs and maximize the quality of prints. For example, the application of intelligent sensors and Internet of Things enables monitoring of the printing systems in a real time, supporting finally more intelligent production methodologies consistent with the aims of the sustainable development. Moreover, understanding of the total life cycle of production, from the project until the end of life cycle, has a key meaning for the effective introduction of AI solutions, what was supported by the newest studies. The implementation of AI not only improves the operating possibilities but also increases the potential of environment-friendly practices, supporting the wider aims of the sustainable development in the printing-packaging sector (Anet Režek Jambrak et al., 2021).

MILESTONES IN THE DEVELOPMENT OF ARTIFICIAL INTELLIGENCE

Evolution of the artificial intelligence (AI) was marked with certain crucial milestones which have meaningfully affected different sectors, including printing and packaging. The significant progress such as development of neutronic networks and algorithms of machine learning has transformed the method of data processing and analyzing, facilitating more advanced creative applications in printing. For example, the ability of AI to recognize the patterns has revolutionized the design processes, enabling a quick generation of unique systems and models, increasing by this the total productivity. Similarly, mechanisms of the quality control, as supported by AI, have introduced the unprecedented level of precision in printing production. The integration of the discussed technologies has been additionally supported by innovations in image processing which enhance the prepress phase and enable creation of personalized printing solutions adapted to the consumer needs. Such achievements reflect the growing effect of AI on different sectors; it results in building the background for the further progress and increase of effectiveness in such sectors as sustainable concrete construction where the similar innovations are also employed with the aim to improve the environmental results (Luis Coelho, 2023; Nilimaa J., 2023).

IMPACT OF DIGITAL TRANSFORMATION ON THE PRINTING-PACKAGING SECTOR

The effect of digital transformation transforms deeply the printing-packaging sector, especially via integration of the artificial intelligence (AI) technology. Gradually with the striving of the enterprises to increase the operating effectiveness, the digital transformation includes different instruments and methodologies which increase the productivity and improve the processes. Implementation of AI enables the analysis of data in a real time what improves the decision-making process and facilitates greater personalization of printing services. Moreover, owing to the technologies such as 3D printing, digital transformation simplifies quick prototyping and adaptative manufacturing processes, reacting by this to the needs of the consumers and minimizing the quantity of the generated waste (Giovanni PD, 2023). However, although the advantages resulting from the discussed progress are meaningful, they bring also certain significant questions concerning the sustainable development, effect on labour force and the needs of the reasonable digital practices. Owing to promotion of the sustainable approach which solves the mentioned challenges,

TAB.1. THE CRUCIAL MILESTONES IN DEVELOPMENT OF ARTIFICIAL INTELLIGENCE

Year	Event
1950	Alan Turing publishes his book “Calculating machines and intelligence” where he suggests Turing test as a measure of machine intelligence
1956	Conference in Dartmouth during which John McCarthy introduced term “artificial intelligence”
1957	Frank Rosenblatt constructs perceptron, the first neural network for computers
1960	The first robot, equipped with artificial intelligence is installed in the assembling line of General Motors. The first chatbot – ELIZA was also invented.
1979	The students of Stanford University develop Stanford Cart, robot capable of conquering the obstacles in a room space
1997	Computer IBM Deep Blue defeats Garry Kasparov in chess game and presents the possibilities of artificial intelligence in solving the complex problems
2009	Google presents its autonomic car, demonstrating the application of artificial intelligence in understanding and processing of natural language
2011	Watson System by IBM conquers the participants in tele-competition Jeopardy! And presents the capability of artificial intelligence to understand and process a natural language
2014	AlphaGo by Deep Mind company defeats the world champion in Go game, what is an evidence of superiority of artificial intelligence in complicated board games
2020	Open AI introduces GPT-3, the most advanced model of artificial intelligence for language processing which is able to generate a text resembling that one, written by man.

Source: own development

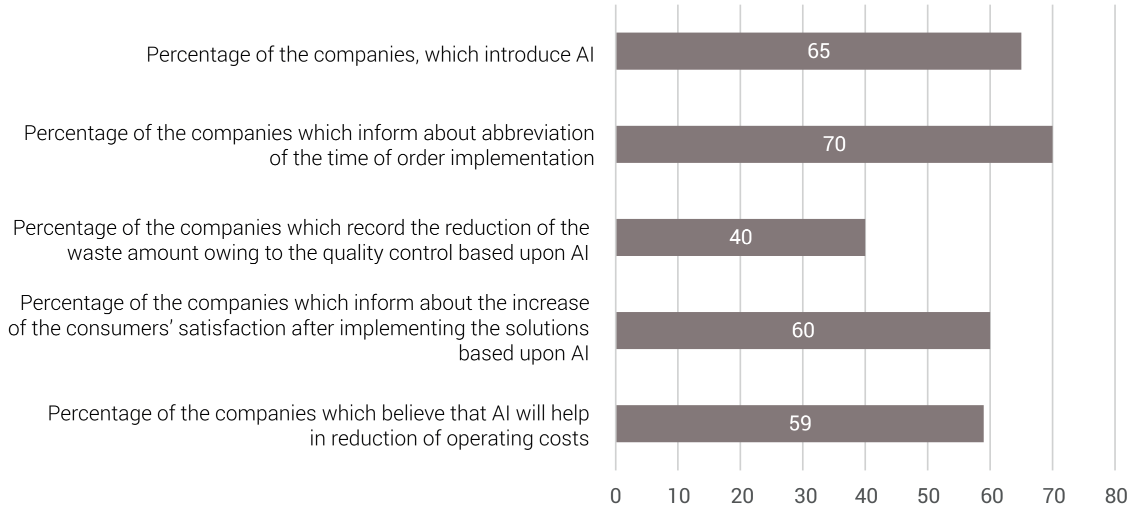

DIAGRAM 1 : IMPACT OF AI ON PRINTING SECTOR [%]. (SOURCE: ESER A, 2025;SANDBOX:/MNT/DATA/SI_IMPACT_PRINTING_INDUSTRY.PNG)

the printing industry may effectively move in the complex problems of digital transformation what finally leads to more agile and competitive market landscape.

Diagram 1 illustrates the impact of artificial intelligence (AI) on the printing sector. It represents the percentage of the printing companies which have introduced AI technologies, and the resulting advantages such as shorter time of the order implementation and greater satisfaction of the customers.
Integration of the artificial intelligence (AI) in the printing processes means a significant evolution in the possibilities of the sector, increasing the productivity and innovativeness. AI technologies, especially in predictive analytics and machine learning, enable optimization of the printing house work and reduction of the generated waste. For example, the intelligent algorithms may analyze the data concerning the printing tasks in order to prognose the potential problems and adapt the parameters in a real time what is translated into higher quality of the prints at lower costs. Moreover, AI facilitates personalization, allowing more efficient printing of variable data where the personalized contexts may be created without sacrificing speed or quality. Progress of 3D printing technology also employes AI, increasing the precision in additive manufacturing what stays in parallel with the improvements in the traditional printing methods. Moreover, together with the increase of demand on the sustainable practices, the applications of AI may considerably reduce energy consumption in manufacturing processes what is consistent with the wider environmental aims. In general, role of AI in the printing sector emphasizes the transformational passage towards more intelligent, and more sustainable manufacturing techniques.

AUTOMATED DESIGN

Integration of the artificial intelligence (AI) and the automated designing processes increases considerably productivity in the printing-packaging sector. The automated design tools employ AI algorithms to facilitate creation of the systems, optimizing the utilization of the space and materials, reducing thus the quantity of the waste and improving the production rate. The discussed systems may quickly generate many iterations of the product based upon the predetermined parameters what allows more flexible approach to the requirements of the project. Additionally, the design applications based on AI may learn from the previous projects in order to supply, gradually with the time, better recommendations, strictly adapted to varying project trends. The mentioned possibility not only improves the labour flow but also ensures more advanced tools for precise performance of the complicated tasks for the designers. The printing industry introduces the discussed technologies more and more frequently; the combination of AI and automated designing reflects a wider trend towards more sustainable and innovative manufacturing practices what was demonstrated in discussions on Industry 4.0 and operating effectiveness (Luo et al., 2023; Akkerman F et al., 2022).

TAB.2. IMPACT OF DIGITAL TRANSFORMATION

Application	The range of change
Predictive maintenance	54% of printing companies apply AI in predictive maintenance of the printing equipment what gives 25% of repair cost savings in the printing enterprises
Management of colors	Solutions for management of colors based on the artificial intelligence have improved the precision of colors in prints by 25%
Personalization of customer	47% of the printing companies have recorded the increase in consumers' satisfaction after implementation of personalization based on the artificial intelligence
Prognosing of demand	Prognosing of demand based on the artificial intelligence has increased the precision of orders for printing by 40%
Optimization of the supply chain	Algorithms of machine learning optimize the logistics of the supply chain in 45% of the enterprises
Optimization of the contents	Optimization of the contents supported by the artificial intelligence has improved index of reaction to marketing materials in the printed form by 15%
Management of resources	Predictive analytics supported by the artificial intelligence helps to prevent the downtime of machines in 60% of the printing companies
Quality control	Quality control systems supported by the artificial intelligence have reduced the number of defects of the printed materials by 35%
Automation of labour flow	62% of the printing companies use tools for automation of labour flow, based on the artificial intelligence; it allows saving 12h per week per one employee, in average
Energy effectiveness	Management of the park of printing machines with the application of the artificial intelligence allows the reduction on energy consumption by 20%, in average.

