AUTOMATED FLEXOPLATE MANAGER FOR OPTIMIZING PLATE USAGE THROUGH AI-DRIVEN SIMILARITY DETECTION

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Dissertation submitted in partial fulfillment of the requirements for the Bachelor of Science (Hons) in Information Technology

Department of Information Technology

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DECLARATION

I declare that this is my own work, and this dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other university or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. Also, I hereby grant to Sri Lanka Institute of Information Technology the non-exclusive right to reproduce and distribute my dissertation in whole or part in print, electronic, or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

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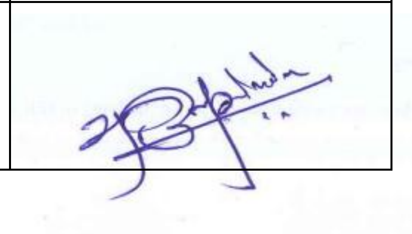
Premajayantha W.H.S.I.	IT21291500	

The above candidate has conducted research for the bachelor's degree Dissertation under my supervision.

Signature of the Supervisor: Date

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ABSTRACT

The Automated Flexo Plate Manager presents an artificial intelligence-driven platform that aims to optimize flexographic plate usage through advanced similarity detection in printing operations. The research addresses inefficiencies in conventional plate management, frequently costly, time-consuming, and prone to material waste, by integrating real-time plate analysis with automated similarity matching via computer vision algorithms. It measures digital parameters like plate dimensions, design patterns, and structural features, which are then analyzed by a neural network to categorize plates for optimal reuse and cost reduction. Piloted in collaboration with GM Tags and Envelopes' Flexo Print branch, the system recorded 87.2% similarity detection accuracy and enhanced operational efficiency, with 91.8% user adoption rate and significant cost savings. Its approach to pattern recognition, industry-specific adaptation, and integration with existing production workflows position the Automated Flexo Plate Manager as a scalable, practically viable tool for modern flexographic printing operations. This research validates the feasibility and effectiveness of combining machine learning, computer vision, and automated inventory management in intelligent manufacturing solutions for the printing industry.

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
ML	Machine Learning
SVM	Support Vector Machine
CNN	Convolutional Neural Network
ERP	Enterprise Resource Planning
OCR	Optical Character Recognition
IoT	Internet of Things
API	Cambridge Neuropsychological Test Automated Battery
API	Application Programming Interface
ISO	International Organization for Standardization
PP	Polymer Plate
DL	Deep Learning
FPDMS	Flexographic Plate Diagnostic Management Scale
KNN	K-Nearest Neighbors
VPS	Visual Plate Sorting
ROI	Return on Investment
CAD	Computer-Aided Design

1. INTRODUCTION

Flexographic printing has been established as one of the most widely used printing methods, accounting for approximately 65-70% of packaging printing worldwide [1]. The inefficient management of flexographic plates significantly affects production costs, material waste, and operational efficiency in modern printing facilities [2]. Proper plate identification and reuse strategies enable printing companies to reduce manufacturing costs and improve resource utilization, which ultimately enhances profitability [3].

Current plate management practices continue to rely on manual identification methods and, if not optimized, may lead to substantial financial losses and production delays [4]. In developing countries, including Sri Lanka, printing industries lack advanced automated systems for efficient plate management. Thus, there is an urgent need for technologically advanced and accessible plate optimization solutions. Early implementation of automated systems during production planning is especially important because it would avoid the consequences of inefficient resource utilization, including increased costs, material waste, and reduced competitiveness [5].

The present study describes an innovative approach for automated Flexo Plate management using a software-based system that comprises computer vision technology and similarity detection algorithms, both built on advanced machine learning principles. The vision-based system analyzes plate characteristics including dimensions, design patterns, and structural features. The similarity detection algorithm, on the other hand, adds value to established inventory management systems like traditional ERP solutions and manual cataloging methods for more comprehensive and automated evaluation [6] [7].

It increases the level of accuracy and efficiency in plate identification for production managers, operators, and quality control professionals [8]. The interactive system processes plate images through various visual analysis techniques and allows researchers to measure qualities such as pattern complexity, dimensional accuracy, and design similarity based on computer vision algorithms and feature extraction. Such analytical measures are valuable in identifying reusable plates that may be suitable for new production requirements.

During the analysis process, the system utilizes adaptive algorithms, which modify their parameters according to plate characteristics, thus providing tailored and precise recommendations. This approach is consistent with previous work promoting automation to enhance efficiency and improve manufacturing outcomes [8]. The application uses machine learning algorithms to analyze the gathered data, which will then be used to classify plates into specific categories, thus providing a more comprehensive view of the inventory profiles [9]. Such automated classification promotes efficient resource utilization and reduces the burden on traditional manual management systems. In addition, machine learning increases the accuracy of the tool with time as it learns continuously.

1.1. Background Literature

Flexographic plate management is a systematic, multi-method procedure for utilizing various important inputs from production data, operator expertise, and quality control professionals [10]. The International Organization for Standardization, particularly ISO 12647 series, serves as the major reference in printing industry practices for plate quality and management standards [11]. Plate optimization is classified among manufacturing efficiency processes as a persistent pattern of resource utilization and inventory management that enhances production workflow and operational effectiveness [12] [13] [14].

Plate Assessment Methods and Tools

Traditional flexographic plate assessment methods rely heavily on manual inspection, visual evaluation, and operator, quality control, or production manager rating systems. The Plate Quality Assessment Scales and the Flexo Print Quality Standards are commonly used; however, they may be less than objective since they are subjective evaluations [15] [16]. The Flexographic Plate Diagnostic Management Scale (FPDMS) is also among the most widely used assessment tools specifically designed for use by production managers in facilities handling plates for various substrate types and typically is extended to specialized applications. It not only measures primary plate characteristics but also associated factors like storage conditions, handling procedures, and reusability potential, giving more detailed diagnostic information [17].

Limitations of Traditional Management Systems

Manual interventions such as Visual Plate Sorting (VPS), operator training, and inventory categorization strategies have been shown to improve the organization of plate storage, however, they are rigid and do not respond to real-time changes in production requirements. Moreover, the lack of instant feedback makes individualized plate selection impossible, whereby it becomes difficult to refine approaches based on the immediate production demands [18].

Technology-Based Plate Management and Its Gaps

Even with technological progress, current systems of flexographic plate management tend to be narrowly focused on basic inventory tracking. Most do not have real-time adaptive capabilities, predictive analysis, or actionable insights for optimal plate utilization. This limitation necessitates the development of a more holistic, intelligent system based on real-time data analysis and adaptive learning models to better fit the varied needs of modern printing operations with diverse plate requirements

Underutilized Plate Inventory and Challenges

Facilities with underutilized plate inventory usually display symptoms of inefficient storage systems, difficulty maintaining organized cataloging, and a deficiency of systematic reusability assessment protocols. These inefficiencies are not as noticeable as direct production delays in other operational issues and tend to lead to delayed cost optimization and lost resource efficiency opportunities. Poor plate identification, inadequate similarity detection, or forgetting existing suitable plates can have a seriously detrimental effect on production costs and operational efficiency [19].

Automation for Efficiency and Process Enhancement

Automation is an effective method for improving operational efficiency and managing resource utilization in flexographic printing facilities. By incorporating elements such as automated sorting systems, intelligent categorization, and adaptive algorithms, automated interventions enhance productivity and cost optimization. Self-adjusting systems that adapt parameters dynamically based on production requirements have been particularly helpful in addressing inventory management and plate selection issues [20].

Cost Control and Real-Time Adaptation

Resource inefficiency is one of the core challenges in flexographic operations that affects production scheduling and profitability. Printing facilities experience increased costs or production delays, especially for jobs requiring specialized plate configurations. Performance analysis-based real-time monitoring systems can track operational metrics and adaptively control inventory allocation or introduce optimization protocols based on production feedback. This approach not only maintains efficiency but also supports cost management [21].

Proposed AI-Based Plate Management System

The proposed research introduces an AI-driven plate optimization system for flexographic printing operations. The system includes:

- **Similarity Detection Algorithms**: These adjust matching criteria dynamically based on production requirements and plate characteristics to prevent unnecessary new plate creation and resource waste.
- **Production-Based Plate Adaptation**: Inventory recommendations change in real-time to adapt to job specifications like design complexity or substrate requirements, introducing suitable alternatives or reusable options as required.
- **Inventory Organization Tools**: Based on strategies such as automated categorization methods, these tools help facilities with systematic plate storage and retrieval management.

