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APPLICATION OF AI DRIVEN SYSTEM FOR ESTIMATION OF ORDERS IN THE PRINTING INDUSTRY

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Abstract

Printing enterprises face growing competition, rapid tech progress, and higher demands for efficiency and quality. In this context, fast and accurate order evaluation is essential for resource optimization, cost reduction, and competitiveness. Traditional methods – manual input, expert judgment, and classic financial models – are labor-intensive, inflexible, and poorly suited to today's diverse technologies.

Intelligent information systems offer significant value by automating data analysis, revealing hidden patterns, and supporting informed decision-making. Their use streamlines production, lowers costs, and boosts financial performance.

Although many printing stages (prepress, color management, quality control) are automated, smart order estimation remains underdeveloped – creating bottlenecks, especially for small and medium print runs.

This article presents the adaptation of the Flex Estimate AI system for the printing industry. Initially designed for IT project evaluation, the system was enhanced with machine learning and data mining to deliver automated, transparent, and accurate order assessment. Its adoption improves planning, optimizes workflows, and strengthens business resilience during digital transformation.

Keywords: *artificial intelligence, optimization, printing, estimates, order management*

Relevance of the problem

Modern printing enterprises operate in a highly competitive environment characterized by rapid technological change and increasing demand for speed, accuracy, and quality. Traditional methods of order evaluation – based on manual input, expert assessments, and static financial indicators – are insufficiently responsive, often resulting in delays and inefficiencies. While automation has advanced in areas such as prepress and ERP systems, the domain of project estimation remains underdeveloped, particularly for small and medium print runs where prompt responses are essential.

This study proposes a scientific framework and system architecture for intelligent order evaluation in the printing industry, integrating machine learning, natural language processing (NLP), and multi-criteria optimization. The developed system − Flex Estimate AI − automates data acquisition, preprocessing, classification, cost prediction, and lead time forecasting, enabling dynamic and scalable estimation workflows.

The research objectives include the critical analysis of existing evaluation methods, investigation of AI algorithms applicable to cost and timing predictions, and the design and implementation of a modular prototype incorporating forecasting, optimization, and dynamic pricing. Empirical validation was conducted using real production data, assessing predictive accuracy and economic efficiency.

Scientific novelty lies in the application of self-learning models and AI-driven analytics to dynamically adapt estimation processes to varying production contexts. The system utilizes regression models for forecasting, classification for order profiling, clustering for production optimization, and NLP for automated analysis of textual specifications.

The proposed solution significantly improves estimation speed and precision, enhancing planning agility and operational efficiency. Flex Estimate AI thus contributes to the broader digital transformation of the printing sector and demonstrates potential for scalability in adjacent domains such as packaging and customized production workflows.

Purpose of the system

Flex Estimate AI is an intelligent information system developed to enhance the speed and accuracy of project estimation through advanced artificial intelligence techniques. Initially designed for IT applications, the system has been adapted for the printing industry, where prompt and precise estimation is essential for maintaining competitiveness. Its modular architecture enables customization to industry-specific operational requirements.

The system automates the acquisition, processing, and evaluation of project data with minimal human intervention. By leveraging AI-driven data analysis, it improves estimation accuracy, minimizes human error, accelerates response times, and supports resource optimization. Key functionalities include:

- Automated extraction and processing of technical and order-specific parameters.
- Predictive modeling (e.g., regression analysis) for lead time and cost estimation.
- Project classification and clustering for effective planning.

- Natural language processing (NLP) to interpret textual specifications.
- Generation of client-ready commercial proposals in real time.

In printing enterprises, the application of Flex Estimate AI enables:
- Significant reduction in quotation preparation time.
- Enhanced estimation accuracy via adaptive AI models.
- Efficient utilization of production resources and reduction of downtime.
- Improved order conversion rates and cost-effective production planning.

The system integrates real-time data on machine availability, material stocks, and current workloads to deliver context-aware estimations. It evaluates technological capabilities – press types, finishing options, inventory levels – to generate feasible, optimized production plans.

Furthermore, the system identifies optimal production slots by analyzing existing and scheduled runs, offering fulfillment strategies based on either cost minimization or lead-time reduction. This supports dynamic capacity allocation and responsive order management.

By transitioning from manual calculation to AI-based estimation, Flex Estimate AI promotes proactive decision-making grounded in data analytics and predictive modeling. It enhances the adaptability and operational efficiency of printing enterprises within rapidly evolving market conditions.