Source: https://wifitalents.com

PREDICTIVE MAINTENANCE OF THE PRINTING MACHINES

Occurrence of predictive maintenance based on the artificial intelligence (AI) has changed meaningfully the operating dynamics of the printing industry. When utilizing AI algorithms which analyze the historical data concerning performance and information from the sensors in a real time, the printing companies may anticipate the failures of machines before they disturb the production timetables. Such proactive approach not only increases the reliability of the equipment but also contributes to reduction of the costs via minimization of the non-planned downtime of the equipment and extension of the life of machines. As it has been stressed in the recent studies, the success of predictive maintenance is dependent on AI capability to recognize the patterns in the data which might indicate the potential defects, facilitating the in-time interventions. Moreover, the productivity obtained owing to the discussed technologies is consistent with the wider trends in the sector where the operating effectiveness and sustainable development become more and more often a priority. Consequently, the integration of the predictive maintenance increases the competitive advantage of the printing enterprises on the quickly developing market.

QUALITY CONTROL AND QUALITY ASSURANCE

In the printing-packaging industry, the integration of the artificial intelligence (AI) and processes of the quality control and quality assurance occurred to be revolutionary, increasing considerably precision and productivity. AI systems analyze the enormous quantities of the manufacturing data in a real time, identifying the potential defects and inconsistencies which may be omitted by the inspectors. Such monitoring in a real time does not only reduce the amount of the waste but also assures that the final products meet the rigoristic quality standards. The new technologies such as additive production show how AI may optimize labour flows via improvement of the materials' processing what leads to a higher quality of the products with the minimum quantity of the waste (Olu-laval KA et al., 2024). Moreover, the appearance of the predictive maintenance based on AI, allows the reaction of the producers to the potential failures of the equipment before they occur, keeping by this the constant quality of production. However, the application of the discussed advanced AI tools rises certain ethical doubts concerning the transparency and potential occurrence of the errors in decision processes what requires a continuous assessment of their impact on the quality assurance (Yogesh K. Dwivedi et al., 2023).

THE PERSONALIZED SOLUTIONS OF PRINTING

Appearance of artificial intelligence has commenced a new era in personalized solutions of printing, changing the landscape of the sector. When utilizing the advanced algorithms, the artificial intelligence may analyze the consumers' data so as to adapt the products to the individual preferences and requirements. Such possibility of personalization has significant implications not only for the traditional printing but also for the applications in such sectors as skin care and pharmaceutics where the precise formulae and packaging may improve the user's experience and effectiveness. For example, integration of 3D printing technology, as supported by the artificial intelligence, allows creation of unique projects of the products and forms of dosage, facilitating more direct adaptation to the needs of the consumers and health results. Additionally, the artificial intelligence increases the performance of manufacturing processes, enabling quick prototyping and reducing the quantity of the waste, contributing thus to more sustainable practices in the industries. Finally personalized printing solutions illustrate how the artificial intelligence revolutionizes personalization in the field of printing. It offers the adapted experiences which satisfy the differentiated requirements of the customers.

OPTIMIZATION OF THE SUPPLY CHAIN

In the printing-packaging sector, the effective optimization of the supply chain is indispensable for increase of operating effectiveness and satisfying the needs of the consumers. The integration of the artificial intelligence (AI) plays a key role in the discussed process as it enables the data analysis in a real time and predictive modelling with the aim to improve the operations. When utilizing AI the enterprises may better prognose the demand, minimizing by this the excessive amount of resources and reducing the quantity of the waste. What important, digitalization of the manufacturing processes, including such innovations as analysis of the big data collections and machine learning, improves the quality of the products, optimizing simultaneously the supply chains; the mentioned aspect was stressed in the newest studies. Moreover, the occurrence of intelligent packaging systems, employing the AI-based functions improves significantly communication and comfort of packaging; finally, it makes the distribution process more effective. In consequence, the strategic application of AI technology in optimization of the supply chain is favourable for more responsive, efficient and sustainable printing-packaging industry.

PROFITS RESULTING FROM THE INTEGRATION OF ARTIFICIAL INTELLIGENCE AND PRINTING

The integration of the artificial intelligence (AI) in the printing-packaging sector brings many profits which increase the operating performance and quality of the products. When utilizing AI-based systems, the printing enterprises may reach the unprecedented level of personalization and automation, improving the labour flows and abbreviating the manufacturing time. For example, AI technologies facilitate a quick prototyping and personalization of the printed materials, allowing the companies to adapt quickly to the consumers' preferences and market trends. Additionally, AI may optimize the management of supply chain via anticipation of demand and minimization of the waste amount, supporting the sustainable practices in the printing industry. The analysis of the data from different manufacturing processes improves additionally decision undertaking and quality control, ensuring the coherence of the results. Moreover, as it was stressed in the studies on the technological progress in the related domains, synergy between the solutions of AI and IoT may lead to more intelligent and responsive environments of printing, rising meaningfully the total productivity and innovative potential of the discussed sector (Yogesh K. Dwivedi et al., 2023).

CHALLENGES AND LIMITATIONS OF ARTIFICIAL INTELLIGENCE IN PRINTING AND PACKAGING SECTOR

Integration of the artificial intelligence (AI) and the printing industry offers the unusual potential, however, the significant challenges and limitations have been encountered. One of the relevant obstacles includes technological intricacy connected with reaching the precise, coherent results as the present AI systems may have the problems with variability, inherent for different materials and printing processes. Moreover, the existing frameworks for AI application often do not consider the complexity of 3 D printing technologies in the sufficient degree; the mentioned processes require advanced algorithms for monitoring and adaptation in the real time as to avoid defects during production. It was stressed in the studies concerning 3D printing in the related domains such as construction and energy storage. Additionally, the dependence of the discussed sector on the qualified labour force remains a barrier because AI implementation requires the labour force which is not only skilled in management of traditional printing methods but also in understanding and manipulation of the advanced AI technologies. The mentioned limitations generate

TAB.3. CHALLENGES AND BARRIERS OF ARTIFICIAL INTELLIGENCE IN PRINTING INDUSTRY

Challenge	Description
Integration with the older systems	Integration of AI technology and the existing systems of older generation may be complicated and expensive, and, also, require considerable investments of time and resources in order to ensure the non-problematic activity
High initial costs	Implementation of AI solutions is connected with the considerable expenses such as the purchase of new machines and AI-serving software, training of the employees and re-designing of labour flows that may become a barrier to small and medium-size enterprises
Gap in skills and training of the employees	Many employees may be lacking of indispensable technical skills to work with AI technologies what causes the necessity of conducting complex training aiming at maximization of the profits, resulting from AI application
Concerns about privacy of the data	The artificial intelligence-based processes are often based on big quantities of data what rises the concerns about privacy and requires application of rigoristic principles of data management in order to protect the confident information
Resistance to the changes	Introduction of artificial intelligence may often face the opposition of the employees who are used to traditional methods; it requires effective management strategies in order to overcome the resistance
Quick technological progress	A quick development of the artificial intelligence technology requires constant adaptation and investment to keep the competitivity what may be suppressing for the enterprises
Data safety and consistency	When implementing the artificial intelligence systems in the printing industry, it is necessary – first of all – to take care of the compliance with the rules concerning the data privacy and protection of confidential information
Intellectual property and creator's property	Application of the artificial intelligence in creation of projects and systems rises doubts in respect of the rights of intellectual property and creative property what requires transparent guidelines and agreements
Impact on the environment	Training of AI models and launching of enquiries in the data centers requires considerable computing power what causes the increased energy consumption and carbon dioxide emission what may have the impact on the activity in favour of the sustainable development

the questions concerning scalability and future of human roles in more and more advanced printing environment.

HIGH INITIAL INVESTMENT COSTS

Integration of the artificial intelligence (AI) in the printing-packaging industry promises a meaningful progress but the significant barriers are also met, especially in a form of high initial investment costs. The expenses connected with the modernization of the existing infrastructure, the purchase of the most modern AI technologies and staff training may be the obstacle for many printing companies. Such financial burdens are often discouraging for small and medium-size enterprises in respect of introducing the AI solutions; finally, it causes slowing down in market penetration by the discussed technologies. Moreover, the long-term advantages, resulting from the increased productivity and lower operating costs may be not recompensated instantly; it causes the hesitations of the potential users. For many companies, especially in the sector which is still fighting with the out-of-date systems, balancing of the mentioned initial costs and the perspective of the future profits remain the crucial challenges. As it was stressed, overcoming of the mentioned financial barriers is indispensable for the support of better implementation of AI innovations in the printing sector and, by this, the increase of total productivity and competitivity of the mentioned industry.

GAP IN TECHNICAL SKILLS' LEVEL OF THE EMPLOYEES

Integration of the artificial intelligence (AI) in the printing-packaging industry has meaningfully highlighted a gap existing in the range of technical skills among the present labour force. Gradually with the evolution and becoming more advanced, the AI technologies such as ChatGPT, require a qualified labour staff, capable of effective utilization of the mentioned tools. The discussed gap not only limits productivity but also generates ethical challenges because a quick development of technology may lead to the loss of workplaces in the case of the lack of appropriate training and support systems. The potential profits coming from the artificial intelligence are obvious; the progress may improve management, marketing and operating performance in the sector. However, the employees must be equipped with necessary technical skills in order to adapt to the digital transformation. Constant training and the possibilities of vocational development are indispensable for coping with the discussed gap, ensuring that the workers shall not be left behind in the epoch, determined by quick technological changes (Budhwar P et al., 2023; Yogesh K. Dwivedi et al., 2023).