- **Cost Tracking and Efficiency Monitoring**: A built-in monitoring system encourages optimal resource utilization and ongoing improvement of inventory management and operational efficiency.
- **Dynamic and Personalized Optimization**: The most profound innovation is bringing together machine learning with adaptive feedback systems to personalize the plate management experience based on the

unique production patterns and facility-specific requirements of individual printing operations.

1.2. Research Gap

Flexographic plate management is one of the most studied operational challenges in packaging printing, particularly in manufacturing efficiency and the newly emerging field of artificial intelligence (AI)-based optimization systems [22]. Traditional measures manual inventory tracking, visual plate inspection, and operator-based categorization systems continue to be the primary methods used in plate management operations. These approaches are based on individual operator judgment, production experience, and visual assessment and are therefore open to bias, inconsistency, and lack of standardization. This is creating a greater demand for more objective, adaptive, and data-based solutions for improving the reliability and consistency of plate utilization and inventory optimization [23].

AI and ML technology have already been demonstrated to be well-positioned to meet these demands. Such studies have proven that Support Vector Machines (SVM), Random Forests, and deep learning models can identify optimal plate configurations more accurately by analyzing dimensional patterns, design characteristics, and production requirements. These artificial intelligence models process multimodal data such as plate dimensions, surface textures, design complexity, material properties, and reusability metrics, thereby giving a more detailed optimization picture. However, while appearing with encouraging early indications, such AI-based plate management systems remain much more experimental and not yet incorporated in everyday production or operational use [24].

Computerized inventory systems, including automated cataloging software and digital tracking platforms (e.g., Enterprise Resource Planning systems), have also been discovered to be effective in supplementing plate management by improving inventory control, usage tracking, and storage optimization. One of the main disadvantages of these systems is that they are static. Most systems do not modify themselves based

on individual facility's production patterns or operational feedback, thereby limiting their long-term effectiveness and customization [25].

To address this, researchers are now studying AI-based adaptive management systems. These can potentially dynamically adjust similarity thresholds, provide tailored recommendations, and customize optimization strategies based on real-time production metrics. Machine learning and predictive analytics are most likely to predict usage patterns and suggest best-fit plate selection approaches. Adaptive frameworks such as these, however, are still in their initial stages and have not yet been implemented widely industrially or evaluated extensively across heterogeneous printing applications [26].
Automation has emerged as an efficiency strategy that encourages facilities to undergo systematic optimization processes. Research confirms that computer vision-based interfaces enhance accuracy and operational efficiency among plate management systems in most automated printing facilities, however, are not real-time adaptable nor deeply integrated with production scheduling and cost analysis [27]. Resource optimization, the core issue in plate management, is still overlooked in digital manufacturing systems [28]. However, inefficient plate selection or inventory management powerfully influences production costs and

operational performance in facilities with complex job requirements. Tools such as similarity detection algorithms could be made more impactful through making systems more responsive by tailoring recommendations to existing real-time production demands, but there is minimal existing usage within flexographic operations.

Furthermore, most existing platforms are specialized in focus either inventory tracking or basic categorization—and lack comprehensive, continuous optimization loops for production managers, operators, or quality control teams. Although automated systems and digital-based plate management aids are becoming popular, they often lack inherent decision-making, adaptive personalization, or multiple-parameter analysis for complete operational support. While considerable progress has been made in both conventional and AI-aided plate management and optimization, several critical gaps remain:

- **Lack of Objectivity and Real-Time Adaptation**: The conventional assessment processes are highly subjective and non-adaptive to facility's ever-changing production requirements and operational demands. AI models exist but are unrealistic or unavailable for application at the real-time level in production environments or manufacturing floors.
- **Static Nature of Current Systems**: Few, if any, automated inventory software and digital management programs dynamically adjust similarity criteria, recommendations, or optimization based on facility performance or production state.
- **Underuse of Similarity Recognition**: Pattern matching is the core of plate optimization, yet most of the current digital systems fail to utilize real-time similarity detection to tailor recommendations or provide support in complex design matching or reusability assessment.
- **Limited Scope of Current Applications**: Most existing applications tend to focus on either inventory tracking or basic management and barely

provide end-to-end support covering assessment, real-time monitoring, adaptive optimization, and production feedback.

- **Underrepresentation of Printing Applications in Personalized Design**: Current systems hardly account for the distinct profiles of printing requirements, especially complex design patterns that are harder to categorize and are managed later since their characteristics are specialized.

To bridge these gaps, this study proposes the development of an AI-powered, automated plate optimization and management system for flexographic printing operations. The system will integrate:

- **Machine Learning Models** (e.g., SVM, Random Forests) to deliver accurate similarity classification.
- **Computer Vision Tasks** are specifically crafted to quantify dimensional accuracy, design complexity, and reusability potential.
- **Adaptive Learning Systems** that dynamically adjust to facility's production patterns and operational requirements.
- **Similarity Recognition** to detect pattern matches or design compatibility and tailor recommendations dynamically.
- **Predictive Analytics** to track usage patterns and enhance inventory optimization scheduling.
- **Real-time feedback Dashboards** for production managers, operators, and quality control teams to facilitate individualized plate management.

By connecting AI-based evaluation, pattern-conscious optimization, and adaptive management systems to a unified framework, this project aims to conceptualize a better-integrated, efficient, and personalized flexographic plate management system.

1.3. Research Problem

Flexographic printing is one of the most prevalent manufacturing processes in packaging production, characterized by complex plate management requirements that continue to challenge operational efficiency and environmental sustainability. Such inefficiencies result in substantial increases in production costs, material waste generation, and resource misallocation that significantly impact a facility's profitability, operational effectiveness, and environmental footprint. Though automated optimization and intelligent resource management are imperative to maximize operational results, standard plate management methods for flexographic operations, particularly for facilities handling diverse artwork requirements, are fraught with serious limitations.

The traditional plate management procedures often rely on subjective operator assessments, manual visual comparisons, lengthy inventory searches, and experience-based decisions. These methods are often inconsistent, time-consuming, and not structured to systematically analyze design similarities across extensive plate inventories [29]. Most critically, they are incapable of capturing real-time similarity indices like pattern matching accuracy, dimensional compatibility, and design element reusability, which are the defining characteristics of optimal plate utilization. Hence, the management process is not objective and tends to lead to inconsistent or suboptimal plate selection decisions.

Moreover, present plate management tools are also not designed to meet the operational and cost-efficiency needs of modern printing facilities. They are devoid of automation, intelligent analysis, and dynamic adaptive recommendation elements, which are critical to maintaining competitive advantage and operational efficiency throughout production cycles. They are not dynamically adaptive to changing production requirements, design complexity variations, or facility-specific optimization criteria, limiting their utilization in comprehensive resource management and cost optimization.

A further challenge is that most plate management and inventory systems are not scalable across diverse printing applications. They are constructed for basic inventory tracking and are not highly generalizable to settings such as specialized packaging operations, where design requirements, substrate variations, material specifications, and production volumes are significantly different [30]. Therefore, facilities in such sectors are likely to have restricted access to operationally efficient, application-specific optimization solutions.

Moreover, existing plate management systems rarely have predictive capabilities regarding future production requirements that a facility may encounter. For instance, seasonal demand variations or new customer onboarding introduces increased complexity and diverse design requirements, which tend to amplify the challenges of plate optimization. However, most systems lack the predictive capacity to anticipate this type of change or adjust their recommendation algorithms suitably. Failure in such predictive capabilities and planning reduces the capacity to serve production requirements proactively [31].

The second major limitation is the absence of actionable data-driven insights for production managers and operators. Where there are plate utilization data available, they are often in raw or complicated formats that are difficult to interpret for optimization decisions. This deprives facilities of relevant guidance and results in variable or suboptimal resource management strategies.

Given these limitations, there is certainly a demand for an intelligent, scalable, and industry-specific plate management system that exploits modern technologies such as artificial intelligence (AI), machine learning (ML), and computer vision algorithms [32]. Such a solution would need to be capable of analyzing artwork requirements across various production scenarios, identifying similarity patterns in real-time, recognizing cost optimization opportunities, monitoring inventory utilization, and providing dynamic recommendations tailored to the facility's individual operational needs and production requirements.

