Development of an Intelligent Innovative Management System Printboost for the Publishing and Printing Industry[*]

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Abstract:
Automated business process management systems at printing enterprises create competitive advantages in the current market. Therefore, the Ukrainian Printboost system, developed in the printing environment conditions, is relevant, based on a solution developed for a specific publishing and printing company. Printboost was created using modern design thinking and service design methodologies, which provides an up-to-date response to the needs of the modern printing market. There has been created an advanced tool that provides maximum convenience for both printing houses and their clients, thanks to its unique capabilities adapted to the specifics of the printing industry. The Printboost system provides the creation of a client-oriented personal website of the printing company with a personal account for the client, the possibility of Web2Print site localization, the creation of product manufacturing algorithms, the creation of technological maps, accuracy and speed in calculating the cost and production times and analysis of the printing enterprise website through tools for optimization and increasing visibility (SEO, Google My Business, Google Analytics). A new approach for the choosing a control system for a publishing and printing enterprise is presented and it is based on the synthesis of a model with factors influencing this process. A methodology for ranking factors is proposed, which allows determining the most significant criteria for making management decisions.

Keywords
intelligent enterprise management system, innovation, publishing, printing, algorithm, server, electronic document flow, database, information and methodological support, service design, design thinking, graphic model, ranking factors. [1]

1. Introduction

The modern development of the world economy is characterized by the active introduction of digital technologies, the concept of Industry 4.0 and intelligent management systems, which significantly change approaches to the organization of production in various industries. The issue of modernization for management systems in manufacturing industries in general and in the publishing and printing sector is the subject of numerous scientific studies. In modern scientific literature, several key areas can be identified that are directly related to the problems of creating intelligent innovative systems.

The importance of automation in the printing industry is confirmed by numerous studies that highlight the implementation of ERP systems, CRM solutions and specialized platforms for managing production processes in many international [1-3] and domestic publications, as well as at international conferences dedicated to the automation of technological processes [4-6]. Scientific publications consider the advantages of integrated information systems that contribute to the increasing productivity and optimizing resources. The growing role of artificial intelligence and

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machine learning in production processes is confirmed by studies analyzing the application of predictive analytics, automated quality control and optimization algorithms [7-9]. Literature sources also indicate the need to develop adaptive systems capable of self-learning and analyzing large data sets that can be used in the publishing and printing industry [10-12]. The analysis of literature sources also confirms the relevance of developing the Printboost intelligent innovation system as a tool for the increasing the management and production processes efficiency in the publishing and printing industry [13-15]. Analysis of modern approaches to automation of publishing activities shows that the implementation of IoT technologies and cloud computing allows creating integrated production management ecosystems [16, 17]. Research into the architecture of modern production management systems shows the importance of integrating different subsystems through unified APIs and microservice architecture [18, 19]. This ensures scalability of solutions and the ability to adapt to different types of printing equipment. Analysis of the economic efficiency of implementing intelligent systems represents that the return on investment is achieved through optimizing material consumption, reducing energy consumption and improving OEE (Overall Equipment Effectiveness) indicators [20].

The publishing and printing industry itself is also experiencing a period of active digitalization, but most enterprises still use outdated or partially automated management systems. Such systems are unable to comprehensively analyze a large amount of production data, timely predict market changes and optimize production flows. As a result, problems arise of overspending of materials, untimely fulfillment of orders, reduction of product quality and limitation of strategic development opportunities. The lack of intelligent management tools slows down the implementation of the principles within the "smart production" in printing. Given the above problems, it becomes obvious that the further development of publishing and printing enterprises is impossible without the use of new generation intelligent management systems. Such systems should combine the functions of data collection and processing, forecasting, automated decision-making and optimization of business processes in real time. It is important that they not only increase production efficiency, but also ensure the strategic sustainability of enterprises in the long term.

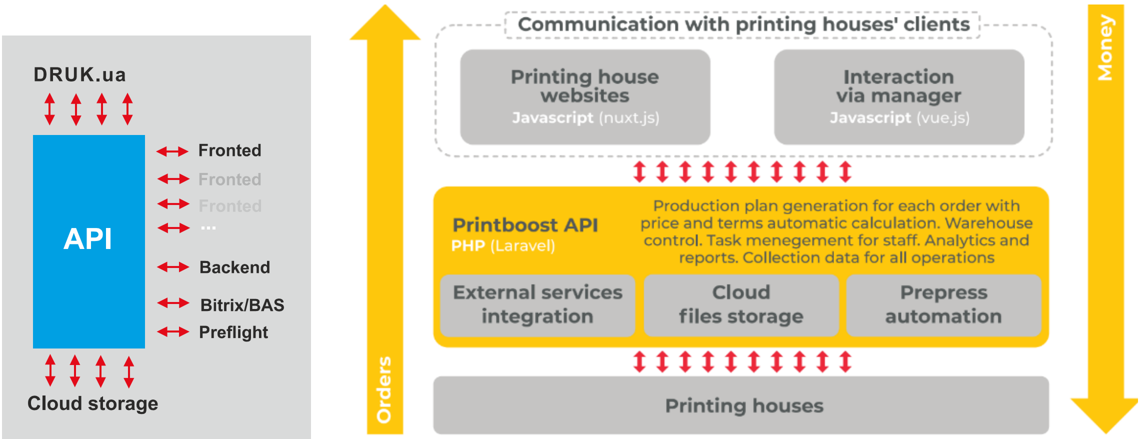
Taking the information below into the consideration, it is important to create an innovative Printboost system that will integrate modern information technologies and optimization algorithms into the management of printing processes. It should become a universal tool for automation, forecasting and increasing production efficiency, contributing to the industry's transition to a model of intelligent production.