Requirements for system functions

Flex Estimate AI is architected to fulfill stringent computational, functional, and integration requirements for real-time, high-precision order estimation in print manufacturing environments. The system integrates machine learning, optimization theory, and natural language processing (NLP) into a modular, scalable architecture optimized for enterprise interoperability and adaptive performance.

Order data is ingested through standardized APIs connected to CRM, ERP, and WMS systems. Unstructured text inputs are processed using NLP techniques – specifically Named Entity Recognition and semantic parsing– to extract and normalize key production parameters. This preprocessing enables downstream computational modeling without operator input.

The system employs regression models trained on historical operational data to predict lead times and production costs, incorporating variables such as equipment load, task complexity, and process type. Graph-based scheduling algorithms are used to model the production environment as a resource-constrained network, enabling optimized task sequencing while minimizing idle time and changeover overhead.

Inventory forecasting is handled through time-series analysis, enabling predictive material management and reduction of stock-related delays. Cost estimation combines deterministic calculations for direct inputs and stochastic models for variable overheads, yielding comprehensive order-level financial projections.

Multi-scenario evaluation is performed using Pareto-based multi-objective optimization, supporting cost-time-resource trade-offs. A dynamic pricing engine utilizes supervised learning to generate adaptive quotations based on market factors and operational constraints.

The system supports business logic reconfiguration through a rules engine, ensuring adaptability across print formats without altering the core architecture. Modular services communicate through standardized data formats (JSON, XML, CSV), ensuring seamless integration and deployment across heterogeneous IT infrastructures.

Flex Estimate AI thus formalizes and automates the order evaluation workflow using robust AI-driven methods, achieving higher accuracy, reduced turnaround times, and improved resource utilization in digitally transformed print enterprises.

Overview of analogs

The global market for printing industry information systems includes numerous platforms for automating production, management, and commercial workflows (Kovtunenko, 2019). Leading solutions include Heidelberg Prinect, EFI Pace, Optimus MIS, PrintVis, PressWise, and Accura MIS, each catering to different scales of operations.

Heidelberg Prinect offers deep integration across prepress, press, and postpress with modules for planning, costing, and quality control. Despite high automation, its order evaluation relies on fixed scenarios and rate tables, limiting flexibility for urgent or non-standard jobs (2).

EFI Pace is scalable and suitable for larger operations, supporting comprehensive order and warehouse management. However, it lacks machine learning-based estimation and depends on static tariffs.

Optimus MIS features modularity and flexible production routing, appealing to small and mid-sized print shops. Still, its order estimation often requires manual input and lacks predictive analytics.

PrintVis, built on Microsoft Dynamics 365, excels in enterprise-level financial integration and process control. Yet, it relies on manual flowchart selection for costing without dynamic optimization or forecasting.

PressWise, a cloud MIS/ERP for SMEs, provides essential automation but limited support for adaptive, AI-driven evaluation models.

Accura MIS is designed for entry-level digitalization, offering basic order, CRM, and planning features. However, it lacks intelligent estimation tools, relying on static templates with minimal real-time adaptability.

Thus, the analysis of existing solutions allows us to draw the following conclusions;

- all major MIS/ERP systems are primarily focused on managing production and accounting processes rather than intelligent pre-qualification of new orders;
- assessment processes in existing systems are based mainly on static reference books of norms and tariffs, without the use of predictive analytics, machine learning and intelligent forecasting technologies;
- there is practically no adaptability of order calculation to the current production load and real-time material balances;
- integration with external data sources (online ordering platforms, electronic document management systems) is often limited or requires the development of additional modules;

Against this background, the Flex Estimate AI system offers a fundamentally different approach;

- Using machine learning to build models for predicting the timing and cost of projects based on accumulated data;
- application of clustering and classification of orders for optimal selection of technological routes of production;
- Integration of Natural Language Processing (NLP) technologies for automatic analysis of textual specifications;
- seamless integration via API with existing CRM, ERP and Prepress enterprise systems;
- construction of multi-scenario evaluations (cost minimization, time minimization, resource optimization) in automatic mode.

Flex Estimate AI does not replace full-featured ERP/MIS-systems, but becomes their powerful complement, which closes the most critical task of modern business – rapid, accurate and intelligent assessment of orders in the printing industry.

Review of methods and criteria for assessing the effectiveness of orders

Effective order valuation is a key element of successful planning, resourcing and management decision making in the printing industry. Traditional methods of financial evaluation were developed mainly in the middle of the 20th century and have since become firmly embedded in the practice of economic analysis.