CONCERNS REGARDING PRIVACY AND SAFETY OF DATA

Together with the increase of popularity of the artificial intelligence (AI) technology in the printing-packaging industry, the serious anxieties appear as regards privacy and safety of the data what requires a thorough consideration. Application of AI for facilitation of production and improvement of the customer service quality may generate enormous quantities of sensitive data, including the projects of the clients, the reserved (registered) manufacturing processes and personal data. The potential non-authorized access to the mentioned data creates the inherent risk, especially when the AI applications become more and more connected with other digital platforms. For example, the gaps in securing of the storage and transfer of the data may lead to infringements which become a threat not only to business operations but also the confidence of the customers. Meeting of the mentioned challenges requires the reliable cybersafety means and ethical framework aiming at protection of the data. Moreover, the enterprises must cope with the complexity of the conformity with the rules and standards concerning the privacy of the data what is especially visible in different AI-employing sectors. The complex strategy is indispensable for protection of the data integrity, with the simultaneous maximization of the advantages, resulting from the artificial intelligence application in the printing sector (Gurjar K et al., 2024).

RESISTANCE IN RELATION TO THE CHANGES IN TRADITIONAL PRACTICES

The resistance to the changes is a significant barrier to implementation of the artificial intelligence (AI) in the printing

– packaging industry, being greatly rooted in the traditional practices which have regulated the activity for a long time. The stakeholders keep often to the conventional methods, as they are afraid of the disturbances which may be introduced by the new technologies to their so-far existing work flow and profitability. Such inertia may inhibit innovation and impede integration of the AI-based solutions which promise the increased performance and productivity. As it was observed in the context of the sustainable practices, the change in the organizational culture has a crucial meaning; the change in the attitude of the workers as well as of the managing staff may facilitate the approval of the new technologies and become favourable for the culture of innovations. Moreover, the interest of the stakeholders in the discussed transformation has a key meaning as the cooperation encourages to acceptation and decreases the resistance (EMBM Karunathilkake et al., 2023). Finally, in order to go forward, the stakeholders in the printing sector must recognize that the approval of the changes using AI is necessary for maintaining the competitivity in the quickly varying market.

CONCLUSIONS

Summing up, the integration of the artificial intelligence in the printing and packaging industry means the transformational change, increasing the operating performance, productivity and innovativeness.

The application of the artificial intelligence-based technologies improves the designing processes, automatizes the routine tasks and offers the advanced analytics of the data, facilitating the companies to adapt to the dynamically varying market landscape. The discussed technological progress is, however, connected with the inherent challenges, including the ethical problems concerning privacy, safety and potential disinformation which require a thorough analysis of the mentioned implications in practice. As it was stressed in the running discussions, the organizations must find a delicate balance between the utilization of the possibilities of the artificial intelligence and overcoming of its limitations in order to ensure the sustainable development. The future studies, and especially those concerning optimal cooperation between man and artificial intelligence and the ethical framework, regulating the mentioned technologies, will have the crucial meaning for the utilization of the full potential of the artificial intelligence in the printing and packaging industry, with the simultaneous limitation of the related risk.

THE FUTURE TRENDS IN RESPECT OF THE ARTIFICIAL INTELLIGENCE IN PRODUCTION OF THE PRINTED PACKAGING

Gradually with the permanent evolution of the printing sector, the integration of the artificial intelligence (AI) is ready to change its future, leading to the increase of the productivity and innovativeness. Importantly, the AI-based technologies such as predictive analytics and automated management of labour flow are developed with the aim to optimize the printing processes, reduction of the waste and facilitation of production on demand. The mentioned progress allows the companies to adapt their offer to the specific requirements of the market, becoming strictly consistent with the principles of Industry 5.0 where the personalized production is found in the central place. Moreover, as the AI tools help more and more often in designing and choice of materials, they enable multi-material printing and the sustainable practices and by this, they solve the environmental problems in the discussed sector (EMBM Karunathilake et al., 2023). The convergency of the AI and the traditional printing methods not only promises the increase of performance but also opens the new possibilities of creativity and personalization; it finally revolutionizes the way in which the printed products will be designed, produced and supplied in the future.

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THE STUDIES ON THE IMPACT OF THE PRINTING SPEED ON THE QUALITY OF FLEXOGRAPHIC PRINTS PERFORMED ON PET FILM

BADANIA WPŁYWU PRĘDKOŚCI DRUKOWANIA NA JAKOŚĆ ODBITEK FLEKSOGRAFICZNYCH NA FOLII PET

ABSTRACT: In the paper, the comprehensive analysis of the impact of the printing process speed on the quality of the flexographic prints, produced on PET film using the Optima 2 press at different printing rates has been presented. The quality assessment was carried out using the parameters such as optical density, colour difference (ΔEab) and resolution. The conducted tests have revealed that the optimum range of the speed for PET film is contained within the range of 400-500 m/min. The key defects, generated during the rise of the speed up to 600 m/min, including the decreased optical density, the increase of colour variations and the reduced resolution in positive and negative forms were identified.
Key words: flexography, PET film, printing speed, quality, optical density

STRESZCZENIE: W artykule przedstawiono analizę wpływu prędkości procesu drukowania na jakość odbitek fleksograficznych uzyskanych na maszynie Optima 2 na folii PET przy różnych prędkościach druku. Ocenę jakości wykonano za takimi parametrami jak gęstość optyczna, różnica barwna (ΔEab), rozdzielczość. Przeprowadzone badania wykazały, że dla folii PET optymalny zakres prędkości zawiera się w przedziale 400-500 m/min. Zidentyfikowano kluczowe defekty powstające przy wzrastaniu prędkości do 600 m/min w tym spadek gęstości optycznej, zwiększenie różnic barwnych oraz zmniejszenie rozdzielczości w formach pozytywowych i negatywowych.
Słowa kluczowe: fleksografia, folia PET, prędkość druku, jakość, gęstość optyczna

During the recent years, the flexographic technology has been considerably improved owing to introduction of innovative solutions. One of the key achievements includes the application of ecological water-based inks, the utilization of which contributes to limitation of a negative effect on the environment. The improvements in design of raster rolls enable more precise dosing of ink what results in the improvement of overprint quality and saving of the used materials.

Today, the flexographic technology has achieved a dominating position in the sector of packaging printing. The flexible print forms, quickly-drying inks and the possibility of overprinting different substrates make that flexography is the optimal choice for many industrial applications. However, together with the increase of the printing speed, the specific technological challenges occur which may affect the quality parameters of the prints, such as optical density, accuracy of colour reproduction or resolution. The experiments carried out by the scientists [1 – 4] revealed a differentiated impact of technological parameters on the print quality, using the orthogonal analysis for assessment of their mutual relations. The results of the mentioned tests indicate that the speed of printing is one of the most significant factors affecting the quality of the flexographic prints. In particular, it was found that the speed of printing had a dominating effect on the length of a series printing – the increase of the printing speed leads to the increase of overprint density. It is especially important in the case of industrial production where the process performance affects directly its profitability The appropriate choice of parameters of anilox cylinder, including ruling and volume of anilox cells (dimples) and viscosity of ink, adjusted to the planned operating speed [5] has a key meaning.

The speed of printing affects directly the thickness of the ink layer applied on the substratum. In the case of lower speeds, the thicker layer is generated what may result in more intensive colors and better coverage but, at the same time, it prolongs the time of drying and increases the risk of defect's occurrence such as flooding of details or streaks and irregularities. With the higher speeds, we may observe a thinner layer of ink what may bring about to a lower intensity of colour and worse coverage but it decreases the risk of occurrence of the mentioned above defects. The changes in the speed of printing affect considerably the stability of sub-assemblies of flexographic machine and the quality of the obtained prints. Too high printing speeds cause the excessive consumption of the components, modification of ink properties and the increase of the risk of generating various defects. Too low printing speeds may lead to the problems with the ink drying-off and its uneven distribution. Therefore, the key problem lies in choice of the optimum speed of printing what will enable maintaining the control of the manufacturing process and obtaining the high-quality prints. Moreover, it is also important to find the appropriate balance between the print speed and the properties of substratum what helps to obtain the high-quality product and, simultaneously, to maintain a stable production and minimum risk of generating the defects [6 – 8].

The aim of the studies was to analyze the effect of the printing process speed on the quality of flexographic prints when overprinting PET film. The samples for the tests were performed in flexographic machine with the central cylinder (CI) Optima 2/8CL (Soma) at the speeds 400 m/min, 500 m/min and 600 m/min. The characteristics of the print made on PET film has been presented in Tab.1.

TAB.1. CHARACTERISTICS OF PRINT, PERFORMED ON PET FILM

Parameters	Characteristics
Thickness	12μm
Colour	Transparent
Width	1250 mm
Ink	Solvent: Soliflex (Sun Chemical)
Print mold	Kodak NX Reproflex Scandinavia
Anilox	Brand: Sandon 75°
Capacity	Capacity 3.3 cm^3/m^2
Ruling	524 l/cm

METHODOLOGY OF THE STUDIES

The assessment of the quality of the print was carried out by measuring the optical density, allowing to determine the colour saturation and colour parameters in Lab space, using spectrophotometer X-Rite 528, enabling the analysis of changes in colors of the print. Pursuant to standard ISO 12647-6 which specifies standards for flexographic printing, the measurements of optical density should be performed in standard conditions, with the consideration of substratum specification and type of ink (ISO, 2020). The obtained results concerning the optical density were expressed as the mean value from five measurements for each color in different sites of the sample. It allowed eliminating the possible errors, resulting from the irregularity of overprint or lack of the precision of positioning of the measuring head.
For visual assessment of the print quality and sharpness and accuracy of reproduction of the details with different printing FIG 1speeds, Siemens Star was employed. The Siemens Star is used in flexography as a calibration model for evaluation of the print quality, precision of reproduction of details and

registration of colors (ISO, 2013). The model consists of 72 pairs of black and white lines situated in the circle around one central point of contact. The mentioned method allows a precise determination of the capacities of the printing system to reproduce small details. The preparation of the sample for the tests includes the prints, containing the model prepared according to standard ISO 12647-2 (ISO, 2013). The mentioned prints are placed in the conditions of uniform, neutral light what eliminates the effect of external factors on the assessment. After obtaining the prints, there were also performed 5 photos of negatives and 5 of positives of the model, using a digital microscope what allows recording of the high-resolution images of the relevant details.