2. General structure of the intelligent system «Printboost»

After many years of research and experiments a new innovative Printboost system, completely different from other systems, was created and it combined interests of printing companies and the final customers of printing products.

While using this innovative solution, the user can conveniently order printing products, after this step the company receives analyzed and prepared information that is easy to process and produce printed products accordingly. The intelligent innovative Printboost system is a service that was developed using design thinking (service design), in particular, interface design, design of the internal architecture of the service, experience design. The PHP and JavaScript programming languages were used to create this system.

The structural diagram of the Printboost tool is presented in Fig. 1.



a) b)

Figure 1: Structural diagram of Printboost.

The system structure consists of a number of components and elements, the interaction between which is presented in Fig. 1.

API. Printing enterprise structure. Employees and roles. Clients (individuals and enterprises). Resources and materials. Technological product flows. Texts and photos of products. Calculation of prices, terms and weight of the order. Performers' interface. Statistics. Finance management (transactions). Telephony management. File storage management. Connection to external accounting systems (Bitrix, BAS, 1c, etc.).

Frontend. Presentation of the printing company on the Internet. Availability of printing enterprise' products. User account. Interface for operations with mockups and freelancers. Adaptive interface without page reloading. Multilingualism. Any needed number of copies on the network. Functionality and appearance depending on the domain.

Bitrix24+BAS. Integration with external accounting systems using the example of Bitrix24 and BAS/1c. Ability to connect the cloud or desktop version.

Bascend. Graphical interface for API. The highly adaptive and flexible interface tool. Reports and analytics, all the numbers and graphics are in one place, which product brings in the most profits, which part of the printing company is the bottleneck, balance sheet, cash flow, profit and loss.

Preflight. Checking and converting customer files for production needs. Landing pages and artistic conversion of input files for the product. Working with cloud data storage and service providers via API and webhooks

Cloud storage. Cloud storage based on S3 protocols is supported (Amazon or local analogues).

Web2Print (Web printing). This is an intelligent innovative system specially designed for printing enterprises, which allows users to create a powerful website-store for the printing business. Due to the intuitive interface, customers will be able to quickly select the desired product, download ready-made layouts and place an order in a few clicks. In addition, the system automatically calculates the cost of printing depending on the print product quantity, which makes the ordering process transparent, clear, and as fast as possible.

Cloud MIS/ERP system for printing house. MIS (Management Information System) is an information management system. It is a centralized database where data about the company's departments, its finances, work processes and employees are collected and stored. This system automatically collects data, structures it and provides information to an authorized user in a form convenient for analysis. This significantly simplifies the management of the organization, because employees do not have to spend time collecting and sorting data, and all this happens at the software automation level. With the help of the MIS system, companies optimize the workflow. This software is used by large organizations to increase their income and the employee efficiency. ERP (Enterprise Resource Planning) is a software solution helping to manage production processes, marketing tools, accounting, personnel, etc. This is a part of MIS, which is responsible for managing production using data about the company's resources and this can be used as an independent system.

ERP (Enterprise Resource Planning) is a software solution that helps to manage production processes, marketing tools, accounting, personnel, etc. It is a part of MIS responsible for managing production using data on enterprise resources, which can be used as an independent system.

Cost calculations. Users can instantly get accurate calculations of the cost of orders and the cost of products due to the built-in ERP module. Also, users need to enter the necessary data and the system will automatically provide all the information. The system allows to check financial indicators and ensure control over costs. Programmed work algorithms make calculations even more accurate and reliable.

Generation of technological maps. After the technologist formulates the sequence of operations for the production, the system will take over all the routine. It will automatically generate a step-by-step technological list of tasks for each order, where each stage of work will be accurately taken into account: from materials and equipment to production details.

Printing company's file management. The intuitive printing enterprise file management system allows users to easily upload and organize files on the site and within the system. No need to waste time searching for the necessary documents, as they are always available in the tasks of employees. There is no more need to scroll through a lot of orders, as all files are easily accessible both in orders and in individual customer profiles. Convenient and centralized access to files will ensure efficient team work and faster order fulfillment.

Access management. The access management feature allows users to fully control access to the system functionality for each employee. By providing different levels of access, the company ensures that employees have access only to the information they need. The owner can precisely configure which actions and data will be available to each user. This allows to ensure data confidentiality and security, and optimizes the workflow, since each employee sees only what is necessary for their work.

Data security guarantee. The system provides a reliable guarantee of data security. This is ensured by the most modern information security technologies. Printing enterprise data is stored on reliable and secure Amazon servers and specialized data centers. These modern storage facilities are based on the highest security standards, including physical control, multi-level authentication procedures and data encryption.

Customer management. Due to the data management tool, companies can store and organize information about customers, their orders, contact details and preferences in one centralized place. There is a technical possibility to make changes to customer profiles, add new data and view the complete order history. This allows to provide a more personalized approach to each customer, understand their needs and provide high-quality service.

Order history management. The system provides order history management. The owner can easily view and analyze all customer orders, track the status, changes and details of each order. Full control over the process and convenient access to information is provided.

3. Mathematical model of the Printboost control system for the publishing and printing industry

Below it is presented a compact mathematical model of Printboost system management taking into account the above architecture (websites/CRM ↔ API DRUK.ua ↔ cloud/file verification/external services ↔ printing houses; «products» move up to the client, "money" — down).