Let us consider the main methods, their theoretical basis, advantages and limitations in the context of today's dynamic market (Nagorny, P., Baziuk O., 2023).

One of the basic tools is the Net Present Value (NPV) method. It is based on the calculation of the present value of all expected cash flows from an order, taking into account the discount rate. The calculation formula is as follows (1):

$$\sum_{t=0}^{n} \frac{CF_t}{(1+r)^t} - C_0, \quad (1)$$

where CF_t is the cash flow at time t, r is the discount rate, C_0 is the initial investment. A positive NPV value indicates the feasibility of order fulfillment.

The scientific basis of the NPV method includes the time value of money theory, according to which the cost of capital decreases over time due to inflation, risks and opportunity costs. The method is the most accurate among traditional methods, as it takes into account the dynamics of cash flows throughout the life cycle of an order.

However, in the printing industry environment, the NPV method has a number of limitations:

- requires accurate cash flow forecasts, which is difficult with high fluctuations in demand and volatile material prices;
- is of little use for small and short-term orders, where the speed of capital turnover rather than long-term profitability is of primary importance;
- Does not consider multi-criteria factors such as production utilization, lead time or level of technology risk.

Another important indicator is the Internal Rate of Return (IRR) − the discount rate at which the NPV of the order is zero. IRR allows to quickly assess the attractiveness of the order in comparison with alternative investments.

Formally, IRR is solved from equation (2):

$$0 = \sum_{t=0}^{n} \frac{CF_t}{(1+IRR)^t} - C_0 \quad (2)$$

The scientific validity of IRR is based on the concept of maximizing return on capital with minimal risks. However, for real printing orders IRR can give false guidance in case of uneven flows or in orders with several changes of sign of cash flows, which reduces the accuracy of its application.

The third widely used indicator is Profitability Index (PI), calculated as the ratio of the present value of future income to the initial investment (3):

$$PI = \frac{NPR + C_0}{C_0}. \quad (3)$$

PI allows comparing the efficiency of several orders with limited investment resources, but just like NPV, it depends on the quality of forecasts.

Payback Period (PP) is another traditional criterion that determines the time it takes for an order to recover its initial investment. Although simple to calculate, the method ignores cash flows after the payback period and does not take into account the time value of money, which limits its application in strategic planning.

Limitations of traditional methods in a real printing environment

In today's printing industry, each order represents not just a financial transaction, but a complex production task influenced by equipment load, material availability, lead times, and urgency. As demonstrated in recent case studies (Kostaryev D. B., Tevyashev A. D., Sizova N. D., & Tkachenko, 2024), effective production optimization requires far more than calculating direct profitability – it demands real-time insight into machine (Bagan, T. G. 2021) center utilization, available time slots, changeover requirements, and multi-stage technological workflows.

Traditional evaluation methods fall short in handling such complexity. Intelligent systems like Flex Estimate AI address these gaps by applying advanced methods:

- Machine learning models predict lead times and costs using historical data;
- Clustering algorithms group orders by complexity and urgency to enhance planning;
- Integration with ERP, CRM, and prepress systems ensures up-to-date data on materials, capacities, and schedules;
- Natural Language Processing (NLP) extracts key parameters from unstructured specifications automatically.

Flex Estimate AI simulates the production environment as a serial-parallel process, with different operations executed in sequence or simultaneously. Accurate order estimation thus requires analysis of equipment availability, changeover times, process synchronization, and load balancing.

Key efficiency metrics – total order lead time, number of changeovers, and machine downtime – are all driven by the accuracy of the initial evaluation. Consequently, intelligent estimation evolves into a strategic instrument for improving production throughput and profitability.

From a production planning perspective, print orders consist of constrained, interdependent operations. Effective optimization involves:

- Constructing optimal production routes (job-shop scheduling.
- Minimizing setup times and idle intervals.
- Maximizing equipment utilization while meeting deadline requirements.

Given the combination of sequential and parallel processes (e.g., printing, folding, gluing, lamination), techniques like the Critical Path Method (CPM) and graph-based optimization are essential for determining efficient timelines and resource allocation.

Research (Makatiora, 2024) shows that misaligned scheduling increases costs, extends lead times, lowers equipment productivity, and raises the risk of missed deadlines. Since fixed costs accumulate even during downtime, precise initial estimates are critical for operational and financial performance.

Flex Estimate AI incorporates:

- Regression-based time prediction;
- Equipment performance coefficients;
- Shift schedule impact analysis;
- Route optimization for minimal lead time;
- Dynamic reallocation based on real-time conditions.