The microscopic analysis of the prints' surface, was carried out by the digital microscope Delta Optical Smart 2 what enabled observation of microstructure of ink layer and its distribution on substratum. The photograph of raster structure was performed using optical device MyScope.

There were carried out five repetitions of the measurements of the quality parameters on the prints: optical density, color difference ΔEab and resolution.

ANALYSIS OF THE RESULTS OF THE TESTS

The results of the tests concerning the mean values of the measurements of optical density of the prints made on PET films, carried out with the different manufacturing speeds and their standard deviation (σ) are given in Tab.2.

Fig.1 illustrates the diagrams of the impact of the printing speed on optical density.

In the case of the printing speed equal to 400 m/min, the discussed process is characterized by a high stability of parameters. Optical density of the print obtained using Cyan ink is maintained at the level of 1.45 with the speeds of 400 and 500 m/min what corresponds to optimum values for the discussed process and at the rise of the speed to 600 m/min, it is decreased. The print made using Magenta ink reaches value of optical quality amounting to 1.27, being found within the range of the correct values. The optical densities in the case of the application of Yellow (0.9) and Black (1.57) inks also indicate the appropriate quality parameters.

The increase of the speed up to 500 m/min caused certain changes in the characteristics of the process. In the case of the prints, using Magenta ink, there was a small decline of

TAB.2. THE MEAN VALUES OF THE MEASUREMENTS OF OPTICAL DENSITY, PERFORMED FOR THE PRINTS ON PET FILM AND THEIR STANDARD DEVIATION (σ)

Printing speed	Cyan	σ	Magenta	σ	Yellow	σ	Black	σ
400 m/min	1.45	0.0127	1.27	0.0143	0.99	0.0115	1.57	0.012
500 m/min	1.45	0.0149	1.18	0.0074	1.19	0.0095	1.8	0.0079
600 m/min	0.94	0.0079	0.87	0.0067	0.67	0.0092	0.98	0.007

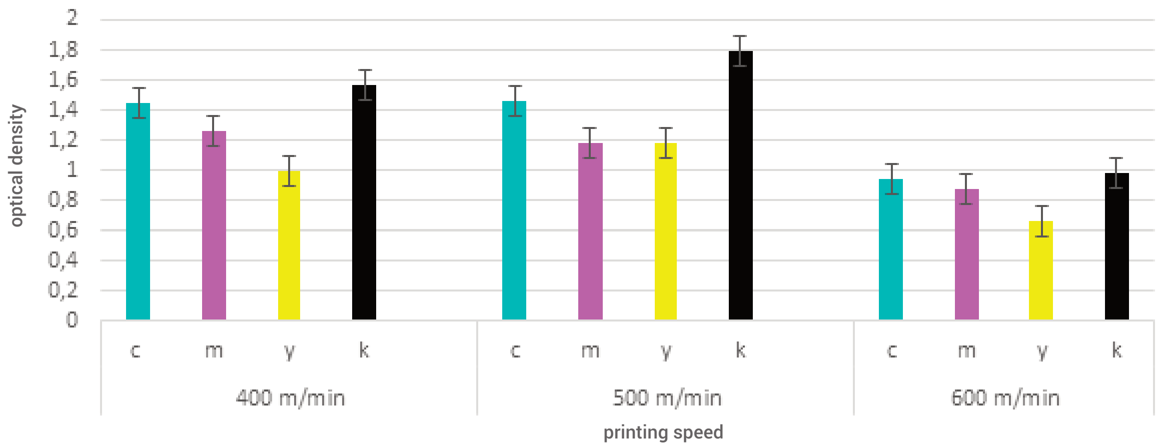


FIG.1. THE IMPACT OF THE PRINTING SPEED ON OPTICAL DENSITY OF THE PRINTS PERFORMED ON PET FILM

value to 1.18 and for the prints made with the use of Yellow and Black inks, the optical density increased up to 1.19 and 1.8, respectively.

The most significant changes were found with the speed of 600 m/min. Under the mentioned conditions, there was observed a considerable decline of optical density (as compared to the speed of 400 m/min) on the prints obtained with the application of all inks: for Cyan - to 0.51; for Yellow – to 0.4 and for Black – to 0.59. The mentioned drops are an evidence of a significant deterioration of the quality parameters of the prints.

When analyzing the reasons for such phenomenon, we should indicate some physical factors, connected with the high speed of the discussed process. First of all, it is the abbreviated time of the ink's contact with the substratum what results in the incomplete transfer of ink. We may assume that at the speed of 600 m/min, the rheological phenomena occur which change the ink flowing properties as affected by high shear forces what leads to placing a thinner layer on the print made on PET film. A significant role is also played by the air turbulences and the increased mechanical vibrations of the machine which disturb the precise and uniform application of the ink. The mentioned factors altogether explain the occurrence of the decline of optical density, indicating simultaneously the necessity to modify the process parameters in the case of such high speeds of printing [11].

The comparison of the obtained results and the binding industrial standards concerning the print on PET films, it may be stated that with the speed of 400 m/min all values are found within the recommended intervals (Cyan: 1.35 – 1.55; Magenta: 1.20 – 1.40; Yellow: 0.90 – 1.10; and Black: 1.60 – 1.90). The parameters of printing in the situation of the mentioned above speed ensure therefore the optimum quality consistent with the industrial standards. In the case of the speed amounting to 500 m/min, optical density values for Cyan and Black remain in accordance with the standards; for Magenta they are found at the lower limit of the acceptable range whereas in the case of Yellow, the discussed values exceed the upper limit of the recommended range what may lead to the over-saturation of the mentioned colour in a final print. With the velocity of 600 m/min, all values decline significantly below the minimum recommended levels what indicates univocally the failure to meet the quality standard and confirms the observed deterioration of the print's quality [10].

From the analysis of the data it results that the impact of the printing speed on the stability of the process for the particular inks is differentiated. With the high speed equal to 600 m/min, the process of ink application becomes more consequent in its imperfection – the ink is evenly distributed but in the insufficient quantities. The mentioned mechanism results from the action of hydrodynamic forces which – at the high velocities – become more predicted and uniform, leading to stable although too thin ink film. Moreover, a shorter time of ink transfer eliminates the variability, resulting from a longer contact with the substrate what, paradoxically, increases the repeatability of the process at the cost of quality.

Tab.3 shows the averaged values of measurements ΔEab on the prints (from five parallel measurements) which allow assessing the stabilities of the colour parameters and identifying the potential factors affecting the variations in colour reproduction in the printing process.

As it can be seen, at the printing speed of 400m/min, the colour difference (ΔEab) for Cyan has value of 14.94, being the highest result in the discussed measuring series. For Black

TAB.3. THE MEAN VALUES OF COLOUR DIFFERENCES FOR THE PRINTS PERFORMED ON PET FILM

Printing speed	Cyan	Magenta	Yellow	Black
400 m/min	1.45	1.27	0.99	1.57
500 m/min	1.45	1.18	1.19	1.8
600 m/min	0.94	0.87	0.67	0.98

ink, the colour difference is 6.64. Magenta and Yellow are characterized by the smallest colour differences, i.e. 3.78 and 4.00, respectively what is an evidence of the conformance with the model values.

In the case of increasing the speed up to 500 m/min, we observe the changes in the process characteristics. The colour difference for Magenta increases up to the level of 14.22, with the simultaneous decline of value for Cyan to 3.71. in the case of Yellow ink, the difference in colour increases to 4.59. The lowest value in difference of colour in the discussed measuring series is found for Black ink - 1.55 what reflects a high consistency with the reference model. With the speed of 600 m//min, values of colour differences for all process inks are subjected to a considerable increase, reaching the similar high level.

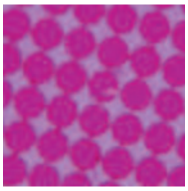
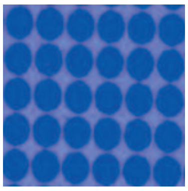
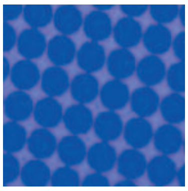
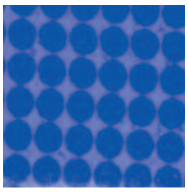
The interpretation of value ΔEab in the context of the printing quality is crucial for the appropriate assessment of the obtained results. In printing practice, it is assumed that values ΔEab below 2 are indiscernible for human eye, the discussed values in the range of 2 – 3.5 are noticeable only by the experienced observers, the range 3.5 – 6 means the noticeable differences and values above 6 indicate the clearly visible colour deviations. When analyzing the obtained results in the light of the mentioned above criteria, we may state that with the speed of 500 m/min Black ink (ΔEab=1.55) and Cyan ink (ΔEab=3.71) reach the acceptable compliance with the model whereas the remaining inks reveal the visible differences [10].

The increase in the ΔEab value with the printing speed of 600 m/min may be connected with the technological factors: the increase of the velocity leads to abbreviation of the time of ink drying what affects its penetration into the structure of PET film. Moreover, in the case of higher speeds, there is a risk of inaccurate application of the ink what may cause the non-uniform coverage of the substrate. The specific properties of PET film , including its smoothness and low absorbance complicate additionally the process of ink transfer at the high speeds, leading to the increased colour differences. It is worthy to mention that the quality of colouring is also affected by rheological properties of inks which in the case of high velocities may be subjected to changes.