3.1. Notation

Plurals. O – order; S – process stages (fc – file check, fp – file processing, prp – prepress, prn – print, pst – postpress, pkg – packaging, dlv – delivery);

M_s – equipment/nodes for stage s; E – external services (acquiring/delivery); G – materials.

Parameters. r_o – arrival time (from websites/CRM); d_o – desired deadline; b_o – file volume/size; w_o – product weight;
p_{osm} – processing time o on machine $m \in M_s$; $\sigma_{oo'sm}$ – changeover time (sequence-dependent, e.g., ink/format change);
t_{oe} – transport time of service e for o; c_{og}^{mat} – material costs; κ_m – machine-hour cost; $c_{oe}^{\exp}$ – external costs (delivery, etc.);
$\alpha \in (0,1)$ – acquiring fee (part of price); B – available cloud storage capacity;
$U_s(o) \in \{0,1\}$ – if stage s is needed for o.

Variables. $a_o \in \{0,1\}$ – accept the order; $y_{osm} \in \{0,1\}$ – machine selection;
s_{os},. $f_{os} \geq 0$ – start/end of the stage; $z_{oo'sm} \in \{0,1\}$ – order o before o' on (s, m);
$q_{oe} \in \{0,1\}$ – external service selection; $\tau_o \geq 0$ – promised deadline; $T_o \geq 0$ – delay;
$P_o \geq 0$ – price for the customer; $c_{og}^{mat} = \sum_g c_{og}^{mat}$ – material costs.

3.2. Restrictions

(A) Purpose and duration

$$\sum_{m \in M_s} y_{osm} = a_o U_s(o), \forall\ _o, s \tag{1}$$

$$f_{os} = s_{os} + \sum_{m \in M_s} y_{osm} p_{osm}, \forall\ _o, s \tag{2}$$

(B) Stage progression (technological process logic)

$$S_{os+} \geq f_{os}, \forall\ _o, s \rightarrow s^+ \in S \text{ with the route o} \tag{3}$$

(C) Machine capacities (disjunctive constraints)
for all o ≠ o′, s, m ∈ Ms:

$$s_{o's} \geq f_{os} + \sigma_{oo'sm} - M\left(1 - z_{oo'sm}\right) - M\left(2 - y_{osm} - y_{o'sm}\right) \tag{4}$$

$$s_{os} \geq f_{o's} + \sigma_{o'osm} - M\left(2 - y_{osm} - y_{o'sm}\right) \tag{5}$$

(D) Delivery and time

$$\sum_{e \in E} q_{oe} = a_o, \tag{6}$$

$$C_o = f_{o,last} + \sum_e q_{oe} t_{oe}, \tag{7}$$

$$T_o \geq C_o - \tau_o, T_o \geq 0 \tag{8}$$

(where *last* is the last production stage for o).
(E) Cloud and file services
(approximation of capacity at the planning horizon)

$$\sum_o a_o b_o \leq B \tag{9}$$

This can easily be extended to step-by-step capacity if needed via additional binary "file active at time" variables.

(F) Materials

$$\sum_{o} a_o c_{og}^{mat} \le \quad available\ \ budget / stock \quad for\ g,\ \forall_{\ g} \tag{10}$$

(G) Pricing with acquiring taking into account
(price has to cover costs and commission; linear due to α)

$$P_o(1-\alpha) \ge C_o^{mat} + \sum_{s,m} k_m p_{osm} y_{osm} + \sum_{e} q_{oe} c_{oe}^{\exp}\ \forall_{\ o} \tag{11}$$

If necessary, a minimum profit $P_o \ge (1+\mu_o)\ \times$ cost is added.
(H) SLA quoting (API DRUK engine ⟶ «promised timeline»)

$$\tau_o \ge r_o + \hat{T}_o^{cyc},\ \forall_{\ o} \tag{12}$$

where $\hat{T}_o^{cyc}$ - is the predicted cycle time (from the model / ML prediction) generated by the API module during online calculation.

3.3. Objective function

Maximization of profit taking into account penalties for delays (SLA) and, optionally, customer priorities:

$$max \sum_{o} a_o \left[P_o(1-\alpha) - C_o^{mat} - \sum_{e} k_m p_{osm} y_{osm} - \sum_{e} q_{oe} c_{oe}^{ext} \right] - \sum_{o} \beta_o T_o \tag{13}$$

where β_o is the cost of a deadline violation (penalty/loss of loyalty).

3.4. Architecture visualization

Websites/CRM ⇄ API DRUK: generate r_o, d_o, b_o, w_o; the online calculation module solves a simplified version of the problem (e.g., with fixed y_{osm} or with aggregated capacities) to obtain (τ_o, P_o).
File verification/processing, cloud: stages $s \in$ {fc,fp} with capacity limit B and machines M_{fc}, M_{fp}.
Printing houses: stages *prp/prn/pst/pkg* with classical *JSSP*-logic (constraint C).
External services: selection of q_{oe} and time/cost t_{oe}, c_{oe}^{ext}.
Cash flow: included in (G) and objectives; commission α models acquiring.

The proposed mathematical model of the Printboost system for the publishing and printing industry reflects the interaction between key components of the architecture namely from accepting an order via the DRUK API to file processing, managing production resources and integrating with external delivery and acquiring services. The model formalizes the main business processes through a system of constraints: resource assignment, technological sequence of operations, material balance, cloud storage capacity limitations and customer obligations. Thus, the model combines economic, logistical and technological aspects of the printing house's operation, providing a single basis for making management decisions.