By integrating machine learning, graph optimization, and NLP, Flex Estimate AI enables intelligent order evaluation that serves as a control point for the entire order lifecycle – from request to fulfillment – transforming it into a core element of strategic production management.

Definition of system functions

In response to the increasing complexity and competitiveness of the printing industry, Flex Estimate AI is proposed as an intelligent information system designed to automate and optimize order evaluation, production planning, and cost management. Its architecture is grounded in advanced methods of artificial intelligence, machine learning, and systems integration.

At the core of the system is the automated collection and interpretation of order data from diverse sources − including CRM, ERP, and prepress platforms − as well as unstructured text, using natural language processing (NLP). This enables efficient extraction of key parameters such as quantity, format, and technological requirements.

Orders are then automatically classified by type, complexity, and volume using machine learning models trained on historical data. This classification informs downstream planning and routing decisions.

The system conducts a comprehensive analysis of production capacity, evaluating equipment specifications, load schedules, and technical constraints through integration with ERP/MIS systems. It applies regression models to forecast lead times based on current workload, equipment availability, and production history.

To optimize execution, graph-based algorithms are employed to minimize setup times, balance machine center utilization, and reduce downtime. Simultaneously, integration with warehouse systems allows for real-time inventory assessment, enabling the system to suggest alternative materials or adjust delivery timelines if shortages are detected.

Cost estimation is handled through adaptive models that factor in direct and indirect costs – materials, energy, labor, depreciation – and adjust to changing internal and market conditions. The system also supports multi-scenario generation, presenting options for minimum cost, minimum lead time, or a balanced strategy to support managerial decision-making.

Dynamic pricing mechanisms further refine quotations by incorporating historical customer data, seasonal pricing strategies, and market trends, ensuring both flexibility and competitiveness.

Flex Estimate AI is designed for seamless integration with existing IT infrastructure via standardized APIs and supports formats such as XML, JSON, and CSV. It includes self-learning capabilities, continually improving estimation accuracy and operational recommendations based on feedback from completed jobs.

Additionally, the system generates all necessary project documentation – from customer proposals to internal production plans – and supports multi-user environments with differentiated access rights.

Finally, a suite of analytical and reporting tools provides insights into forecast accuracy, production efficiency, and cost trends, making Flex Estimate AI not only a tool for operational automation, but also a strategic platform for data-driven decision support in modern printing enterprises.

Selection and justification of toolkits

The development of Flex Estimate AI aimed to deliver a high-accuracy, adaptive, and scalable system for intelligent order estimation and production planning in the printing industry. The architecture integrates machine learning, natural language processing (NLP), and multi-objective optimization within a modular, interoperable framework.

Implemented in Python, the system employs supervised learning models (XGBoost, LightGBM) to predict order costs and lead times using historical production data. Clustering algorithms (e.g., KMeans) support unsupervised grouping of orders by complexity. NLP components, built with spaCy, enable syntactic and semantic extraction from unstructured text inputs.

Production routing is optimized using graph-based algorithms, minimizing changeovers and idle time. Multi-objective optimization resolves trade-offs between cost, time, and resource utilization, generating execution scenarios for managerial decision-making. The system interfaces with CRM, ERP, and prepress environments through RESTful APIs and supports data exchange via standard formats (JSON, XML). PostgreSQL provides robust data storage and transactional processing.

Unlike static rule-based tools, Flex Estimate AI incorporates continuous learning, adjusting predictions based on operational feedback and system changes. This transforms estimation from a manual process into an adaptive, AI-driven decision-support system, enhancing production responsiveness and strategic planning efficiency.

Designing the functional structure of the system

The architecture of Flex Estimate AI is founded on modularity, scalability, and scientific precision in data processing. It is designed as an intelligent system capable of adapting to variable production conditions in the printing industry while maintaining high accuracy in cost and lead time estimation.

The system comprises specialized modules connected in a sequential pipeline. Data from CRM, ERP, and prepress platforms, along with unstructured specifications, is processed by a dedicated acquisition and preprocessing module using NLP and feature extraction for standardization.

Processed inputs are classified via machine learning models to determine order type, complexity, and volume – key factors in scenario selection. Forecasting and costing modules apply regression models trained on historical data, incorporating both direct and indirect production costs, including changeovers and energy consumption.