The results of the measurements of optical parameters, dimensions of raster points and raster structure are given in Tab.4.

When comparing the optical parameters, measurements and shape of raster point, it was noticed that together with the increase of the speed, the distribution of ink inside the raster point was changed – a dark "edge" appeared around it, ink was

TAB.4. PHOTO OF THE STRUCTURE OF RASTER POINTS AT VARIOUS PRINTING SPEEDS

	400 m/min D = -1.53 l = 45.52 a = 78.78 b = -0.72		400 m/min D = -1.7 l = 49.9 a = -32.15 b= -56.91
	500 m/min D = -1.54 L= 45.52 a = 78.92 b = -1.04		500 m/min D = -1.7 L= 49.7 a = -32.20 b = -57.02
	600 m/min D =- 1.68 L = 44.82 a = 79.16 b = -2.96		600 m/min D= -1.76 L= 49.02 a = -31.49 b = -57.55

pulled between the dots and at the speed of 500 m/min, the streaks were generated between the dots.

In consequence, optical density is changed and the discussed changes may be caused by the phenomenon called "bouncing" which is a defect of printing and may become intensified in the projects where the areas of uniform print are intermingled with the considerable areas of white space. In such designs there is also a noticeable phenomenon of "ghosting" which is intensified in the case of higher velocities of printing; it is connected with the ink transfer from anilox cell on the printing element of form; therefore, we may suppose that in the discussed case, the mentioned change may be dependent also on the ink behavior and may change due to the changes in temperature and rheology at high velocities. The discussed problem is very interesting and requires further studies [8, 9].

The analysis of control models of Siemens Star, as printed on PET film at different printing speeds is illustrated in tab.5.

As it can be seen, the print made using Cyan ink (speed of 400 m/min) reveals a distinct radial structure with perfectly preserved sharpness of the edges of lines in the both forms (negative and positive) of Siemens Star. The negative shows especially good contrast between the elements which remains stable in the total range of the image. The positive form is characterized by even distribution of the elements and preservation of uniform geometry. Tonal passages in the both cases reveal the exceptional liquidity and uniformity what proves the correct behaviour of ink during the printing process.

TAB.5. PHOTO OF CONTROL PAIRS OF LINES OF SIEMENS STAR ON THE PRINTS

Speed: 400 m/min		
Speed: 500 m/min		
Speed: 600 m/min		

Printing at the speed of 400 m/min is characterized by the same diameter of the central field, amounting to 2 mm for all colors (black, cyan, magenta and yellow) and forms. The mentioned value results in the constant resolution equal to 11.94 for pairs of lines/mm in the case of positives as well as negatives. The lack of differences in the resolution between the forms indicates the stability of the process at the mentioned speed [10].

TAB.6. THE MEAN VALUES OF THE MEASUREMENTS OF SIEMENS STAR RESOLUTION ON THE PRINTS PRODUCED ON PET FILMS

Colour	Form	Central diameter [mm]	Resolution [pairs of lines/mm]
Black	Negative	2	11.94
	Positive	3	7.96
Cyan	Negative	2	11.94
	Positive	3	7.96
Magenta	Negative	2	11.94
	Positive	3	7.96
Yellow	Negative	2	11.94
	Positive	3	7.96

The results of the analysis of the mean values of print resolution measurements on the prints (from five parallel measurements), at the printing speed of 500 – 600 m/min is given in Tab.6.

With the increase of the speed up to 500 – 600 m/min, a distinct difference in the diameter of the central field between the negatives (2mm) and positives (3mm) is found. It results in the differentiation of the resolution – being higher for the negatives (11.94 pairs of lines/mm) as compared to the positives (7.96 pairs of lines /mm). The systematicity of the mentioned difference is the evidence of the predictable impact of the increased speed on the printing parameters.

The analysis of the studies shows that the increase in the speed to 600 mm/min causes a considerable decline of optical density for all the examined inks. Cyan ink revealed a special stability in the range of speeds of 400 – 500 m/min. BOPP film is characterized by better stability with the higher speeds, with lower variations of optical density. The highest stability of the parameters was recorded for Magenta ink.

From the analysis of color differences (ΔEab) we may conclude the significant relationship between the printing speed and the quality of colors' reproduction. The smallest color differences, occurring on PET film are found at the speed of 500 m/min whereas the increase of the printing velocity to 600 m/min results in the considerable deterioration of the quality of reproduction of all colors.

In respect of the print resolution, the highest and the most stable values were obtained with the velocity of 400 m/min. The increase of the printing speed leads to the differentiation of the resolution between the positive and negative forms.

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SUSTAINABLE PACKAGING DESIGN: DESIGN OF A CARDBOARD BEVERAGE CARRIER

ZRÓWNOWAŻONY DESIGN OPAKOWAŃ: PROJEKT TEKTUROWEGO NOSIDEŁKA NA NAPOJE

ABSTRACT: The article presents the implementation stages of a disposable packaging project for takeaway food products. The beverage holder was designed for cups of various capacities available at catering points, based on specific assumptions regarding the size, shape and weight of the carried products, as well as functionality and environmental issues. The design that was the simplest in terms of assembly and the most economical in terms of substrate use was selected among the three initial conceptual sketches. The structural grid drawn in 2D allowed to create a 3D visualisation and cut out prototypes from two types of E and B corrugated cardboard, which were subjected to load tests using 200, 300 and 400 ml cups. The design was evaluated positively in terms of both aesthetics and functionality. The conclusion indicated the possibility of modifying the project to a four-cup version and personalising it with printing, e.g. a logo. The implementation of the project confirmed that it is possible to combine aesthetics, functionality and ecology.
Key words: takeaway packaging, beverage holder, corrugated cardboard packaging, ecological packaging

STRESZCZENIE: W treści artykułu przedstawiono etapy realizacji projektu opakowania jednorazowego na produkty spożywcze „na wynos". Na podstawie określonych założeń dotyczących wielkości, kształtu i ciężaru przenoszonych produktów, jak również funkcjonalności oraz aspektu ekologicznego zaprojektowano nosidełko do napojów dla różnych pojemności dostępnych w punktach gastronomicznych. Spośród trzech szkiców wstępnych koncepcji wybrano konstrukcję najprostszą do składania i ekonomiczną z punktu widzenia wykorzystania podłoża. Rozrysowanie siatki konstrukcyjnej pozwoliło utworzyć wizualizację 3D, a następnie wyciąć prototypy z dwóch rodzajów tektury falistej: E i B, dla których przeprowadzono testy obciążeniowe z wykorzystaniem kubków o pojemnościach: 200, 300 i 400 ml. Projekt został oceniony pozytywnie zarówno pod względem estetycznym, jak i funkcjonalnym. W podsumowaniu wskazano możliwość modyfikacji projektu do wersji czterokubkowej oraz personalizacji poprzez nadrukowanie np. logo. Realizacja projektu potwierdziła, że można połączyć estetykę, funkcjonalność oraz ekologię.
Słowa kluczowe: opakowanie „na wynos", nosidełko na napoje, opakowanie z tektury falistej, opakowanie ekologiczne

INTRODUCTION

In view of growing consumer environmental awareness (Saini & Nisha, 2023) and stricter European Union regulations (EY – Ireland, 2025), designing packaging in line with the principles of sustainable development is becoming a key element of responsible design (Koklacova & Atstaja, 2011). Contemporary packaging not only serves a protective function – it is a communication tool, a marketing element, and a means of supporting sustainable development (Lisińska-Kuśnierz & Ucherek, 2003; Emblem & Emblem, 2014). The cardboard beverage carrier is an example of an innovative approach to design that combines functionality, aesthetics, and concern for the natural environment.

Nowadays, the pace of life has definitely increased, the catering sector is constantly developing (Restaurateur Report, 2025), and, at the same time, the demand for disposable packaging for takeaway food products is growing. In light of recent European Union regulations, it is recommended to reduce the use of plastic materials in disposable packaging (European Commission, 2025; European Parliament, 2025). Therefore, it is advisable to look for new solutions using solid or corrugated cardboard. Cardboard is a renewable raw material that is easy to process (Drzewińska et al., 2005). It offers a range of construction and design possibilities. However, its effective use requires designing packaging that takes into account technological and functional aspects (Michnowska, 2017). The type of cardboard must be selected appropriately (Emblem & Emblem, 2014, Jakucewicz, 2003), but also the design, to ensure stability, ease of assembly, and comfort of use.

The aim of the project was to develop eco-friendly corrugated cardboard packaging for carrying takeaway drinks. This type of carrier should be easy and intuitive to assemble, especially for people working in high-traffic locations. The structural grid should be simple so that it can be laid out economically on the printing substrate and generate as little material waste as possible. The most eco-friendly solution is a design that does not require the use of glue or other additional elements. Instead, locks and hooks used in cardboard packaging can be used.

PROJECT SCOPE AND CONCEPT

The scope of the project included an analysis of commercially available solutions used for disposable cardboard packaging, selection of the appropriate material, design of the structure, drawing of a 2D structural grid, and 3D visualization (Rozmuszyńska, 2025). The final result was the creation of a prototype and its evaluation in terms of functionality and durability, as well as load testing.

The concept of a cardboard beverage carrier was designed to respond to the need for eco-friendly, practical, and aesthetic solutions in the catering industry. The main goal was to create functional, environmentally friendly disposable packaging that would allow for the safe and convenient transport of two or four cups of hot or cold beverages, while reducing the carbon footprint and packaging waste.