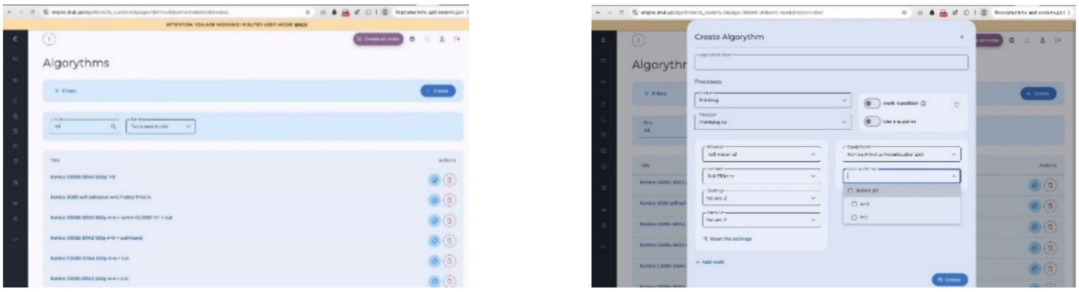
The practical use of the model allows the optimization of equipment loading, rational selection of orders, formation of competitive price offers and forecasting of execution times. This creates the prerequisites for the implementation of the Printboost intelligent innovative management system, which will contribute to increasing the efficiency and competitiveness of printing industry enterprises in the conditions of digital transformation.

4. Algorithms of work in the intelligent innovative Printboost system

Algorithms are a sequence of operations that are necessary to manufacture a product and the operations include equipment and materials with the necessary characteristics. In order for the system to understand how to manufacture a particular product, it is important to create algorithms correctly. The algorithm includes the characteristics of materials and equipment for performing a specific operation. Also, it is essential to remember that the algorithm refers to the production of one part (Fig. 2). Since the product can consist of several parts, there can be several algorithms. Also, the post-printing processing stage often includes an assembly algorithm, which is later added to both the technological map and the product calculation.

In the Printboost system, there are two options for creating an algorithm: 1 – from the algorithm library level. Users go to Library ⟶ Algorithms. In order to create a new algorithm, click the Create button (Fig. 2a).

In the new window, users select the operations that should be included in this algorithm, and also give it a name (Fig. 2b). It is better to add to the name unique characteristics that are included in this algorithm. Then it will be easier to search for the necessary algorithms for the production of product parts. For example, if the algorithm uses coated paper 300 g/m2, double-sided color printing, and this algorithm also includes cutting, lamination, or other operations, then it is better to add this to the name.



a) b)

Figure 2: Creation of an algorithm: a) - list of algorithms; b) - formation of the name and list of operations in the algorithm.

After the «Algorithm name» is already created, all the operations for this algorithm are added one after another (for example, the simplest algorithm is to print and then to cut). That means that the first process is the sheet printing that has a list of materials and equipment, from which users select the one that is needed for this algorithm. After that, the characteristics that were previously set in the library according to the materials and equipment are set up for the material and equipment. If the characteristic has only one value, then the selection will be inactive. Otherwise, users can select the desired value from the drop-down list.

Similarly, we add the «Cutting» operation. In this operation, only one type of equipment with one characteristic is specified, so the selection will be made automatically. After all operations have been added, click the Save button (Fig. 3).

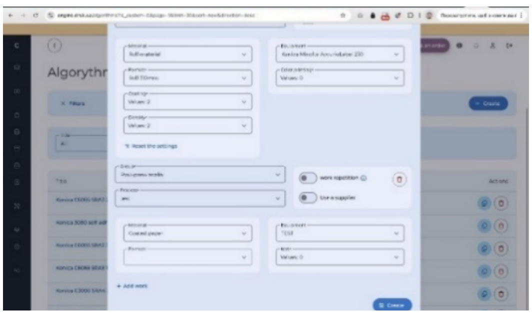
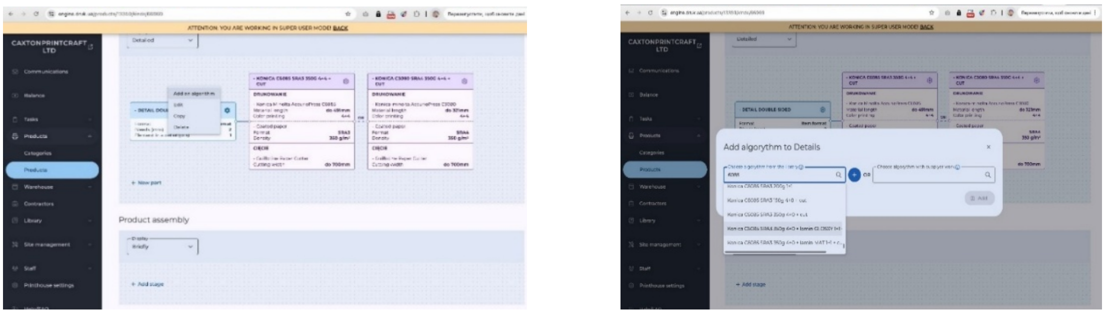


Figure 3: Selection of operations in the algorithm.

The second option for creating an algorithm is connected with the product level and its details. Users go to the product and type for which they want to configure the algorithm. Then the action is to click the button next to the desired detail and select «Add algorithm» from the menu (Fig. 4a).

In the new window, users can select the desired algorithm from the algorithm library. If there is no such an algorithm, users click the «Add» button (Fig. 4b).