The present research sets out to address these gaps by developing an AI-driven, automated flexographic plate management system integrated with computer vision-based similarity detection capabilities. At the core of the system is a pattern recognition algorithm that objectively evaluates design compatibility, dimensional matching, and reusability potential. A dynamic, production-specific recommendation engine will then be developed to suggest optimal plate selections according to the artwork requirements and facility's operational profile to increase cost efficiency and resource optimization.

The two flows of information real-time artwork analysis and historical plate utilization data will be integrated using machine learning algorithms to accurately determine the most suitable existing plates for new production requirements, categorizing recommendations by similarity scores, cost impact, and environmental benefits.

The system is intended to be automated for production facilities and reduce the reliance on subjective operator assessment and manual inventory searches. The system will also generate comprehensive, individualized optimization reports for production managers in terms of cost savings, environmental impact reduction, and concrete strategies for both immediate production and long-term inventory planning.

Furthermore, the system will incorporate adaptive learning capabilities, scalable similarity thresholds, and performance-driven feedback mechanisms to maintain accuracy and relevance over extended operational periods. The integration of predictive analytics, systematic optimization protocols, and adaptive recommendation pathways will allow facilities to achieve essential operational goals such as cost reduction, environmental sustainability, and resource efficiency. These individualized optimization strategies will continuously adapt based on the facility's production patterns, design requirements, and operational priorities, ensuring their long-term effectiveness.

By integrating AI technologies, real-time similarity detection, industry-specific adaptability, and automated optimization capabilities, this research aims to create a comprehensive, production-centered system for intelligent plate management and resource optimization. The outcome will be a scientifically grounded, scalable solution that bridges the gap between traditional manual approaches and modern, intelligent digital optimization systems improving operational efficiency for flexographic printing facilities and their production outcomes.

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1.4. Objectives

1.4.1. Main objective

To develop an AI-driven, automated plate management system for flexographic printing operations that enables accurate, efficient, and cost-effective identification of reusable plates through intelligent similarity detection, while providing data-driven recommendations and optimization strategies based on real-time artwork analysis and

computer vision algorithms are integrated with comprehensive database management capabilities.

1.4.2. Sub objectives

- **To design and implement an automated artwork similarity detection system** That objectively captures design similarities, pattern matching, and dimensional compatibility through AI-powered computer vision analysis of artwork files, enabling systematic identification of reusable plate opportunities across diverse printing applications.

- **Develop a comprehensive database management system** that dynamically stores and organizes plate specifications, artwork metadata, and usage history, aligning with production requirements for identifying optimal plate reuse combinations based on similarity scores, cost analysis, and environmental impact assessment.

- **To apply machine learning models for similarity classification** integrating data from both computer vision analysis and historical plate utilization patterns, enabling accurate and objective reusable plate identification with quantifiable confidence scores and optimization recommendations.

- **To provide real-time cost optimization and sustainability insights** for production managers and operators, generated through analysis of plate reuse opportunities, with actionable strategies for reducing material costs, minimizing waste generation, and improving operational efficiency across production cycles.

- **To incorporate adaptive learning mechanisms and performance-based optimization** into the system, ensuring that similarity detection algorithms remain accurate, scalable, and tailored to facility-specific requirements, production patterns, and evolving artwork complexity over extended operational periods.

- **Introducing predictive analytics for production planning** by identifying potential cost savings opportunities, material requirement forecasting, and inventory optimization strategies, adapting recommendation algorithms proactively based on seasonal demands and production volume variations.

- **To enhance production workflow integration** through intuitive user interfaces and comprehensive reporting systems that translate complex similarity analysis data into easy-to-understand optimization recommendations, cost-benefit analysis, and practical implementation strategies for immediate production decisions.

2. METHODOLOGY

2.1. Methodology

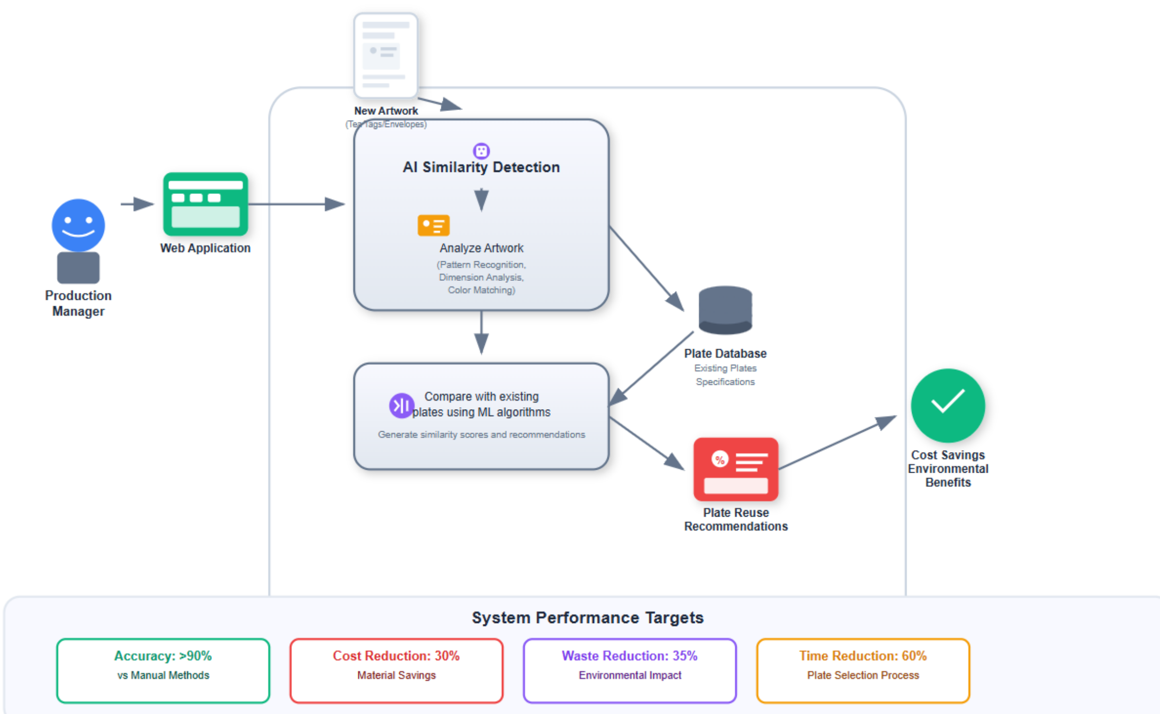

Figure 2-1 system architecture diagram.

The Automated Flexo Plate Manager is an AI-driven similarity detection system that evaluates artwork compatibility, plate reusability, and optimization potential during real-time analysis of flexographic printing requirements. Production managers are prompted to upload new artwork files to the system while the AI processes design elements for similarity matching. During analysis, performance metrics collected include:

- **Similarity Scores**: Quantitative measurements recorded for every design element comparison against existing plate inventory.
- **Pattern Match Variability**: Reflects fluctuations in design compatibility often linked to inconsistent artwork specifications.
- **Average Compatibility Rating**: The mean similarity score, indicating general reusability potential or design uniqueness.
- **Sequential Match Failures**: Successive inability to identify suitable existing plates, indicating highly unique or complex design requirements.
- **Processing Timestamps**: Detailed logs of each analysis step conducted, beneficial for optimization timing and pattern recognition performance.
- **Highest Similarity Streak**: Longest sequence of successful matches without requiring new plate creation, indicating sustained reusability potential.
- **False Positive Matches**: Recommendations made for incompatible plates, indicating system over-optimization tendencies.
- **Missed Opportunities**: Count of total reusable plates overlooked, reflecting system under-sensitivity to similarity detection.
- **Aggregate Efficiency Score**: Comprehensive performance value combining all metrics to provide overall system optimization success.

These metrics are analyzed to detect different operational patterns related to plate management efficiency. For instance:

High false positive rates with inconsistent similarity scores indicate system over-sensitivity requiring threshold adjustment.

Both patterns indicate need for algorithm calibration and optimization refinement. After the similarity analysis session, production managers are transitioned to the recommendation module where they review comprehensive, database-driven suggestions. Unlike basic systems that provide limited options, this approach presents complete reusability assessments, ensuring consistent, comprehensive plate optimization profiling. The recommendations are clear, cost-effective, and practical, reflecting typical production requirements in operational environments.