MATERIAL AND STRUCTURE SELECTION

The cup carrier design uses corrugated cardboard, which is a perfect combination of durability, lightness, and eco-friendliness. It is a material commonly used in packaging, but thanks to the appropriate design of the structure, it gains new functionalities – in this case, ensuring stability and convenience in transporting beverages. The project uses 1.5 mm thick E-flute cardboard and 3 mm thick B-flute cardboard. This material is eco-friendly and can be printed on.

An additional advantage of corrugated cardboard is its ease of processing – it can be cut, bent, and formed quickly and repeatedly, making it ideal for mass production. The material withstands point loads well, so the cups are held securely in the cut-out holes without the risk of tipping over or moving during transport.

Based on preliminary assumptions and requirements for the packaged product, such as size, shape, and weight (Table 1), as well as the presence of a handle, initial concept sketches were made (Fig. 1). Of the three design proposals for the carriers, variant c) was selected, while variants a) and b) were

TAB. 1. DIMENSIONS OF BEVERAGE CUPS IN RELATION TO THEIR VOLUME.

Cup capacity	Height of the cup in mm	Diameter of the cup base in mm	Diameter at a distance of 15 mm from the base of the cup in mm	Diameter at the top edge of the cup in mm
200 ml	95	55	60	75
300 ml	110	60	65	85
400 ml	135	60	65	90

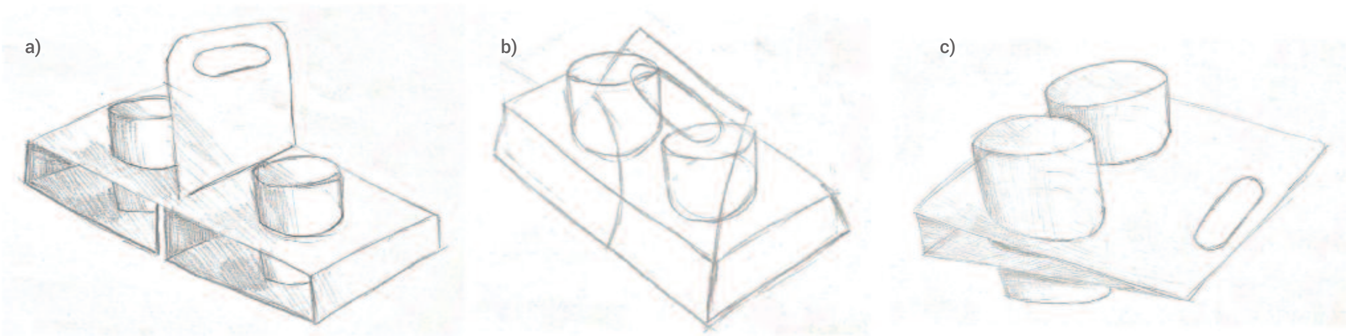

FIG. 1. SKETCHES OF INITIAL CONCEPTS FOR THE DESIGN OF THE CARRIER

rejected due to the overly complicated shape of the mesh and the complex and unintuitive folding method.

PROJECT IMPLEMENTATION

CONSTRUCTION MESH AND ITS MODIFICATIONS

The structural mesh of the carrier was designed using Artios CAD software, which allowed for 3D visualisation and cutting out a prototype on a cutting and creasing plotter. This helped to verify the construction quickly and make the necessary modifications. The initially rectangular structural grid (Fig. 2a) was given rounded corners and reinforcements at the holding points and cup openings to stabilize them (Fig. 2b). In addition, two variants of the carrier were created: with cut corners (Fig. 2c) and with finger holes in the bottom layer of cardboard (Fig. 2d).

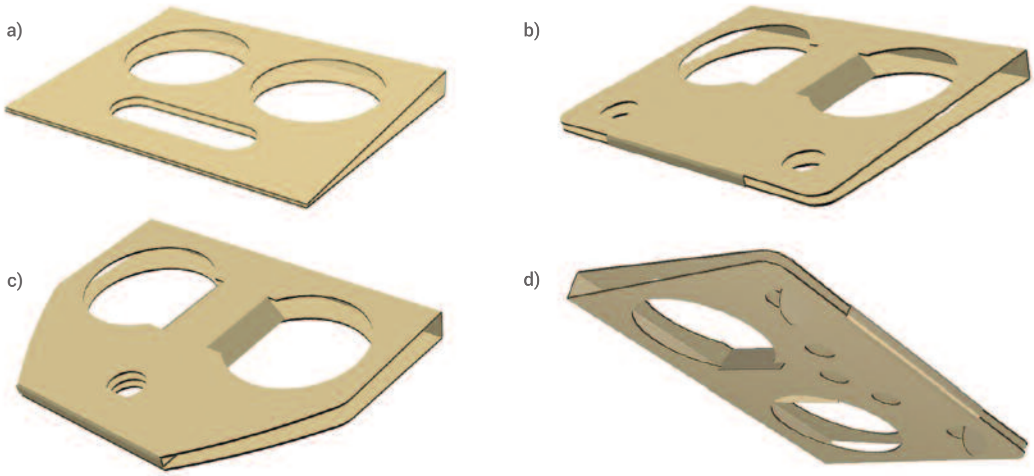

FIG. 2. 3D VISUALIZATION OF SUBSEQUENT MODIFICATIONS TO THE CARRIER DESIGN

TAB. 2. WEIGHT OF BEVERAGES IN GRAMS DEPENDING ON CUP VOLUME

Type of beverage	Weight of the beverage in grams depending on the volume of the cup		
	200 ml	300 ml	400 ml
Tea	200 g	300 g	400 g
Ice tea	215 g	312 g	414 g
Black cofee	208 g	312 g	414 g
Milk coffee	222 g	332 g	430 g
Iced coffee	202 g	304 g	402 g
Matcha	202 g	304 g	404 g
Matcha with milk	230 g	340 g	450 g