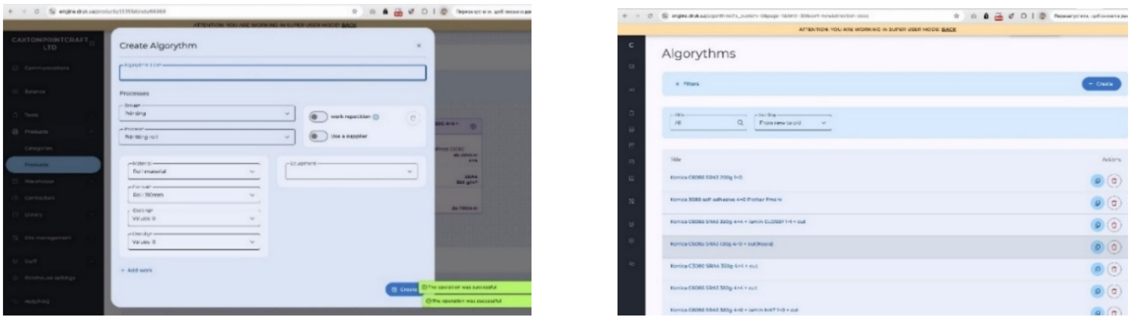


a) b)

Figure 4: Adding an algorithma: a) – add algorithm; b) – add algorithm to part.

The standard algorithm creation window will be opened. After filling it in, click the «Create» button (Fig. 5a).

At any time, users can edit the desired algorithm or delete it. There are two options for editing an algorithm: 1) edit from the algorithm library. In this case, users just click on the desired algorithm (Fig. 5b).



a) b)

Figure 5: Second version of algorithm creation: a) – create an algorithm; b) – invocation of the algorithm name

The algorithm details will open in a new window. Users click «Edit algorithm» and make the necessary changes or delete the algorithm (Fig. 6).

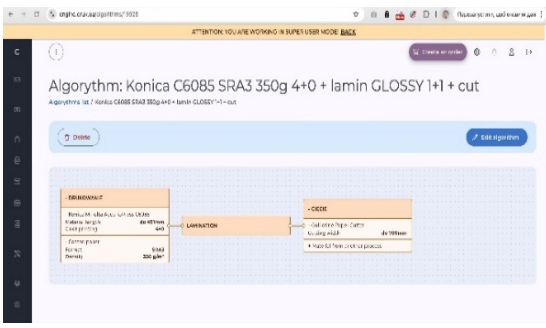


Figure 6: Editing or deleting an algorithm

The second option is the editing in the product manufacturing levels. Here users go through the desired product, where the algorithm has already been added. The action is to click on the gear next to the desired algorithm, select «Edit» and make the necessary changes (Fig. 7). These changes will be assigned to the whole algorithm.

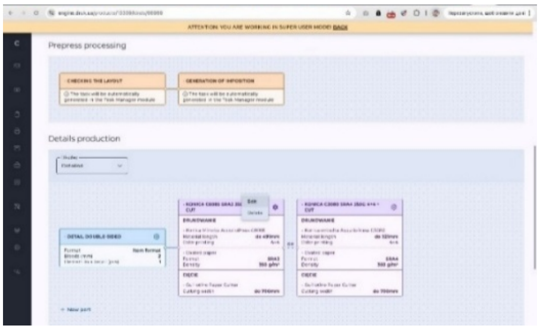


Figure 7: Editing an algorithm.

The Printboost system guarantees the correctness of the compilation and verification of technological maps using an algorithm library, which provides: 1) algorithm architecture: each stage (prepress/press/postpress/packaging) has algorithm(s) with clear interfaces: input parameters → rules → output/metrics/errors; the Algorithm Library is a verified catalogue; the Rule Engine combines business rules (SLA, economics, security) with technological constraints (materials, formats, machines, ICC profiles, approvals); 2) verification rules: typing and ranges: all fields of the technical map are strictly typed; validators check ranges and units of measurement; node compatibility: ICC profile ↔ material; linework ↔ anilox; ink ↔ substrate; format ↔ sheet/roll; minimum cut margins ↔ machine; route integrity: each step has defined input/output; all mandatory operations are present (preflight → trapping → imposition → proof → CTP/CDI → printing → varnish/finishing → cutting/gluing); invariants as protection against "silent" errors: minimum pin, minimum line width, minimum indents, registration approvals, maximum speeds; SLA rules: deadlines ↔ available changes/resources; automatic recalculation of buffers and priorities; economic constraints: cost/price calculation is not separated from the map as the validator controls consistency (materials ↔ cost norms).

The usage of design thinking and service design methodologies, in particular, in-depth interview techniques or Customer journey map analysis (a concept of describing and using data about the customers' path they take from the moment of the very first contact with the company to the loyal customers status), made it possible to make the service as convenient as possible for customers and significantly reduce processing time and the number of errors.

5. Model of factors for the process of selecting a control system within a publishing and printing enterprise using the ranking method

To further verify the compliance of the developed Printboost system with modern requirements, a factor model for selecting a management system for a publishing and printing enterprise was synthesized using the ranking method.

To identify the key factors influencing the choice of management systems in the publishing and printing industry, a survey was conducted among over one hundred printing enterprise managers. Based on the survey results, the most critical factors, as perceived by the enterprise leaders, include the following:

1. Scale of production (small, medium and large printing enterprises);
2. Price of the basic system configuration;
3. System modularity (the ability to purchase only the necessary modules);
4. Possibility of further updates of the system;
5. Printing method;
6. Economic effect of implementation;
7. Specialization by product types;
8. Implementation terms.