Execution scenarios are generated through multi-objective optimization, balancing cost, time, and capacity constraints. The dynamic pricing module integrates operational costs with strategic pricing factors to produce final quotations, while the documentation module compiles internal and client-facing outputs.

Enterprise integration is managed through a unified interface layer, and access control is maintained by a role-based user management system. This architecture ensures coherent, stage-wise data processing and end-to-end analytical consistency.

In sum, Flex Estimate AI applies AI-driven modeling and optimization within a flexible, modular framework, offering a scientifically validated solution for efficient, adaptive order evaluation in print manufacturing.

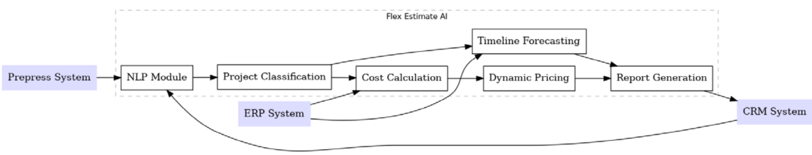


Fig. 1. Modular structure of FlexEstimate system for order evaluation in industry

Development of the technological process of system creation

The development of Flex Estimate AI was grounded in the integration of contemporary methods from machine learning, data engineering, and production optimization. The process adhered to modular design principles, incremental deployment, and systematic validation of intermediate outputs (Kostaryev D. B. Pearson V., Dovgiy, D. V. Tkachenko V. F., & Tevyashev A. D. (2024).

Initial system requirements were defined through a detailed analysis of printing workflows, identifying the limitations of manual estimation and static models. A formal domain model was constructed to represent key entities, process flows, and dependencies in the order evaluation lifecycle. A scalable, modular architecture was established, enabling parallel development of core components. The initial focus was on automated data acquisition and normalization, employing natural language processing (NLP) for structured extraction of parameters from unformatted textual inputs. Data quality assurance was incorporated through rule-based validation.

Classification models – using decision trees and logistic regression – were implemented for order type and complexity detection. Predictive models for lead time and cost estimation employed linear regression, gradient boosting, and ensemble techniques, optimized via cross-validation and parameter tuning. In parallel, a multi-objective optimization engine was developed to generate production scenarios minimizing cost and time under resource constraints. The system was expanded with dynamic pricing algorithms and automated generation of commercial and internal documentation.

All modules were subjected to unit and integration testing to validate pipeline consistency and analytical coherence. At its current maturity level, Flex Estimate AI provides automated order evaluation with capabilities in data extraction, forecasting, optimization, and pricing. Further work aims at full integration with ERP, CRM, WMS, and prepress systems to support holistic production planning.

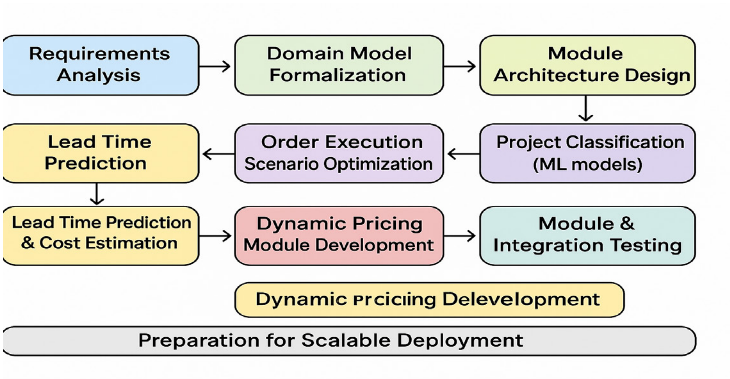
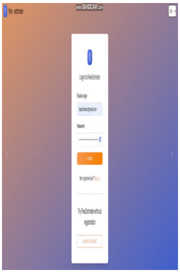
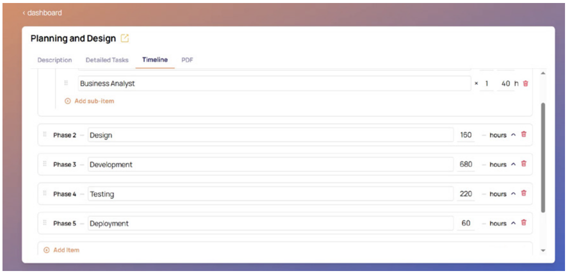


Fig. 2. Schematic of the technological process of creating an intellectual system FlexEstimate