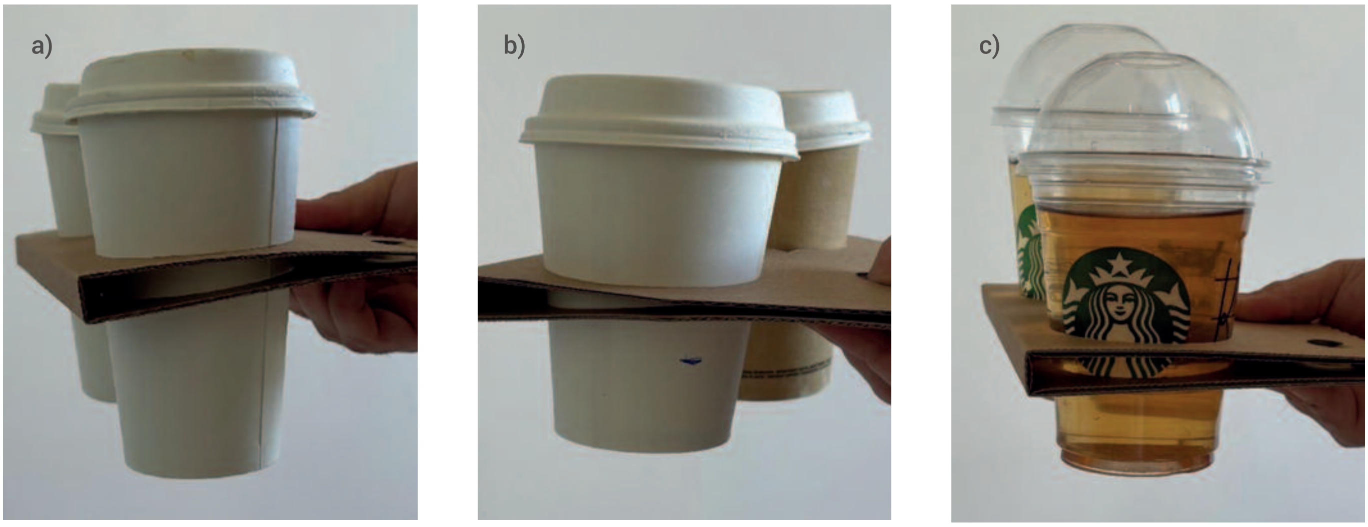

FIG. 3. PHOTOS TAKEN DURING THE LOAD TEST OF THE CARRIERS

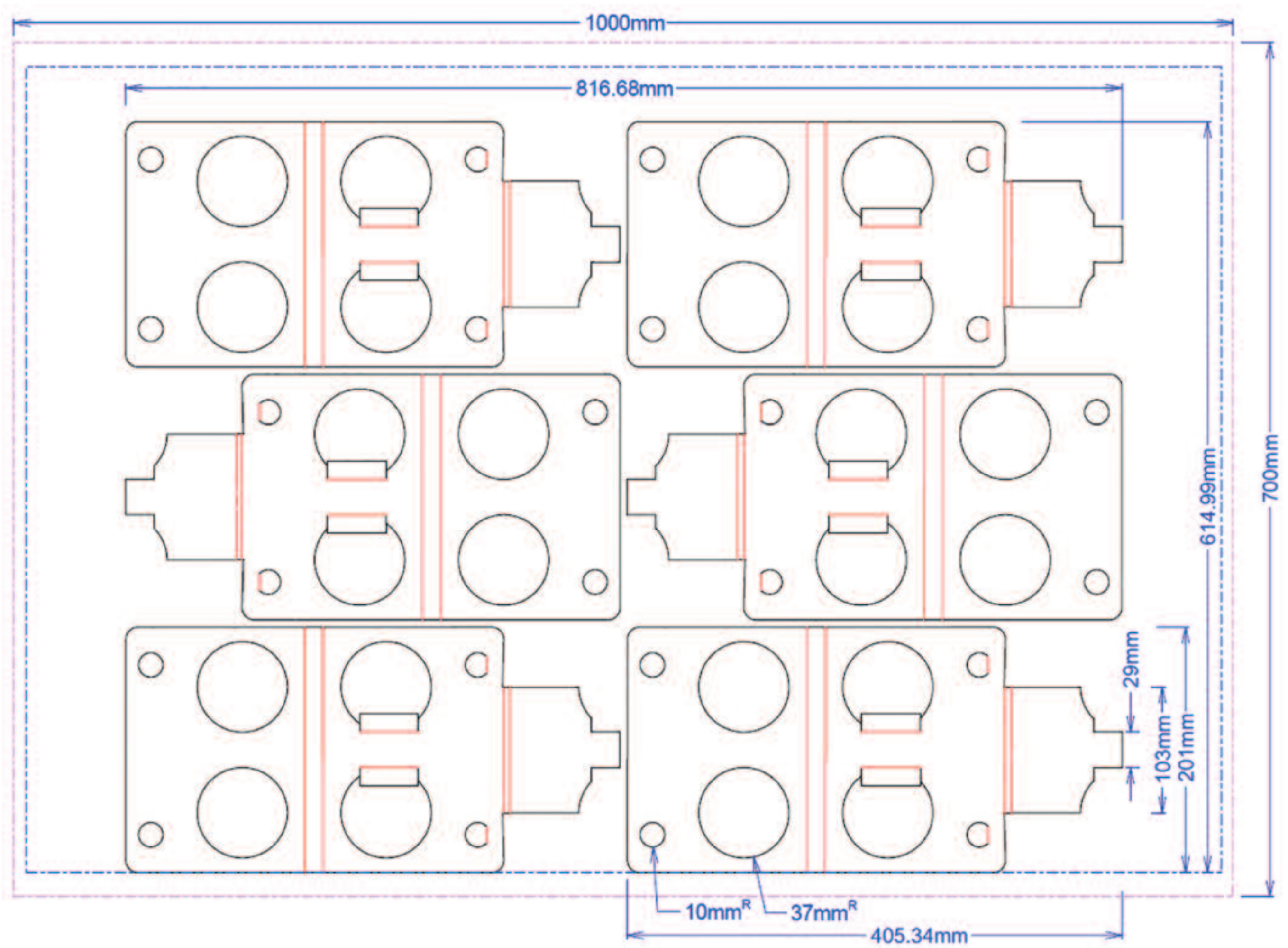

FIG. 4. IMPOSITION OF 6 PIECES OF THE CARRIER'S STRUCTURAL MESH ON A B1 SHEET

LOAD TESTS

The strength of the carriers was tested for sample types of beverages with different cup volumes (Table 2). The visible bending of the cardboard structure under the weight indicated the need to use a thicker base to cut out the carrier for larger capacity cups. Carriers made of E-flute cardboard deformed when loaded with 400 ml cups (Fig. 3a). E-flute is more suitable for cups with a capacity of 200 ml and 300 ml (Fig. 3b). Trays made of B-flute withstood the load well even for cups with a volume of 400 ml (Fig. 3c), which makes them more versatile.

IMPOSITION

The manufacturing module in Artios CAD enabled the conversion of a single design into a layout, considering the specific sheet format and spacing between components, as well as the calculation of the used sheet area and the percentage of waste. For each of the three final variants of the structural mesh of the carrier on sheet B1 (with the wave direction parallel to the longer side), there are 6 usable areas (Fig. 4). The degree of substrate utilization is approximately 60%, with 40% waste resulting from the irregular shape of the cut-out usable area and the presence of holes in the structural mesh.

SUMMARY AND CONCLUSIONS

The prototype carrier meets the initial design specifications. The carrier is functional, eco-friendly, and aesthetically pleasing. The corrugated cardboard used to make the prototypes ensures durability and ease of recycling. In addition, the simple shape of the structural mesh and the glue-free assembly method facilitate use, and the possibility of transporting the cut blanks in flat form reduces the carbon footprint. The shape of the carrier's structural mesh allows for efficient use of the substrate – the imposition fits 6 blanks on a B1 sheet.

Load tests have shown that the design fulfills its purpose. It ensures stability, protects the contents, and allows for convenient transport of beverages. The tests confirmed the strength of the E-flute cardboard carrier for two 200 and 300 ml cups and the need to use B-flute cardboard for larger volume cups.

In the future, it may be possible to modify the design to accommodate four drinks, but this would require the use of more durable B-flute or even C-flute cardboard due to the need to carry a heavier load. Additionally, it is possible to personalize the carrier by printing (e.g., a café logo) on the top side.

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STEFAN JAKUCEWICZ

“SAFE PACKAGING 15” – AS COMMENTED BY THE HOST OF THE EVENT

The fifteenth edition of the Conference “Safe Packaging” which was held on 5 – 7 November, 2025 at the Sheraton Hotel in Sopot has confirmed that the subject of packaging safety remains one of the crucial challenges of the sector. The three-day event gathered almost 230 participants and filled the program with the intensive presentations, workshops, discussions and the study tour at Laboratory J.S. Hamilton in Gdynia. As being the “master of the ceremony” of all so-far conducted editions of the conference, I may state that this year’s presentations were characterized by especially high professional level and a distinct orientation to practice and new regulations in the discussed sector.

After three years of pause, “Safe Packaging” returned to Sheraton in Sopot. This year’s edition was opened – the first time in the history of the event – by the Wednesday workshops, prepared by Esko and Digiprint companies. The attention was focused on standardization in printing, quality control, keeping the standards and working with colour in graphic studio. The workshops were preceded by the traditional evening meeting of the sector in SPATiF, being organized as usually, by Laboratory J.S. Hamilton.

The partners of the Conference were the following companies: Bank Pekao SA, Bobst, CMC Consulting, eProductivity Software, Heidelberg, hubergroup, Digiprint, Esko, GMG, X-Rite, Koening& Bauer, Metsä Board and Print Coatings/WAB. The event had also a significant expert background owing to professional partner – Laboratory J.S. Hamilton.

FOUR THEMATIC BLOCKS AND 11 LECTURES – A DISTINCT POLARIZATION OF THE PROBLEMS

During the Conference, 11 very interesting lectures on a high professional level, were delivered. They were classified in four blocks, having a similar problematics; each block was ended by the intensive session of questions and answers. The themes of the presentations were as usually connected with the widely

THE 15TH EDITION OF THE "SAFE PACKAGING" CONFERENCE ATTRACTED NEARLY 230 PEOPLE. PARTNERS INCLUDED BANK PEKAO SA, BOBST, CMC, DIGIPRINT, EPRODUCTIVITY SOFTWARE, HEIDELBERG, HUBERGROUP, KOENIG & BAUER, METSÄ BOARD, PRINT COATINGS, AND WAB ARTYKUŁY POLIGRAFICZNE understood idea of "safe packaging". During the present event, each of the lecturers had a different approach to the discussed problem, therefore, there was observed a certain polarization of some subjects. They included: sustainable development, carbon footprint, correctness of technical performance and protection of packaging, guaranteeing the mark of the packed product.

As the moderator of all previous conferences, I may state that the problematics presented during the current edition was very interesting, up-to-date and on a very high professional level. Year by year, the mentioned level grows up, and the range of the idea of safe packaging outlines wider and wider framework.

PACKAGING SECTOR EVALUATED BY THE ANALYSTS

In the first block, three lectures were delivered. The first lecturer was **Krzysztof Mrówczyński, the manager of the Team of Sector Analyses**, who presented the elaboration of the analysts of Bank Pekao SA, entitled: **"Maintaining the advantages at the cost of margins. Polish packaging sector in relation to a slowdown in Europe and the challenges of the labour market"**. It was a generally outlined presentation of the characteristics of the packaging production in Poland and in the EU, with a special consideration of wood, paper, glass, plastics and metal packaging sector. In the lecture, the data from the years 2022 and 2024, or the first half of 2025, were compared.

The mentioned lecture contains several dozen of diagrams and charts. It would be worthy for the decision-makers of the discussed sector to get familiarized with the discussed elaboration of Bank Pekao SA, published intentionally for the 15th edition of the Conference "Safe Packaging" in a form of 60 pages-counting brochure. The mentioned document attracted the attention of many persons.

SAFETY, DIGITALIZATION, STANDARDIZATION, MARK PROTECTION AND TECHNOLOGY

The second lecture was delivered by **Sylwia Łuba, a specialist in technology and trade, representing the commercial company Print Coatings/WAB Artykuły Poligraficzne**. The title of the lecture was: **"Safe packaging with Print Coat varnishes from Print Coatings Polska"**.

The lecturer discussed in detail the EU regulations in respect of the requirements of the materials intended to have a contact with food and the Swiss Ordinance, EuPIA, ISEGA guidelines and a new German Ordinance. The recent document enters into life on January 2026. It regulates the application of printing inks and varnishes intended to come into direct and indirect contact with foods. It contains the company's own lists of non-admitted substances and their limits.

THE BANK PEKAO SA REPORT IS AVAILABLE AT: WWW.PEKAO.COM.PL/ANALIZY-MAKROEKONOMICZNE/RAPORTY-SEKTOROWE.HTML

In the lecture, the dispersive varnishes sold by Print Coat company were characterized; the mentioned products are adjusted to the regulations of the safety of ecology and environment. Briefly speaking, the company produces varnishes which meet the severe legal and market requirements when allowing simultaneously the safe, effective and sustainable packaging production.