The aforementioned factors, which play a crucial role in selecting a management system for a publishing and printing enterprise, can be represented using a set of linguistic variables. This selection process serves as an imprecise analogue of the factors influencing any arbitrary process. The authors of the article interpret the procedure of choosing a management system as a function, where the previously identified factors act as its arguments.

$$P = F(s_1, s_2, s_3, s_4, s_5, s_6, s_7, s_8) \quad (14)$$

where s_1 – scale of production (SP); s_2 – price of the basic system configuration (PC); s_3 – system modularity (SM); s_4 – possibility of further updates of the system (PU); s_5 – printing method (PM); s_6 – economic effect (EE); s_7 – specialization by product types (SP); s_8 – implementation terms (IT).

The identified factors are categorized as linguistic variables based on their terminology and essence, serving as parameters that influence the selection of a management system for a publishing and printing enterprise. To analyze these relationships, the authors developed an input graphical model in the form of a directed graph, incorporating expert evaluations of the pairwise influence and interconnections between the factors (14).

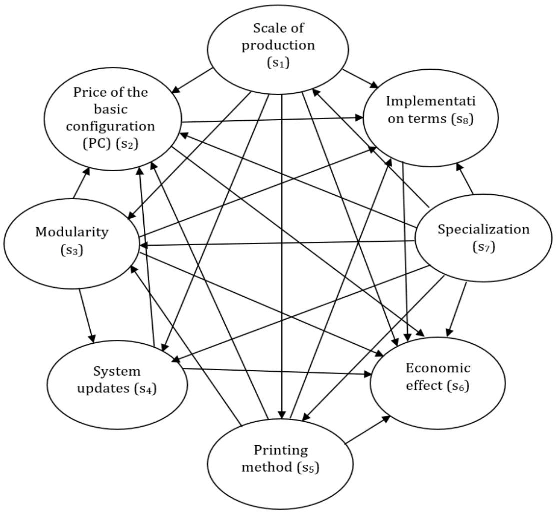


Figure 8: The initial graph of relationships between factors influencing the process of choosing a management system for a publishing and printing enterprise

To resolve these contradictions, the method [21] was applied, which considers not only the number of influences or dependencies between factors but also differentiates their types by assigning varying expert weights to each. The essence of the proposed factor ranking method, which evaluates the impact on the quality of implementing arbitrary technological processes, will be demonstrated using the analysis of relationships between factors influencing the choice of a management system.

Based on the definitiona and statements described [22], there are given conditions that for $D(w) \equiv w_j > w_{j+1}$ for $(j = 1, 2, \dots, n - 1)$ the following entry will be valid:

$$(\forall\ w) D(w); w \in W \quad (15)$$

The synthesis of the factor priority influence model on the technological process is carried out by identiifying key factors specific to the process, constructing and analyzing an initial graphical model, and processing expert assessments that define relationships between factors. The number of factors and their conditional weights, based on different types of relationships, ultimately determine their priority impact on the process.

The proposed mathematical model is based on numerical indicators that reflect the number of influences and dependencies between factors, along with their corresponding weight coefficients. In this approach, the authors distinguish direct influences, referred to as 1st-order influences, and indirect influences, classified as 2nd-order. Similarly, dependencies are categorized into 1st and 2nd orders, with levels of importance also taken into account.

To determine the total weight values of both direct and indirect influences of factors, as well as their overall dependence on other factors, the authors introduce appropriate notations. Let kijk_{ij} kij represent the number of influences or dependencies between j factor ($j=1,\ldots,n$); w_i is the weight of the i type.

In this context, the authors classify the relationships between factors based on the value of the relationship type index. This classification allows for distinguishing different types of interactions, which influence the prioritization and weighting of factors in the selection process, i.e.: $i=1$ is 1st-order influences; $i=2$ is 2nd-order influences; $i=3$ is 1st-order dependencies; $i=4$ is 2nd-order dependencies.

For the calculations, the authors assign specific conditional values to the weight coefficients based on the types of dependencies. It is assumed that the weights for both types of influences will be positive, ensuring that their impact on the selection process is quantitatively accounted for, i.e. $w_1>0$, $w_2=\frac{w_1}{2}$, respectively, for the dependencies will be negative, namely: $w_3<0$, $w_4=\frac{w_3}{2}$. The integral weight values of the factors by the sums of the weights of all types of relationships will be denoted as S_{ij}.

Finally, the authors derive the following formula for calculations, incorporating the assigned weight coefficients and relationship types to quantify the total influence and dependence of factors within the model:

$$S_{ij}=\sum_{i=1}^{4}\sum_{j=1}^{n}k_{ij}w_i \tag{16}$$

where n is a conditional number of the management system selection factor.

If a certain type of relationship is absent due to some factor, the corresponding value kijk_{ij}kij in expression (16) will clearly be zero. This formula forms the foundation for determining weight values, which serve as the basis for ranking factors while considering the different types of relationships between them.

Since, based on the given initial conditions, $w_3<0$ i $w_4<0$, the corresponding partial sums will also have a negative value: $S_{3j}<0$ i $S_{4j}<0$. To adjust the weight values of the factors "to the origin," ensuring they are positive, it is necessary to conditionally shift the histogram of the integral graphical representation of all types of relationships upward. This requires introducing a correction, which is determined based on the following relation:

$$\Delta_j=max\left|S_{3j}\right|+max\left|S_{4j}\right|,\left(j=1,2,\ldots,n\right) \tag{17}$$

Taking into account (17), the final calculation formula for obtaining the final weight values of the factors will look like this:

$$S_{Fj}=\sum_{i=1}^{4}\sum_{j=1}^{n}\left(k_{ij}w_i+\Delta_j\right) \tag{18}$$

The values S_{Fj} serve as the basis for ranking weights, i.e., establishing the levels of factors in the technological process, which enables the synthesis of a resulting model that prioritizes the influence of factors on the studied process. Based on this model and the scale of relative importance of objects [22], a matrix of pairwise comparisons is constructed [22], the analysis of which leads to an optimized model for ensuring the quality of the technological process.