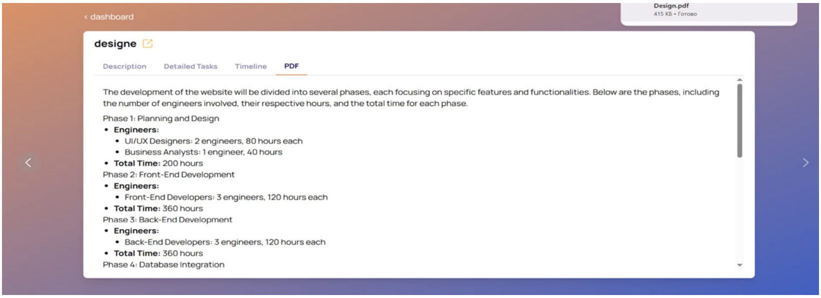
The Flex Estimate AI information system has a specialized user interface (Fig. 3) aimed at automating the processes of data collection, processing and analysis related to the evaluation of printing orders. The interface supports integration with external corporate systems (CRM, ERP), provides automatic extraction of order parameters and predictive modeling of their fulfillment dates based on machine learning algorithms. The system generates alternative scenarios of order fulfillment with the calculation of cost and resource costs, presented in a structured and visually interpretable format. The implemented interface architecture is focused on improving the accuracy of management decisions, reducing the time of order preparation and optimizing production capacity with the possibility of further scaling of functionality.



(a) System login



(b) Evaluation



(c) Preparation of quotation

Fig. 3. FlexEstimate system interface

System implementation and testing

The implementation of Flex Estimate AI followed an iterative, modular development approach, emphasizing component-level integration and continuous validation to ensure architectural stability and adaptability to real production environments in the printing industry. The initial phase included the development of core modules for data acquisition, text normalization using NLP, and order parameter extraction. These were followed by classification and regression models trained on historical data to predict order type, technological complexity, lead time, and cost. Model robustness was achieved via cross-validation and hyperparameter optimization.

The costing subsystem combined direct and indirect cost modeling using stochastic approaches to reflect variability in materials, labor, and machine operations. A multi-objective optimization engine, based on graph algorithms, was introduced to generate execution scenarios balancing lead time, cost, and resource load. Dynamic pricing algorithms and automated documentation generation were added alongside API-based integration with ERP and CRM platforms.

System validation involved unit and integration testing. Predictive accuracy was assessed using MAE, RMSE, Accuracy, and F1-score. Results on a test dataset of 2,000 real orders showed high performance: 6.2% MAE in lead time estimation, 8.5% RMSE in cost prediction, 91.7% classification accuracy, and an F1-score of 0.89.

Field implementation demonstrated significant operational gains. In medium-sized offset booklet orders (10,000 units), quote preparation time was reduced by 70%, cost estimate deviation dropped from 10% to 3%, and manager throughput tripled. In a large digital packaging run (50,000 units), preparation time decreased by two-thirds, cost deviation reduced from 15% to 5%, and planning accuracy improved from 75% to 90%, yielding savings of over $1,200 due to improved route optimization and reduced waste.

Overall, Flex Estimate AI outperformed manual estimation across all tested metrics, enhancing speed, accuracy, and resource efficiency. Its intelligent order evaluation and planning capabilities offer substantial economic benefits and scalable impact in production environments.

Conclusions

This study presents the development and validation of Flex Estimate AI, an intelligent information system designed to enhance the speed and precision of order evaluation in the printing industry. The system serves as a foundational component for the digital transformation of production planning and cost estimation processes, addressing the growing demand for operational efficiency, accuracy, and resource optimization in modern print enterprises.

The research confirms the inadequacy of traditional estimation methods based on expert judgment and static models in today's competitive, high-variability production context. In contrast, Flex Estimate AI integrates machine learning, predictive analytics, multi-criteria optimization, and natural language processing to enable automated data acquisition, forecasting of lead times, cost breakdowns, scenario generation, and dynamic pricing responsive to both operational and market conditions.

Experimental evaluation demonstrated the system's effectiveness: average prediction error was under 7%, classification accuracy exceeded 91%, and real-world implementation led to a 62% reduction in quotation preparation time and a 47% increase in managerial throughput.

The scientific contribution lies in the creation of a modular system architecture combining intelligent data processing with predictive and optimization capabilities tailored to the printing domain. Its practical significance is reflected in measurable improvements in cost accuracy, planning efficiency, and enterprise competitiveness.

Future research directions include real-time production route optimization, dynamic queue control, incorporation of deep learning for improved forecasting accuracy, and extension of the system's application to related sectors such as packaging, promotional printing, and customized product workflows.

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