The next lecture: **"From implementation to success! Safety at every manufacturing stage"** was delivered by **Paulina Podobas and Łukasz Szymański from Digiprint company**. The authors presented the safety of packaged product obtained owing to the application of protected packaging, i.e. use of protected patterns, application of protected printing inks, reflection holograms and self-sticking protecting sealings. Production of the protected packaging must by compliant with the ISO/TC standard of packaging production, including as follows:

development of graphic idea, conception of packaging, manufacturing workflow, calculation of carbon footprint, moving between the standards and digital transformation. In the lecture, the meaning of digital transformation and AI application within the total process was emphasized.

After coffee break, there was the lecture of **Robert Kuczera, the boss of CEE cluster hubergroup** – it was entitled: **"From pigment to confidence. Colour technology as a guarantee of packaging quality"**. In his appearance, the author provocatively used word: colour instead of taint – it is employed in everyday language. The thesis of the discussed lecture is the association of the packaged product via the identification of colours of its packaging. As it was stated by the author, colour means the emotion, recognition sign and mark guarantee; a customer perceives the colour of the market shelves, not the printing process or composition of the printing ink. The lecturer stressed that it is just the colour which is the first item of the contact between the trade mark and the man. The colour represents a wide knowledge, technology and responsibility of the producer of printing ink. A long lasting colour guarantees the taint repeatability of the printed volumes, affects the shine, contrast and feeling in touch, ensures the compliance with the rules of food safety, protects from wearing, light, humidity and migration to the packaged products. Briefly speaking, the printing ink (or, more exactly, its colour) constructs the confidence between the printing house and the consumer.

Paweł Krasowski from Koening & Bauer company delivered the lecture **"Solutions allowing to take care of the protection of trade mark and quality control in your production"** and submitted the systems, employed for this purpose. Control of authenticity of the product is applied at three levels: haptic control (touching), control with the use of tools and verification using the external carrier. The technology of protection by K & B is adapted to each task. Their verification is carried out by Ovjer, Daktylo and Stegano. The application of Ovjer system allows checking, at a short time, whether it is your product registered in your basis. Daktylo andf Stegano are the protections employed in a form of overprinted micro-test and they are easy to be identified. Another mark-protecting solution is a quality control during printing on offset sheet machines. It includes, inter alia, K&B company measuring system – QualiTronicColorControl, furnished with different functions, measuring the process of printing and performed prints. The system is installed in machines and controls the total process, ensuring the repeatable print, what affects, inter alia, the protection of mark.

Małgorzata Szczotka from CEO CMConsulting.pl, the successive speaker delivered the lecture: **"Standardization and optimization of the process decreases the quantity of waste paper and time of setup – a case study"**. The author presented the method for standardization of spot colors. The procedure consists of four stages: statement of the current status of information flow concerning spot colors in the printing house, development and implementation of standardization operations with the application of the technological capacities of the printing house, validation of the process and introduction of the process at all stages of reproduction of the spot colors. Thus, we have to deal with the exchange of information on spot colors, based upon ISO 20654, with individual spot colors (ISO 17972-4), with the certifying program and with proof GMG. We should also mention the systems of dosing the ink in the mixing department, certified program printer, that is, the total certifying system, the system of color management and the management of residual inks from the mixing department and the measuring system of the printing machine.

After the next coffee break, the representatives of Heidelberg Polska took the floor: **Alicja Bednarek, Marketing Manager, and Jarosław Krasnodębski, Consumables Sales Director**. The delivered lecture had a title: **"How to understand safety in packaging production"**. The lecturers submitted their idea of "safe packaging", presenting the examples of Heidelberg solutions. The safety of packaging production is protected by inspection system, system of (non)fitting, clear pile and the appropriate color. Additionally, the company procedures are employed, such as Prinect Touch Free, VLF, Anicolor, Jetfire, Scodix and the company consumables Saphira.

The choice of the employed procedures (read: programs) is intended for the specified offset machines of Heidelberg company. Printing of packaging may be protected by Scodix or/and Multidot systems. The authors when answering the question :" Safe packaging - what does it mean?" express the opinion that it must have the ensured **production safety** and **financial safety**.

The next lecture was delivered by the representatives of **Bobst company**: **Krzysztof Dąbrowski, service manager ; Szymon Ochociński, manager for digital solutions and Marcin Wicha, sales manager**. The title of the lecture was: **"Optimization in the process of safe packaging production, with the utilization of BOBST solutions"**. Each of the lecturers submitted the system solutions, serving (in the field of particular specialization) for production of safe packaging from the viewpoint of its manufacture. In connection with the above fact, several Bobst company systems were presented. The safety of the produced packaging was considered in three planes: machines, digital workflows and data analysis, and service of production support. In the "machine" section, a new folding-glueing Novafold machine was characterized: its present capabilities, the systems protecting a correct and repeatable production and the change in relation to its previous version. In block: digital workflow and data analysis, the so-called intelligent communication, i.e. BOBST Connect system was discussed.

The mentioned part of the session was ended by the appearance of **Piotr Orliński, Technical Service Manager from Metsä Board**, who delivered the lecture: **"Cooperation in favour of safe, regulations-compliant, low-emission packaging. A case study"**. The author presented the rise of the requirements in the chain of packaging values, stressing the growing requirements in respect of the sustainable development, the increase of demand on productivity, necessity of reducing the quantity of traditional plastic materials and elimination of disturbances in the delivery chain. Metsä Board company remains in a full compliance with the EDUR Regulation of the European Union in two areas: process of the appropriate care in respect of wood obtaining (assessment of a risk specific for a given country and plan for limiting the risk) and the EDUR information transfer from Metsä Board cardboards in the total chain of values. In its functioning, the concern is oriented to reduction of carbon footprint of its products what will enable its reduction to 45 – 60% until 2030. The philosophy of production of different types of cardboards which is manifested by reduction of weight and replacement of cardboards with the purely cellulose multi-layer FBB cardboards, would allow decrease the carbon footprint by more than 50%, and in the case of food packaging as much as by 65%. Such possibilities may be obtained with the application of the newest version of cardboards – Classic FBB by Metsä Board.

KRZYSZTOF MRÓWCZYŃSKI PRESENTED A GENERAL OVERVIEW OF THE PACKAGING PRODUCTION SECTOR IN POLAND AND THE EU, WITH PARTICULAR EMPHASIS ON THE WOOD, PAPER, GLASS, PLASTIC, AND METAL PACKAGING INDUSTRIES

After the next, last coffee break, there were two lectures presented. The first one – was delivered by **Paul Backhouse, Product manager of Radius eProductivity**: **"Automatic certificates of carbon footprint in eERP Radius"**. Automatization of CO_2 measurements for sector of packaging and printing in a modern ePS solution. As compared to manual calculation, the automatic calculation method allows for reduction of the time of calculation by 95%. Determination of carbon footprint covers three levels: operational, delivery chain and products. CarbonQuota is an automated calculator of carbon dioxide (CO_2) emission which was included into the developed software ePs.

NEW REGULATIONS FCM AND NIAS

The second, last lecture was developed and delivered by **Adam Fotek, the studies expert at J.S. Hamilton**. The title of the lecture was: **"The newest legal changes in respect of migrating substances intended to have the contact with food (PPWR, NIAS, Bisphenol A, BFR)"**.

In the presentation, there were discussed, inter alia, the new limits concerning the substances present in packaging in accordance to the **Regulation (EU) 2025/40 of the European Parliament and of the Council of 19 December 2024 on packaging and packaging waste**. The sum of the concentrations of the so-called heavy metals i.e. lead, cadmium, mercury and hexavalent chromium shall not exceed 100 mg/kg, i.e. it cannot be more than 0.01%. From 12 August 2026, food-contact packaging shall not be placed on the market if it contains per- and polyfluorinated alkyl substances (PFAS) in a concentration equal to or above the following limit values to the extent that the placing on the market of packaging containing such a concentration of PFAS is not prohibited pursuant to another Union legal act.

Commission Regulation (EU) 2025/351 of 21 February 2025 amending Regulation (EU) no 10/2011 on plastic materials and articles intended to come into contact with foods amends many previous requirements and introduces, inter alia, definition of a high degree of purity. The Swiss Ordinance has been amended, as well. German Ordinance has appeared together with the new data as well as recommendations of BRF XXXVI of 1 October 2025 concerning the limitations in relation to the use of the recycled materials. In the opinion of the author of the present article, the decisions relating to materials, containing per- and polyfluorinated alkyl substances will be most severe because they are employed as waterproofing substances in relation to paper and cardboard. According to my knowledge , paper industry needs somewhat more time.

In the evening of the same day, the solemn dinner had place; its main attraction was AI photo-kiosk, ensured by the monthly "Packaging" (Polish: Opakowanie) which celebrates the Jubilee of the 70th anniversary of activity this year. As **Anna Naruszko, the editor-in-chief** of the mentioned periodical said when opening the evening: *common photos in arrangements generated by artificial intelligence will remain longer in our memory than the taste of the best cake*. And she was right. There were long queues to the mentioned attraction; it could be seen it brought great joy and lot of fun to the participants of the event. The next day, that is, on Friday, 7 of November, there was organized a visit to Laboratory J.S. Hamilton in Gdynia. The program included laboratory analyses, the newest amendments in FCM regulations and NIAS problems.

The 15th Conference "Safe Packaging" has been already behind us. We will meet in November 2026 during the 16th edition of the discussed Conference. Where it will be held? We will hear about it soon.

During the gala dinner, the main attraction was the AI photo booth provided by the monthly magazine "Opakowanie", which celebrates its 70th anniversary this year

Packaging Review

"PACKAGING REVIEW" REVIEWING PROCEDURE

"Packaging Review" quarterly magazine's reviewing procedure is multilevel in order to maintain high quality content and consists of the following steps:

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