For further discussion, the authors will utilize the original graph of relationships between factors (see Fig. 9). Using this graph as a foundation, they will construct hierarchical trees of relationships for each factor, considering both direct and indirect influences.

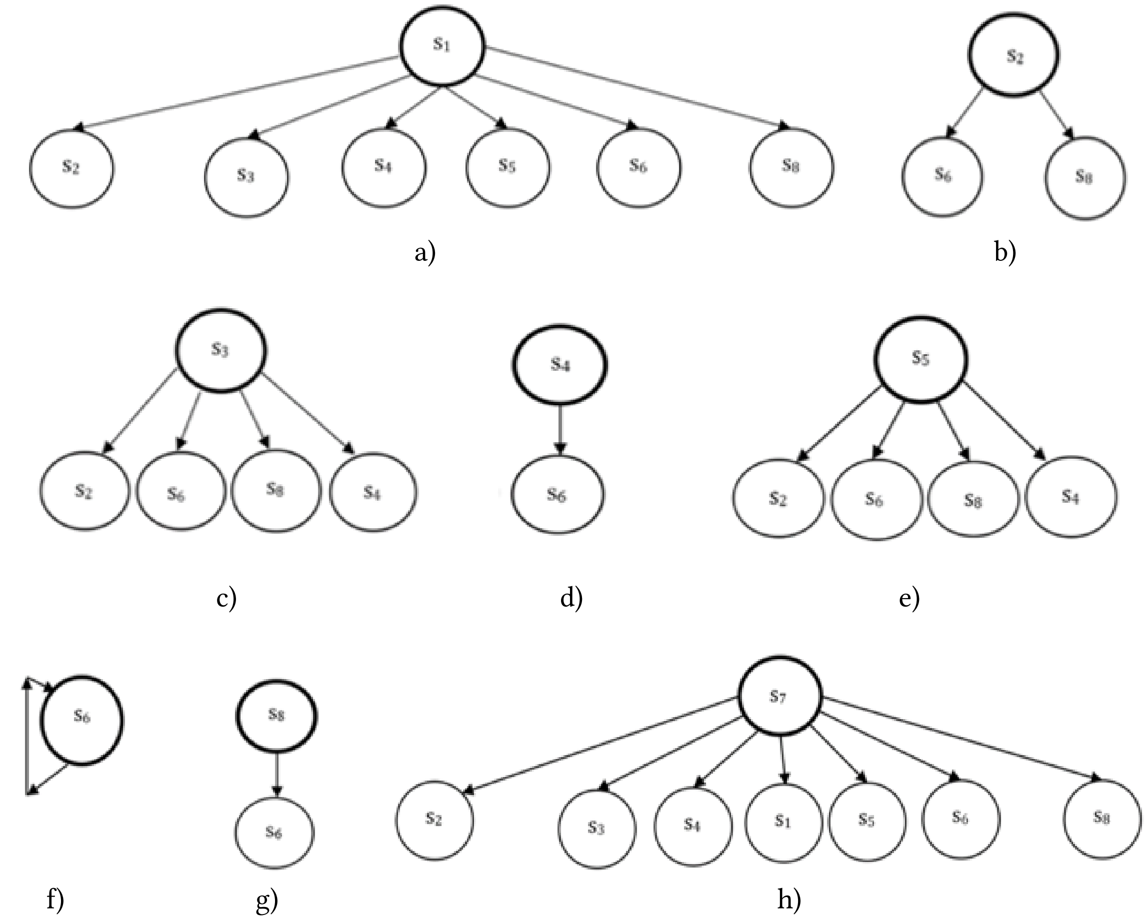


Figure 9: Graphs of multi-level hierarchical relationships for factors of the selecting a management system process for a publishing and printing enterprise: a) – h).

Option f) represents the absence of influence of factor s6s_6s6 (economic effect) on other factors, meaning its connection forms a loop.

The total weight values of direct and indirect influences of factors, as well as their integral dependence on other factors, were calculated, considering the notation and conditions introduced above.

For the calculations, the authors will assume the following conditional values for weight coefficients in conventional units: $w_1 = 10$, $w_2 = 5$, $w_3 = -10$,$w_4 = -5$.

As a result, for the original graph in Fig. 1, taking into account (3), authors obtain an expression for calculating the intermediate total values of factor weights:

$$S_{ij} = \sum_{i=1}^{4} \sum_{j=1}^{8} k_{ij} w_i \tag{19}$$

Taking into account (19), the authors obtain partial sums of factor weights, calculate the correction for negative sum values, and, based on (18), construct Table (1), which establishes the ranks of factors and their corresponding levels of priority influence on the process of implementing descents. As can be seen from Table (1), 1, $max\left|S_{3j}\right| = 40; max\left|S_{4j}\right| = 15$. The specified values are added in each row to the partial total values of the weights in the columns S_{1j}, $S_{2j} S_{3j}$, та S_{4j}. The resulting weight S_{Fj} serves as a basis for the factor rank set up r_j and its level, that is equal to the factor influence priority on the process of the management system choice (table 1).