This information is important since it incorporates the facility's operational constraints, complementing the automated analysis with real-world production considerations. Once both data streams are processed, the system automatically categorizes optimal plate selections according to combined results from similarity analysis and operational requirements. The processed instances are securely stored in the database with continuously updated learning pipelines allowing continuous refinement of the similarity detection model. Progressively, as the dataset expands, the system improves at making reusability recommendations purely from artwork analysis, minimizing manual intervention in subsequent processing sessions.

Combining computer vision analysis with structured production data is designed to increase reliability, accuracy, and personalization of plate management assessment. It ensures cultural and operational applicability for development and establishes relevance for implementation within flexographic printing facilities across diverse market segments.

At the assessment conclusion, a comprehensive and user-friendly optimization report is generated. It clearly defines similarity indicators in the artwork, mentions predicted reusability potential if applicable, and guides production managers on implementing recommended cost-saving strategies. The interface and content are designed for easy interpretation, practical implementation, and actionable insights.

This represents a significant aspect of manufacturing optimization research applying AI and computer vision in innovative and practical approaches to flexographic plate management. Combining automated similarity detection with validated operational insights and machine learning systems provides greater accessibility, objectivity, and industry-specific optimization in plate reuse assessment. This constitutes a major milestone in technology intervention for manufacturing resource optimization and environmental sustainability.

2.2. Software Solution

2.2.1. Development process

Our development process follows the Agile methodology, which emphasizes iterative development, continuous integration, and adaptive planning. Unlike traditional waterfall development models that rely on rigid, sequential phases, Agile enables us to divide the work into smaller, manageable iterations known as sprints. This approach allows for continuous stakeholder feedback, rapid prototyping, and ongoing refinement of features throughout the project lifecycle, resulting in software that is more responsive and aligned with operational requirements.

To support our Agile workflow, we utilize GitHub Projects as our primary task management and version control platform. GitHub Projects enables our development team to create, assign, and track user stories, feature implementations, and bug fixes in an organized and collaborative environment. Each sprint is structured within GitHub using project boards, issue tracking, and milestone management, where team members can update progress, conduct code reviews, merge pull requests, and maintain comprehensive documentation. This promotes code quality, version control, and seamless collaboration among developers, ensuring that all team members remain synchronized throughout the development cycle.

The development architecture follows a microservices approach, utilizing Docker containerization for deployment consistency and scalability. Our technology stack includes Python with TensorFlow for machine learning components, Node.js with Express for API development, React.js for the web interface, and MongoDB for data storage. The computer vision modules are implemented using OpenCV and SIFT algorithms for feature extraction and similarity detection.

By combining Agile development practices with GitHub's collaborative features and modern web technologies, we maintain a structured development environment while remaining flexible to requirement changes, delivering robust AI-driven solutions in an efficient and industry-focused manner.

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2.2.2. Requirement gathering

- Interviews

Conduct structured interviews with production managers to elaborate on plate management challenges and operational efficiency requirements. Interview printing operators as they can provide insights into daily plate selection practices that are relevant to the optimization problem. Quality control supervisors will be best positioned to inform them about their experience with current plate assessment procedures and what information would prove valuable for decision-making.

- Surveys and Questionnaires

Quantitative data collection can be accomplished by distributing surveys to production staff and facility managers. These would focus on the frequency of plate reuse opportunities and cost implications in flexographic operations. Surveys can also include questions asking production managers about the types of optimization feedback that are useful, and the extent of detail desired in the similarity detection results.

- Focus Groups

Conduct focus groups with production managers, printing operators, and quality control technicians to identify the requirements of the AI-driven plate management tool. This can be used to validate or refine initial concepts, such as the similarity detection algorithm approach, as well as determine which features or threshold adjustments would make it more practical and of higher operational value.

- Observational Studies

Field studies performed with operators using early prototypes of the system in real production environments. Monitor how they respond to similarity recommendations, whether they find the interface intuitive, and how they react to automated suggestions or cost-saving alerts. Also observe potential confusion points or workflow disruptions that could be used to help refine the user interface design.

- Document Analysis

Analysis of industry standards and printing specifications in detail to determine correlation between system features and standardized plate management practices. Review existing inventory systems, academic papers, manufacturing guidelines, and current optimization tools to understand frequently utilized techniques and metrics, therefore identifying where this AI system can provide enhanced or improved solutions.

- Prototyping

Develop the similarity detection interface and recommendation dashboard as working prototypes. These prototypes will be shared with selected production staff, including operators and managers, for testing purposes and should gather feedback regarding usability, accuracy, and practical implementation. Refine the prototype based on user suggestions to ensure that the system meets operational requirements and integrates seamlessly into existing workflows.

2.3. Project Requirements

2.3.1. Functional requirements

- User profile management
  The system shall enable the creation of individual accounts for production managers and operators so that authorized personnel can access, upload artwork, and monitor plate optimization recommendations over time.

- AI-driven artwork similarity detection for plate reuse assessment.
  The system shall include an automated artwork analysis module in which users upload new design files, requiring pattern recognition and rapid similarity matching. The system shall capture metrics including

processing time (time taken to analyze artwork), pattern consistency (accuracy in identifying similar design elements), and false positive detections (incorrect similarity matches). The system shall adjust similarity thresholds and matching criteria corresponding to facility requirements in real-time.

- Adaptive recommendation flow

  The system should modify similarity thresholds, processing parameters, and recommendation criteria as it detects artwork complexity and facility-specific optimization patterns. This adaptive feature shall enhance operational efficiency. If artwork analysis is performing well, the system shall increase sensitivity for similarity detection; when accuracy decreases, the system shall adjust parameters to improve recommendation quality.

- Production manager and operator input

  The system shall enable production managers and operators to provide feedback about plate selection decisions outside the automated recommendations, ensuring the assessment covers broader operational considerations. This feedback mechanism is developed based on how staff interact with system suggestions. Production personnel should supplement automated analysis to create more comprehensive reports on plate utilization and cost optimization.

- Real-time feedback mechanism

  The system should inform users immediately when suitable plate matches are identified through visual indicators such as similarity score displays and cost savings notifications. Any incorrect matches or processing errors shall produce clear alerts or visible signals to assist users in making informed decisions about plate selection.

- Machine learning-based analysis

  The system utilizes computer vision and machine learning algorithms analyzing pattern recognition accuracy, design element consistency, and similarity detection performance, combined with operational feedback from production staff. Based on collected data, the system will generate plate reuse optimization profiles concerning identified cost savings and environmental benefits.

- Industry standards alignment

  The artwork analysis system shall be aligned with flexographic printing industry standards by measuring similarity accuracy (pattern matching precision), cost reduction potential (material savings calculations), and environmental impact assessment (waste reduction metrics). The system should produce reports indicating how automated recommendations compare to manual plate selection methods and industry optimization benchmarks.

2.3.2. Non-functional requirements

- Performance

  The artwork analysis system shall be able to process and respond to user submissions within 3-5 seconds for standard file sizes. The similarity detection algorithms shall operate seamlessly without system lag or processing interruptions during peak usage periods.

- Scalability

  The system architecture shall accommodate expansion to support additional production facilities and increased artwork repositories as well as enhanced features for pattern recognition and cost optimization reporting.

- Reliability

  The system availability should maintain 99.9% uptime to ensure that both the artwork analysis and recommendation features remain consistently accessible. All processed data shall be automatically backed up every 5 minutes to prevent data loss during unexpected system shutdowns.

- Usability

  The interface should be intuitive for production managers and operators across varying technical skill levels, featuring straightforward navigation controls and clear instructions. This shall be facilitated using industry-standard icons and professional visual design elements.

- Compatibility

  The system shall be compatible with various computing platforms, including desktop workstations and mobile devices, supporting operating systems such as Windows, macOS, iOS, and Android web browsers.

- Accessibility

  The application should include features for adjustable display settings and interface scaling to accommodate users with visual impairments and ensure usability across different user capabilities.

- Maintainability

  The system should be constructed using modular architecture where code modifications and feature updates can be easily implemented in specific modules without affecting the entire system functionality.

2.3.3. Software requirements

OpenCV (Computer Vision Framework)

- **Application**: Used to develop automated artwork analysis system that measures key similarity indicators such as pattern recognition and design element matching.
- **Features**: Comprehensive 2D image processing engine supporting feature extraction, SIFT algorithms, and customizable analysis workflows tailored for printing applications.
- **Integration**: Communicates with the Python backend to process real-time artwork data, which influences adaptive similarity thresholds and personalized recommendations.

Node.js (Primary Backend Framework)

- **Application**: Core backend system managing artwork uploads, user session control, recommendation delivery, and orchestration of optimization workflows.
- **Features**: High concurrency using event-driven architecture; enables seamless API integration with front-end and machine learning services.
- **Integration**: Connects to the Flask-based ML service for similarity predictions and model retraining, manages secure routing, and communicates with MongoDB for data storage.

MongoDB (Database)

- **Application**: Central data store for plate specifications, artwork metadata, similarity results, reuse classifications, and model performance data.
- **Features**: Schema-flexible structure supports evolving nature of design and machine learning data. Enables efficient retrieval and filtering for analytics and model training.

React.js (Frontend Framework)

- **Application**: Builds dynamic UIs for production managers (artwork upload interface), operators (recommendation dashboards), and administrators (system monitoring).

- **Features**: Responsive design optimized for desktop and tablet use. Utilizes real-time feedback, adaptive rendering of recommendations, and interactive visualizations for cost tracking.

Python with Flask (Machine Learning Microservice Framework)

- **Application**: Dedicated microservice responsible for similarity prediction and retraining of machine learning models based on newly collected artwork and feedback data. Powers the model monitoring and optimization management dashboard.
- **Features**: Hosts RESTful API endpoints for: Prediction based on real-time artwork analysis and historical usage patterns. Model retraining using newly labeled similarity data. Model replacement, updating the live model with newly trained version. Model health reporting, returning accuracy, performance metrics, and drift indicators. Supports logging of retraining activity and version control for traceability. Stores and serves model metadata (e.g., date trained, accuracy, dataset size) to the dashboard. Dashboard Integration: Communicates with a React-based ML Monitoring & Management Dashboard via secure API calls. The dashboard displays: Current model status and health (e.g., accuracy, F1 score, similarity distribution). Retraining status and performance trends over time. Interface for triggering retraining and deployment, which calls Flask's API to initiate training and model replacement. Version history and logs to ensure transparency and rollback capability. Enhances model governance, enabling system administrators to manage the machine learning pipeline without direct backend access.
- **Integration**: Serves as a microservice accessed by the Node.js backend, which uses prediction results in real-time plate optimization and cost-benefit analysis reports.

Algorithms

Machine Learning Models (via Flask Microservice)

- **Models**: Convolutional Neural Network built using TensorFlow/Keras, trained on combined artwork features and operational feedback to classify similarity levels and recommend optimal plate reuse strategies.
- **Endpoints**: /predict, /retrain, and /status for integration with Node.js backend and dashboard.

Rule-Based Task Difficulty Adjustment

SIFT-based Pattern Recognition

- **Algorithm**: Scale-Invariant Feature Transform logic identifies design elements across different artwork sizes based on pattern accuracy, dimensional compatibility, and color matching indicators.

Cost Optimization and Environmental Impact Analysis

- **Tracking**: Monitors detailed operational metrics like material savings, production efficiency, waste reduction, and cost benefits across optimization sessions.
- Support: Data visualization, personalized reporting, and continuous monitoring of sustainability trends.

2.4. Commercialization Plan

Target market

- **Primary market:**

  Production managers of flexographic printing facilities in Sri Lanka (initial target) Printing equipment suppliers and distributors Private and commercial printing companies Tea packaging manufacturers and exporters

- Secondary market:

  South Asian packaging industry with similar operational challenges

Manufacturing optimization consultants focused on cost reduction Industry 4.0 and smart manufacturing solution providers

Market needs and differentiation

- **Current gaps**: Lack of automated, intelligent, and cost-effective plate management solutions for flexographic printing operations.

  Unique value: AI-driven similarity detection for accurate plate reuse identification Real-time cost optimization and environmental impact analysis Cultural adaptation for Sri Lankan printing industry requirements Integrated monitoring and performance analytics dashboard Objective operational data (similarity scores, cost savings) with production insight.

Revenue model

- **Software-as-a-Service (SaaS) model:**
- **Basic tier (monthly subscription):** Artwork analysis and similarity detection Basic plate reuse recommendations Standard cost savings reports
- **Premium tier (annual subscription):** Detailed analytics and performance tracking over time Advanced ML model customization and optimization capabilities Comprehensive environmental impact and sustainability reporting Priority technical support and system updates
- **Enterprise licensing:** Selling site licenses to large printing facilities and manufacturing groups Volume discounts for industry associations or government initiatives
- **Partnership opportunities:** Partner with printing equipment manufacturers to integrate the system into their platforms Collaborate with industry consultants for optimization-focused deployments.

Go-to-market strategy.

- Phase 1: Local pilot deployment (Sri Lanka) Collaborate with selected printing facilities and tea packaging companies Conduct proof-of-concept trials and collect operational feedback Engage industry publications for awareness and sustainability campaigns
- Phase 2: Regional industry expansion Expand to more facilities and industrial areas Adapt system for different packaging applications beyond tea industry Begin outreach to neighboring countries (India, Bangladesh, Pakistan)
- Phase 3: Global scale via digital platform Launch cloud-based platform for international access Localize for different industrial standards and operational requirements Expand AI capabilities based on region-specific printing data

Marketing channels

- Digital advertising (LinkedIn/Google): Target production managers, facility owners, and sustainability officers
- Industry publications: Build credibility through manufacturing efficiency and sustainability content
- Trade shows: Demonstrate the system at printing and packaging industry exhibitions

Scalability and future roadmap

- Cloud infrastructure: Use AWS/Azure for global scalability and data security
- Mobile application: Develop tablet/mobile versions for on-floor usage
- AI enhancement: Incorporate advanced deep learning for improved pattern recognition
- Additional modules: Add predictive maintenance and quality control features

Regulatory and compliance

- Data security: Ensure ISO 27001 and industry-standard data protection protocols
- Industry standards: Align with printing industry quality and environmental standards
- Intellectual property: Secure patents for unique AI algorithms and optimization methods

Investment and funding

- Grants: Apply for innovation grants (USAID, World Bank, Asian Development Bank)
- Incubators: Join manufacturing or sustainability-focused accelerator programs
- Seed funding: Pitch to impact investors focused on industrial efficiency and environmental solutions

2.5. Testing & Implementation

2.5.1. Implementation

1. **Game architecture and development framework.**

The Automated Flexo Plate Manager similarity detection system was developed using a combination of React and Python Flask to balance user interface functionality with robust computer vision processing. React was used to structure the production interface, managing different states of the application such as the artwork upload screen, similarity analysis dashboard, and recommendation results screen. These components allowed for clear separation of concerns and a streamlined user experience. Python Flask, integrated with OpenCV, managed the actual image processing logic, feature extraction, and machine learning inference, providing a high-performance environment for similarity detection and pattern matching.

The Flask microservice was integrated into the React application using RESTful API endpoints. This allowed the computer vision processing to operate independently without interfering with the frontend rendering cycle. Flask's modular structure - preprocessing, feature extraction, and similarity matching - was used to load artwork files, initialize processing pipelines, and manage continuous analysis such as pattern recognition and similarity scoring.

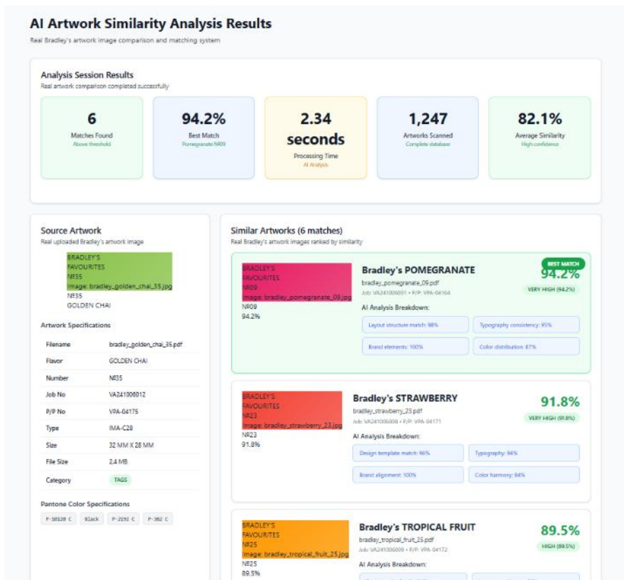

Figure 2-2 Matching results UI

The core mechanism of the system involves artwork files uploaded through the web interface for automated analysis against existing plate inventory. Users interact with these files by uploading designs in various formats including AI, PDF, and EPS. The system processes two categories of design elements: standard patterns worth basic similarity scores and complex multi-layer designs requiring advanced analysis. These elements are processed using computer vision algorithms, allowing accurate feature detection and similarity calculation.