Table 1
Estimated data and ranking of factors influencing the process of selecting a management system

Number of factor j	k_{1j}	k_{2j}	k_{3j}	k_{4j}	S_{1j}	S_{2j}	S_{3j}	S_{4j}	S_{Fj}	Rank of factor	Priority level
1	6	0	1	0	60	0	-10	0	105	7	2
2	4	2	2	0	40	10	-20	0	85	6	3
3	2	0	2	0	20	0	-20	0	55	3	6
4	1	0	4	0	10	0	-40	0	25	1	8
5	4	0	2	0	40	0	-20	0	80	5	4
6	0	0	6	0	0	0	-60	0	35	2	7
7	1	0	0	0	10	0	0	0	65	4	5
8	7	0	1	1	70	0	-10	-5	110	8	1

The use of data from the "Rank of factor" column makes it possible to construct a multilevel model that prioritizes the influence of factors on the process of selecting a management system (Fig. 10).

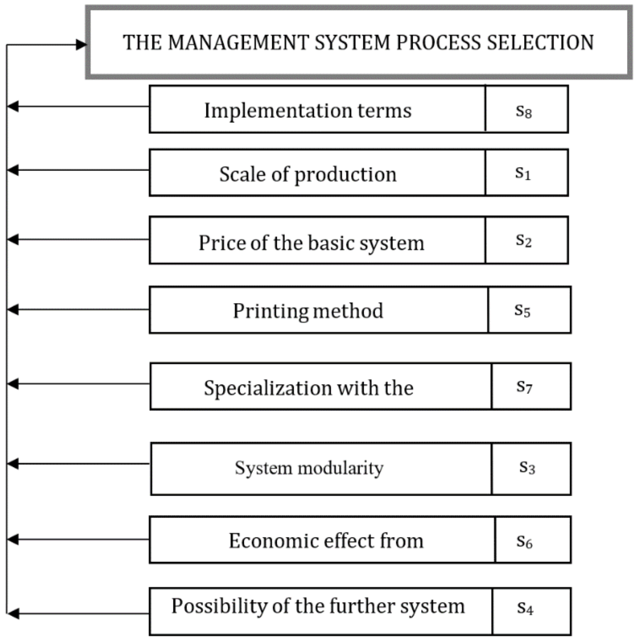


Figure 10: Model of priority influence of factors on the selection of management system.

Thus, as a result of applying the ranking method, the ranks of factors were determined, forming the basis for synthesizing a multilevel model of their priority influence on the selection of a management system. The proposed ranking method enables the systematization and prioritization of factors affecting the choice of a management system for a publishing and printing enterprise.

The developed model can be used to make informed decisions in selecting the optimal management system, ultimately contributing to increased enterprise efficiency.

The intelligent PrintBoost system, designed using innovative principles, meets the requirements of modern automated production in the publishing and printing industry while aligning with the expectations of printing company managers.

6. Conclusion

The analysis of the current conditions of the publishing and printing industry showed that traditional management systems do not provide sufficient flexibility, data integration, and optimization of production processes. This creates a need for the implementation of intelligent innovative solutions to increase the efficiency of enterprises.

The development of the Printboost as an intelligent system, which is based on the principles of design thinking, service design, and UI/UX design, allows users to integrate data from all stages of the production process, automate planning and control, improve product quality, and most importantly, the tool has a flexible modular structure and customer-production interconnection.

The integration of intelligent algorithms into the Printboost system was ensured, which allows users to automatically optimize the use of resources (materials, equipment, human resources) and minimize production costs while maintaining high quality of the final product. The analysis confirmed that the use of Printboost allows users to increase the productivity of publishing and printing enterprises by 15–25%, reduce equipment downtime, reduce the percentage of defects, and also provide a more flexible response to the individual needs of customers.

The indicator of the productivity increase in the Printboost system by 15–25% was determined based on the results of comparative experimental modeling and implementation of the system prototype at a printing enterprise. To analyze the effectiveness of Printboost, a comparative method “before/after” (baseline vs optimized) has been used, which included three stages: the basic scenario (AS-IS) meaning the operation of the enterprise without Printboost, with traditional workflow systems and manual planning; the optimized scenario (TO-BE) meaning work with the integrated Printboost system, which implements automated planning, MILP optimization, CRM integration and the DRUK API; comparison of key performance indicators (KPI) for identical or simulated orders.

The increase in productivity by 15–25% happens due to a combination of the following factors: automated scheduling and resource assignment (MILP module); reduction of downtime and waiting time between workflow stages; elimination of manual data entry via CRM-API connection; increasing the accuracy of forecasting deadlines (SLA control).

The Printboost intelligent management system contributes to the transition of printing enterprises to the "smart production" model, increasing their competitiveness, flexibility and strategic stability within the market.

The implementation of the innovative Printboost system at a printing company, the system which is developed based on the principles of design thinking, service design and UI/UX design, allows companies to automate labor-intensive processes: quickly perform calculations, prepare mockups for printing in one click, simply manage orders and production.

The developed algorithms for the printing products manufacturing are formed for a specific type of equipment, types of work performed by employees, in particular, there are no restrictions on the number of employees, equipment and materials.

The ranking method allowed to determine the most significant factors for the management system choosing and build a multi-level model that takes into account their influence.

Thus, the Printboost intelligent innovative management system is a promising tool for increasing the efficiency and competitiveness of publishing and printing enterprises, and its implementation will contribute to the digital transformation of the industry as a whole.

Declaration on Generative AI

The authors have not employed any Generative AI tools.

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