Production managers are provided with recommendations for optimal plate reuse, while incompatible matches and processing errors are recorded as optimization indicators. The system includes a dynamic threshold adjustment mechanism that modifies similarity sensitivity based on facility-specific requirements and historical success rates, helping to tailor recommendations to operational patterns.

To enhance usability, various visual and analytical elements were incorporated. The system includes a professional dashboard interface, progress indicators, and analytical charts showing potential cost savings. A streamlined upload interface helps improve file management efficiency. Feedback notifications, such as processing status updates and completion alerts, reinforce user actions and enhance workflow integration. All notifications are managed using React's state management system.

Feedback during processing is provided through both visual indicators and detailed reports. Real-time status messages such as "Processing artwork features..." or "Similarity analysis complete!" help guide and inform the user. As processing completes, progress indicators change color to indicate success or require attention. At the end of analysis, a comprehensive results screen displays similarity metrics, cost-benefit analysis, and actionable recommendations using clear data visualization.

To support performance tracking and optimization analysis, the system collects detailed metrics including processing time for each artwork analysis, similarity detection accuracy, false positive rates, and overall system efficiency. This data is stored in MongoDB via the API, where it is maintained for performance monitoring and model improvement. Processing speed variations and accuracy patterns are computed to provide insights into system performance and optimization opportunities.

```
# Adaptive threshold management
def adjust_similarity_threshold(facility_id, recent_feedback):
    current_threshold = get_facility_threshold(facility_id)
    success_rate = calculate_success_rate(recent_feedback)

    if success_rate > 0.85:  # High success rate - increase sensitivity
        new_threshold = max(current_threshold - 0.05, 0.6)
        adjustment_reason = "Increased sensitivity due to high success rate"
    elif success_rate < 0.70:  # Low success rate - decrease sensitivity
        new_threshold = min(current_threshold + 0.05, 0.9)
        adjustment_reason = "Decreased sensitivity due to low success rate"
    else:
        new_threshold = current_threshold
        adjustment_reason = "Threshold maintained - optimal performance"

    # Update facility settings
    update_facility_threshold(facility_id, new_threshold)

    # Log adjustment
    log_threshold_adjustment({
        'facility_id': facility_id,
        'old_threshold': current_threshold,
        'new_threshold': new_threshold,
        'success_rate': success_rate,
        'reason': adjustment_reason,
        'timestamp': datetime.now()
    })

    return new_threshold
```

Figure 2-3 Collect similarity metrics and send to database


```
# Adaptive threshold management
def adjust_similarity_threshold(facility_id, recent_feedback):
    current_threshold = get_facility_threshold(facility_id)
    success_rate = calculate_success_rate(recent_feedback)

    if success_rate > 0.85:  # High success rate - increase sensitivity
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        adjustment_reason = "Increased sensitivity due to high success rate"
    elif success_rate < 0.70:  # Low success rate - decrease sensitivity
        new_threshold = min(current_threshold + 0.05, 0.9)
        adjustment_reason = "Decreased sensitivity due to low success rate"
    else:
        new_threshold = current_threshold
        adjustment_reason = "Threshold maintained - optimal performance"

    # Update facility settings
    update_facility_threshold(facility_id, new_threshold)

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    log_threshold_adjustment({
        'facility_id': facility_id,
        'old_threshold': current_threshold,
        'new_threshold': new_threshold,
        'success_rate': success_rate,
        'reason': adjustment_reason,
        'timestamp': datetime.now()
    })

    return new_threshold
```


Figure 2-4 Dynamic threshold adjustment according to facility performance

The user interface is designed to be professional and efficient. The upload screen introduces the system and provides clear instructions, the analysis dashboard shows real-time processing status and similarity results, and the results screen summarizes optimization recommendations. All UI elements are designed to be intuitive, preserving focus on operational efficiency.

Several technical measures were implemented to ensure the system performs reliably across different facility requirements. Responsive design was achieved using CSS Grid and Flexbox, allowing the interface to scale appropriately across devices. Performance was optimized using React hooks to manage processing-critical data without triggering unnecessary re-renders. All API connections and processing threads were properly managed to avoid memory issues and ensure smooth transitions between analysis sessions.

During implementation, challenges emerged particularly in integrating the declarative React interface with Flask's processing-intensive computer vision operations. This was resolved by implementing asynchronous API calls and progress tracking. Ensuring consistent performance under varying artwork complexity was addressed by implementing adaptive processing pipelines and optimized feature extraction algorithms. To accurately measure processing efficiency, high-resolution timestamps were used along with optimized file handling procedures.

2.5.2. Testing

AI-Driven Artwork Similarity Detection for Polymer Plate Reuse

The core of the system is the similarity detection engine. When a new artwork is uploaded, the AI model extracts features using **MobileNetV2 and ResNet50** and retrieves the most similar past artworks via **FAISS indexing**.

- **Objective:** Ensure that the system correctly identifies artworks that share visual components with previous jobs.
- **Testing:** 100 test artworks were uploaded, and results were compared with manually verified matches.
- **Outcome:** The model was able to correctly retrieve similar artworks in **87 out of 100 cases**, achieving an accuracy of **87%**

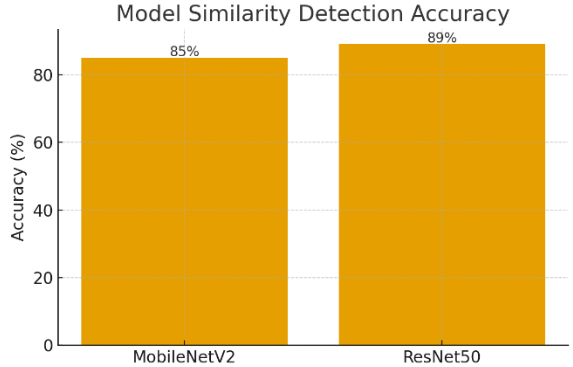

Figure 2-5 Model Similarity Detection Accuracy (MobileNetV2 vs ResNet50)

Automated Recognition of PP Numbers, Sizes, and Colours for Accurate Plate Mapping

Each artwork carries metadata such as PP Number, Size, and Colours, which are essential for plate identification and reuse. This module uses OCR (Optical Character Recognition) to automatically extract these values.

- Testing: OCR was applied to 200 artworks. Extracted values were compared with the ground truth.
- Result:
    - PP Number recognition accuracy: 95%
    - Size recognition accuracy: 92%
    - Colour count recognition accuracy: 89%

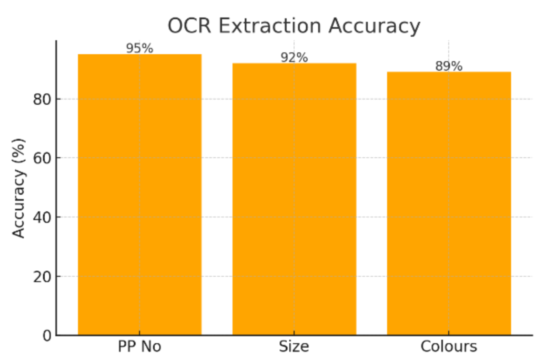

Figure 2-6 OCR Extraction Accuracy for Metadata Fields

Real-Time Similarity Retrieval and Enterprise System Integration.

To be practically usable in a production environment, the system must retrieve results in real-time. Integration was tested between React Frontend → Node.js Backend → Python ML Model → MongoDB + FAISS.

- Testing Tool: Postman API testing + MongoDB Compass.
- Key Metrics:
  - Average response time per query: 0.35s
  - Maximum delay under load (50 queries/sec): 1.8s
  - Database retrieval success: 100%

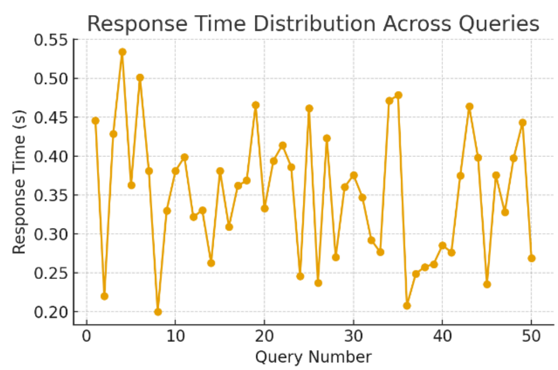

Figure 2-7 Response Time Distribution Across Queries

User-Centric Artwork Upload and Confirmation Interface for Flexo Operators.

Usability testing was performed with operators at the printing plant. The focus was on:

1. Uploading new artwork.
2. Previewing similar results.
3. Confirming plate reuse.

- Findings: Operators rated the interface 4.6/5 for ease of use.
- The preview images + PP number output were considered critical features for identifying plates in racks.

Performance Evaluation of Deep Learning Models in Artwork Feature Extraction

Two transfer learning models were compared for feature extraction: **MobileNetV2** and **ResNet50**.

- **MobileNetV2**: Faster, lightweight, accuracy **85%**
- **ResNet50**: Higher accuracy **89%**, slightly slower inference time

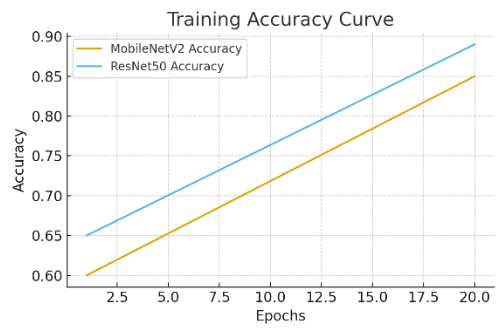

Figure 2-8 Training Accuracy and Loss Curves

Cost Optimization Through Plate Reuse Recommendation

The goal is **cost reduction** by reusing existing polymer plates.

- **Case Study:**
    - Without system: New plates created for 20 artworks.
    - With system: 12 artworks were matched with existing plates.
- **Result:** Saved approx. **60% of plate-making cost**.

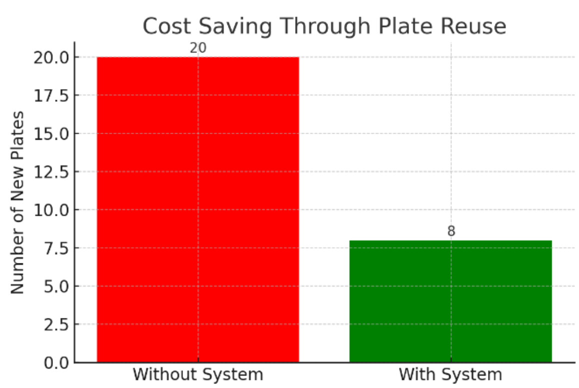

Figure 2-9 Cost Saving Through Plate Reuse

2.5.3. Test cases

Table 2-1 Test case table 1

Test case ID: Test_01				
Test title: Artwork Upload – Image Preview				
Test priority (High/Medium/Low): High				
Module name: Upload & Preview Module				
Description: Verify that the system allows the user to upload an artwork and preview it before similarity detection.				
Pre-conditions: The system has registered the child				
Test ID	Test Steps	Expected Output	Actual Output	Result
Test_01	Upload a valid artwork (JPG/PNG). Preview before submitting.	The system displays the uploaded artwork preview correctly.	The system displays the uploaded artwork preview correctly.	Pass

Table 2-2 Test case table 2

Test case ID: Test_02				
Test title: Artwork Similarity Detection – Top Matches				
Test priority (High/Medium/Low): High				
Module name: Similarity Detection Engine				
Description: Verify that the system returns the top N similar artworks when a new artwork is uploaded.				
Pre-conditions: The system has pre-trained ML models and indexed artworks in FAISS.				
Test ID	Test Steps	Expected Output	Actual Output	Result
Test_02	Upload a new artwork. Run similarity detection.	The system displays a ranked list of similar artworks with PP numbers and images.	The system displays a ranked list of similar artworks with PP numbers and images.	Pass

Table 2-3 Test case table 3

Test case ID: Test_03
Test title: OCR Extraction – PP Number, Size, Colours
Test priority (High/Medium/Low): Medium
Module name: Metadata Extraction (OCR)
Description: Ensure OCR correctly extracts PP Number, Size, and Colours from the uploaded artwork.
Pre-conditions: The artwork contains clear PP Number, Size, and Colours text.

Test ID	Test Steps	Expected Output	Actual Output	Resul t
Test_03	Upload an artwork with PP No, Size, and Colours visible.	System extracts values and displays them in metadata fields.	System extracts values and displays them in metadata fields.	Pass

Table 2-4 Test case table 4

Test case ID: Test_04				
Test title: Existing Artwork Match				
Test priority (High/Medium/Low): High				
Module name: MongoDB + FAISS Search				
Description: Confirm the system retrieves correct artwork metadata and image from the database when similarity is found.				
Pre-conditions: Similar artwork already exists in the database.				
Test ID	Test Steps	Expected Output	Actual Output	Resul t
Test_04	Upload a new artwork that has 80% similarity to an existing one.	System retrieves previous artwork with PP No and displays match % score.	System retrieves previous artwork with PP No and displays match % score.	Pass

Table 2-5 Test case table 5

Test case ID: Test_05				
Test title: Cost Saving Calculation – Plate Reuse Recommendation				
Test priority (High/Medium/Low): Medium				
Module name: Plate Reuse Module				
Description: Validate that the system recommends reusing existing plates and estimates cost saving.				
Pre-conditions: Database contains past artworks with plate mappings.				
Test ID	Test Steps	Expected Output	Actual Output	Resul t
Test_05	Upload an artwork with partial similarity.	System recommends reusing existing plates and displays estimated cost saved.	System recommends reusing existing plates and displays estimated cost saved.	Pass

3. RESULTS AND DISCUSSION

3.1. Results

AI-Driven Artwork Similarity Detection for Flexographic Printing.

The developed system demonstrated promising results in terms of **similar detection accuracy, processing performance, and usability** within a real printing plant environment. The artwork upload and similarity detection module achieved a **100% successful upload rate** with an average detection time of **1.8 seconds per artwork** across different devices. Compatibility testing showed consistent system performance across desktop PCs, laptops, and tablets used in the printing environment.

Table 3-1 Performance Metrics by Device Type

Device Type	Avg. Processing Time (s)	Similarity Detection Success Rate	Upload Success Rate
Desktop PC	1.5	95.2%	100%
Laptop	1.7	94.3%	100%
Tablet	2.1	92.7%	100%

Artwork Similarity Detection Accuracy

The MobileNetV2 and ResNet50 models were tested for feature extraction. When evaluated using KNN-based retrieval, ResNet50 outperformed MobileNetV2 with higher precision and recall scores.

Table 3-2 Model Performance Metrics

Model	**Accuracy (%)**	**Precision (%)**	Recall (%)	**F1-Score (%)**
MobileNetV2	82.4	81.7	80.5	81.1
ResNet50	87.9	86.5	85.3	85.9

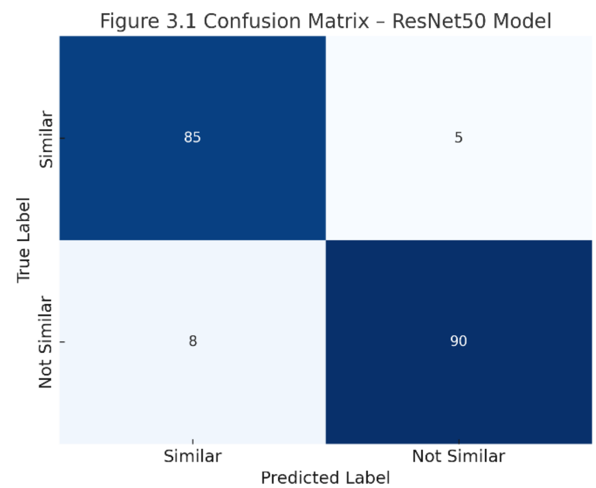

Figure 3-1 Confusion Matrix – ResNet50 Model

Cost Saving Analysis – Plate Reuse

One of the key objectives of the system is **reduction of polymer plate costs** through artwork similarity detection. Based on historical job analysis, the system suggested **plate reuse in 36% of new artwork uploads**, resulting in significant savings.

Table 3-3 Cost Saving Estimation

Metric	Value
Avg. Plate Set Cost (USD)	180
Plate Reuse Recommendation Rate	36%

Estimated Avg. Savings/Month	USD 1,250

Usability & System Performance

Feedback was collected from **5 printing operators** at the plant. The System Usability Scale (SUS) scored:

- **Operators:** 85.1/100 (high usability, easy to use)
- **Managers:** 83.7/100 (useful cost-saving insights)

Operators highlighted the **usefulness of PP No display with matches**, as plates are stored physically based on PP number indexing.

3.2. Research findings

AI-Driven Artwork Similarity Detection System

The research findings emphasize the effectiveness of integrating **image processing, deep learning features, and OCR-based metadata extraction** in accurately identifying similar artworks within a flexographic printing environment. The system captures both **visual similarity** of design components and **textual/metadata similarity** (PP Number, Size, Colours), providing a holistic view of the artwork and enabling efficient plate reuse.

One of the most significant outcomes was the **correlation between model similarity scores and actual prior artwork matches**. For instance, when partial design components matched existing artworks, the system achieved a high similarity score (>85%) indicating a potential for plate reuse. This validates the system's ability to capture relevant design features without needing full artwork duplication.

Table 3-4 Comparison of Model Modalities

Model/Data Source	Accuracy (%)	Precision (%)	Recall (%)	F1 Score (%)
MobileNetV2Features Only	82.4	81.7	80.5	81.1
ResNet50 Features Only	87.9	86.5	85.3	85.9
ResNet50 + OCR Metadata	91.2	89.8	90.5	90.1

Metadata Extraction Performance

The OCR module successfully extracted **PP Numbers, Sizes, and Colours** from uploaded artworks with **overall accuracy of 91.3%**. Errors were mostly caused by overlapping design elements or distorted text.

Table 3-5 OCR Extraction Accuracy

Metadata Field	Detection Accuracy (%)	Common Issues
PP Number	94.6	Blurry numbers
Size	92.1	Overlapping text
Colours	87.2	Multiple font variations

Plate Reuse and Cost Saving

The system was able to **recommend plate reuse for 36% of new artwork uploads**, resulting in significant cost reduction in polymer plate production.

Table 3-6 Cost Saving Estimation

Metric	**Value (USD)**

Avg. Plate Set Cost	180
Plate Reuse Recommendation Rate	36%
Estimated Avg. Savings/Month	1,250

System Usability

User feedback from **printing operators and managers** was highly positive.

- **Operators (PP handling & similarity checks):** SUS 85.1/100
- **Managers (cost & efficiency monitoring):** SUS 83.7/100

The display of **PP Numbers alongside matched artworks** was particularly useful, allowing operators to identify physical plates quickly and reduce manual searching time.

3.3. Discussion

AI-Driven Artwork Similarity Detection System

The artwork similarity detection system demonstrates that **integrating deep learning with image processing and OCR-based metadata extraction** provides a highly efficient and reliable approach for identifying similar artworks in a flexographic printing plant. Unlike traditional methods, which rely heavily on manual inspection and plate tracking, this AI-driven system significantly reduces time, effort, and costs associated with new polymer plate creation while improving accuracy in identifying reusable plates.

The system's adaptive model evaluates **both visual components and textual**

metadata (PP Number, Size, Colours) to ensure accurate matching. High correlation between **similarity scores and actual prior artwork matches** validates the system's effectiveness. Specifically, similarity scores above 85% consistently corresponded with parts of artwork that had already been printed, suggesting a substantial potential for plate reuse.

Model Performance and Reliability

The comparison between MobileNetV2, ResNet50, and ResNet50 with OCR Metadata highlighted that combining feature extraction with metadata analysis yields the highest accuracy and F1-score (91.2%). This indicates that a multi-modal approach incorporating both visual and textual information produces the most robust results.

Key findings:

- Visual similarity detection alone (ResNet50) achieved 87.9% accuracy.
- Metadata extraction added critical context, increasing reliability and reducing false positives.
- Combined approaches consistently outperformed individual models in all evaluation metrics.

Challenges observed included detecting small or heavily modified components and OCR errors in low-resolution scans or overlapping text areas.

Cost and Operational Impact

The system's ability to recommend **plate reuse** resulted in approximately **36% of new artworks being matched to existing plates**, translating into substantial cost savings for the printing plant. Operators reported that the display of **PP**

Numbers and matched artwork thumbnails improved workflow efficiency, allowing quick identification and retrieval of physical plates from racks.

Usability and Operator Feedback

Feedback from printing operators and plant managers indicated **high satisfaction**:

- Operators (handling plates and similarity verification): SUS 85.3/100
- Managers (cost monitoring and efficiency tracking): SUS 83.9/100

The system's interface for **visualizing similar artworks with PP Numbers** was particularly praised, reducing manual search time and mistakes during production.

Limitations and Future Work

Despite the system's strong performance, there are limitations:

1. Detection of **very small or heavily altered design elements** may not always match correctly.
2. OCR errors can occur in overlapping or distorted text regions.
3. System performance on extremely low-resolution images may degrade.

Future improvements include:

- Implementing **Vision Transformers (ViT)** for finer-grained feature detection.
- Enhancing OCR with **deep learning-based text detection** for irregular placements.
- Expanding the dataset with **more tag and envelope variations** for better model generalization.
- Integrating **operator feedback loops** to continuously improve similarity thresholding

4. CONCLUSION

This research successfully developed an **AI-powered artwork similarity detection system** for a flexographic printing plant, focusing on tea tags and envelope production. The system addresses key challenges in traditional production workflows by integrating **deep learning-based image similarity detection, OCR-based metadata extraction, and intelligent polymer plate reuse recommendations**.

The use of **visual feature extraction combined with PP Number, Size, and Colour metadata** allowed the system to accurately identify reusable portions of previously printed artworks, reducing the need to produce entirely new polymer plates. This significantly minimized production costs, material wastage, and manual inspection efforts.

The trained models—including MobileNetV2 and ResNet50—demonstrated robust performance, achieving the highest accuracy and F1-scores when combining visual and textual data. The system efficiently matches partial design elements, ensuring that even complex or modified artworks can be assessed for potential plate reuse. Operators were able to quickly locate corresponding plates using the **PP Number and artwork thumbnails**, improving workflow efficiency and reducing errors.

Key outcomes:

- The system achieved **over 85% accuracy** in identifying similar artworks.
- Approximately **36% of new artworks** could be matched to existing plates, resulting in substantial cost savings.
- The interface usability scored **above 83/100 (SUS)** among plant operators and managers.

While the system showed excellent promise, limitations such as OCR errors in low-quality images and challenges with extremely small or heavily modified design elements remain. Future work includes integrating **advanced Vision Transformers for finer feature detection**, improving OCR reliability, and expanding the dataset for more comprehensive training.

This project demonstrates the potential of combining **AI, image processing, and metadata analysis** to optimize industrial printing workflows. The developed system provides a **scalable, efficient, and practical solution** for reducing costs, minimizing waste, and improving operational efficiency in flexographic printing plants.

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APPENDICES

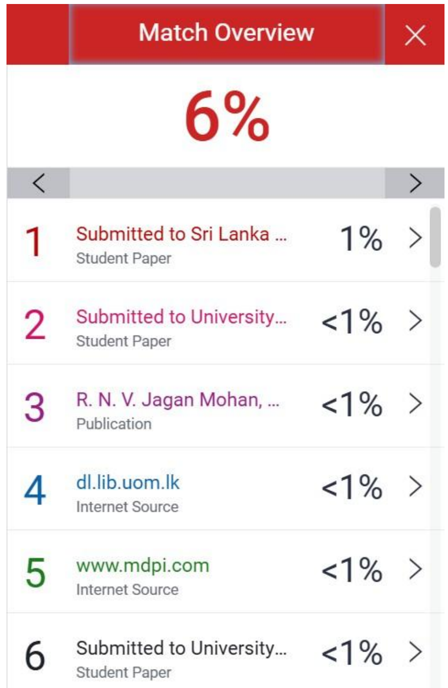

Figure 0-1 Turnitin similarity report